Education for Resilience with Emerging Technologies: A Qualitative Study on the Learner – Media Relationship in Product Design Education

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Abstract

This doctoral dissertation explores how emerging technologies, especially 3D printing, can affect pedagogy. The purpose is to provide practical and theoretical knowledge that can strengthen sustainable education. The aim of this work is to provide a perspective about learning and pedagogy considering the disruption caused by emerging technologies. It explores both practical and theoretical questions. The practical questions address issues of formal education and pedagogy, which are challenged by emerging technologies. The theoretical question addresses issues around how learning could be explained in the context of these technologies. The primary research question, therefore, is this: *How can resilient learning be assisted by emerging technologies in product design education?*

The research mainly relied on qualitative methods that included participant observation, artefact analysis, and content analysis of lived situations in formal higher design education settings. However, the study also included a variety of methodological approaches, including case studies, action research, hermeneutical text analysis, and design science. The methodologies were changed during the project because there were dissimilar purposes in the different articles, and they reflected different aspects of the problem and the changing positionality of the researcher. The dissertation is written as series of articles collected in a summary.

There is a need for this research question because formal education deals simultaneously with two trends: standardization in globalized mass education and the need for revisions of curriculum due to the flux of technological changes. Emerging technologies, such as artificial intelligence, virtual reality, 3D printing, and others, are characterized by diverse procedural knowledge that yields unpredictable outcomes and yet to be discovered technological applications. Future students will have to deal with ill-structured problems and unpredictable results that will not only present environmental, ethical, and societal challenges but also opportunities that remain to be revealed. This makes it useful for research as an educational technology and a learning medium in formal education.

Now that emerging technologies are becoming ever more present in educational situations, there is a need to research how to teach by using them. Thus, it is crucial to better understand which pedagogical approaches are suitable in these learning and teaching activities. There is also a need for a more general understanding about how this learning can be more sustainable as the technologies are perpetually evolving. The research provides novel insights into how

technological media affect learning, what the very notion of learning might mean in these new technological contexts, and consequently the effects of this perspective on design pedagogy. Further, the research provides a new perspective on design as a discipline, which is less focused on the designer and design conception, but rather gives an ecological perspective on design activities.

3D printers and the other developing technologies are versatile. They are characterized by innovative handling processes and, as yet, represent undetermined applications. The design studio pedagogical setting provides an environment in which 3D printing can be researched in the context of sustainable higher education where this versatility of the emerging technologies can be explored. The design studio is formal education, but is closest to its informal counterpart, makerspace. This is because of its focus on open and free learning, which is characterized by divergent and convergent phases in learning and frequent use of media.

A knowledge gap has emerged, however, as 3D printers were not previously researched as a medium for resilient learning. As the literature review of this dissertation reveals, most of the studies have focused on using 3D printing as the medium for efficacy in teaching and learning, as well as different applications of 3D printers and emerging technologies for the existing curricula. This knowledge gap is practical in the sense that there is a need for new pedagogical approaches for resilient learning. The gap is also theoretical as it explores media as the key factor of learning instead of emphasizing the importance of the learner and the teaching content.

This dissertation proposes the adoption of relational ontological and postphenomenological approaches to provide more adequate answers about learning in unpredictable technological contexts in formal education. In the relational view, an individual becomes a learner when she participates in socio-technological arrangements. As media becomes transparent to learners, they manage to develop and stabilize new routines and anticipate the outcomes of their intentions. They finally manage to utilize media for intended purposes for the group and organization. In relational ontology, technology is seen as a medium that amplifies or diminishes learners’ intentions in the rearrangement processes. Consequently, pedagogy is defined by rearranging relationships among learners as well as other stakeholders in a learning situation, which is mediated by technology. From this perspective, the role of pedagogy is the facilitation of the learners’ connection to their socio-technological environment and resilience to changes in it.

Oppsummering

Denne doktorgradsavhandlingen undersøker hvordan nye teknologier, spesielt 3D-printing, kan påvirke pedagogikk. Hensikten er å fremstille praktisk og teoretisk kunnskap som kan bidra til bærekraftig utdanning. Målet med dette arbeidet er å gi et perspektiv på læring og pedagogikk med tanke på forstyrrelsen forårsaket av nye teknologier. Den utforsker både praktiske og teoretiske spørsmål. De praktiske spørsmålene tar for seg utfordringer rundt formell utdanning og pedagogikk, som blir utfordret av nye teknologier. De teoretiske spørsmålene tar for seg spørsmål rundt hvordan læring kan forklares i sammenheng med disse teknologiene. Forskningsspørsmålet er derfor dette: Hvordan kan læring for resiliens bli understøttet ved bruk av nye teknologier i produktdesignutdanning?

Forskningen baserte seg hovedsakelig på kvalitative metoder som inkluderte deltagerobservasjon, artefaktanalyse og innholdsanalyse av levde situasjoner i formelle settinger for høyere designutdanning. Studien inkluderer en rekke metodiske tilnærminger, blant annet casestudier, aksjonsforskning, hermeneutisk tekstanalyse og designscience. Metodologiene ble endret i løpet av prosjektet fordi forskjellige artiklene hadde forskjellige formål, og de gjenspeilte forskjellige aspekter av problemet og forskerens endrede posisjonalitet. Avhandlingen er skrevet som en serie artikler samlet i en kappe.

Det er behov for dette forskningsspørsmålet fordi formell utdanning tar for seg to trender samtidig: standardisering i globalisert masseopplæring og behovet for revisjoner av pensum på grunn av strømmen av teknologiske endringer. Fremvoksende teknologier, for eksempel kunstig intelligens, virtual reality, 3D-print og andre, er preget av mangfoldig prosessuell kunnskap som gir uforutsigbare resultater og som teknologiske anvendelser som ikke er oppdaget ennå. Fremtidige studenter vil måtte håndtere åpne problemstillinger og uforutsigbare resultater som ikke bare vil by på miljømessige, etiske og samfunnsmessige utfordringer, men også muligheter som fremdeles gjenstår å utforske. Å utforske dette kan være nyttig for forskning om utdanningsteknologi og læringsmedier i formell utdanning.

Nå som nye teknologier blir stadig mer integrert i utdanningssituasjoner, er det behov for å undersøke hvordan man kan undervise ved å bruke dem. Dermed er det avgjørende å bedre forstå hvilke pedagogiske tilnærminger som er egnet i disse lærings- og undervisningsaktivitetene. Det er også behov for en mer generell forståelse av hvordan denne

læringen kan være mer bærekraftig, ettersom teknologiene endrer seg ofte. Forskningen gir ny innsikt i hvordan teknologiske medier påvirker læring, hva læring som konsept kan bety i disse nye teknologiske sammenhengene, og dermed effektene av dette perspektivet på designpedagogikk. Videre gir forskningen et nytt perspektiv på design som disiplin, som er mindre fokusert på designeren og designkonseptualisering, men heller gir et økologisk perspektiv på designaktiviteter.

3D-printere og de andre utviklende teknologiene er allsidige. De er preget av innovative håndteringsprosesser og representerer enn så lenge ubestemte applikasjoner. Den pedagogiske settingen i designstudio gir et miljø der 3D-print kan utforskes i kontekstet med behov for bærekraftig høyere utdanning der allsidigheten til de nye teknologiene kan utforskes. Designstudioet er formell utdanning, men ligger nærmest det uformelle motstykket, makerspace. Dette er på grunn av fokuset på åpen og fri læring, som er preget av divergente og konvergente faser i læring og hyppig bruk av medier.

Et kunnskapsgap har imidlertid vist seg, siden 3D-skrivere ikke tidligere ble utforsket som et medium for resilient læring. Som litteraturgjennomgangen i denne avhandlingen avslører, har de fleste studiene fokusert på å bruke 3D-print som medium for effektivitet i undervisning og læring, i tillegg til forskjellige anvendelser av 3D-printere og nye teknologier for eksisterende læreplaner. Dette kunnskapsgapet er av praktisk art i den forstand at det er behov for nye pedagogiske tilnærminger for resilient læring. Gapet er også teoretisk, da det utforsker media som nøkkelfaktor for læring i stedet for å legge vekt på lærerens betydning og innholdet i undervisningen.

Denne avhandlingen foreslår å ta i bruk en relasjonell ontologisk og postfenomenologisk tilnærming for å gi mer adekvate svar om læring i uforutsigbare teknologiske sammenhenger i formell utdanning. Fra et relasjonelt synspunkt blir et individ lærende når hun deltar i sosio-teknologiske miljøer. Når media blir gjennomsiktige for lærende, klarer de å utvikle og stabilisere nye rutiner og forutse resultatene av sine intensjoner. De klarer til slutt å bruke media til tiltenkte formål for gruppen og organisasjonen. I relasjonell ontologi blir teknologi sett på som et medium som forsterker eller reduserer elevenes intensjoner i omorganiseringsprosessene. Pedagogikk er derfor definert som en omorganisert relasjon mellom lærende og andre deltagere, som er mediert ved bruk av teknologi. Fra dette perspektivet er pedagogikkens rolle tilrettelegging for elevenes tilknytning til deres sosioteknologiske miljø og resiliens i møte med endringer i det

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Key terminology:

Additive manufacturing or colloquially called three-dimensional (3D) printing in the contexts of personal use is the process of fabricating 3D objects of almost any shape or geometry by fusing successive layers of material. The mass production character of the process is enabled by translating a digital model or other electronic data into material layers (Lancu, Lancu, & Stăncioiu, 2010).

The design studio is a form of education common in formal higher education for design and architecture studies. The pedagogy is based on problem-based learning where students are presented with a problematic situation. Further, they are asked to analyze the situation, identify key issues or problems, and define preferences from which a solution is to be developed. Consequently, students must present a series of solutions, scrutinize them from their preferences and criteria, and test them on the given situation (D. A. Schön, 1985, p. 6). Learning emerges from the divergent and convergent phases of the design process. Learning can involve clients, users, or other stakeholders as well as collaboration among the students, or it can be achieved transdisciplinarily with other professions (M. M. Tovey, 2015).

"*Makerspaces* are informal sites for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" (Sheridan et al., 2014, p. 505). They are direct result of maker movement which is known for organizing non-formal learning spaces where enthusiasts gather their digital tools and knowledge to launch their individual projects (Dougherty, 2012, pp. 12-13)

Preface

The doctoral study position on the topic of additive manufacturing, was opened in 2016 by Oslo Metropolitan University. The studies are part of the program for educational science at the Department of Vocational Teacher Education, but the topic is closely related to the Department of Product Design. The release of the doctoral position correlates with establishing a 3D printing lab for plastic materials at the Department of Product Design, as well as the introduction of two fusion deposit 3D printers for clay and concrete in the ceramics workshop in the same department. The released text is cited without modifications as follows:

Workshop Learning: design and technology competence in 3D printing

Description:

The aim of the project is to expand understanding of how learning occurs and how users gain experience in new 3D prototyping- and production techniques applied in materials such as clay-based materials, polypropylene, and cement composites. Digital production techniques are integrated into the labor market increasingly. There is a continuous development of 3D printers (Rapid Prototyping) to prototypes and products. However, there is little research on how learning occurs through workshop practice (Mjelde, 2008) in clay-based materials, polypropylene, and cement composites in relation to creative and artistic production techniques in 3D printing. The project will collaborate with partners internationally. Through developing existing expertise with recently invested 3D printers this competence can contribute to students who eventually can become leaders in the future ceramic production techniques. The project will connect research in product design and research in vocational teaching by focusing on workshop learning in practice in different professional contexts. This will provide insight into how action research, participatory design, and case studies can be used as a strategy to develop professional knowledge and experience in research-based development and change processes (Berg, 2014; Brevik, 2014).

References:

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- Brevik, B. (2014). LEGO & læring : en kvalitativ studie av elektrofaglæreres bruk av LEGO mindstorms som læringsverktøy i norsk videregående skole. (nr. 195), Det utdanningsvitenskapelige fakultet, Universitetet i Oslo, Oslo. [LEGO & learning: a qualitative study of the use of LEGO minstorms by electro course teachers as a learning tool in Norwegian upper secondary school. (no. 195), Faculty of Educational Sciences, University of Oslo, Oslo]

- Mjelde, L. (2008). *Magical properties of workshop learning* (Vol. 39, pp. 573–574). Oxford, UK: Conceptual Framework.

1. Introduction: Researching technology and the humans who use it

This dissertation is a result of the Product Design Department's initiative to develop research and teaching practice around the newly opened three-dimensional 3D printing lab. The lab utilizes various additive manufacturing techniques in plastic materials, including powder and laser sintering as well as fusion deposit modeling with filaments. The department had also acquired a fusion deposit printer for clay and composite materials such as concrete which is mostly used by ceramicists in the department.

At the time I applied for this PhD position, I had four years of practice as a design pedagogue in higher education. I had also published six articles on the topic of design education and a practitioner book on design sketching. I had five years of previous experience as a designer of technical equipment for subsea exploration as well as seven years as a designer for products, packaging, and graphics in advertising agencies. Throughout my career, I have used digital modelling and graphics extensively as well as having experience with 3D printing in the context of rapid prototyping of industrial products. Concurrently, I used 3D printers in my design practice; these machines were expensive, and the design bureaus would outsource production of 3D printed parts to other specialized companies. This means that I have not had the opportunity to produce 3D printed parts on my own throughout the entire process from modelling to printing.

By the time this PhD position was announced at Oslo Metropolitan University, my interest in 3D print was waning, as the last fifteen years in the design discipline have brought many changes. Today, the design discipline has moved into many different fields where digital manufacturing is not necessarily the most important topic. Prototyping has also been an extensively discussed topic in design. I began to believe that 3D printing was an exhausted and potentially fruitless research topic. I had many reasons to think this. The 3D printing technology had been accessible for some time and had already been researched by many education practitioners in formal education as well as in informal learning contexts such as makerspaces. Furthermore, 3D printing had not seemed to have experienced increased use on the industrial scale as expected, even though industrial 3D printers had become a common sight in companies mostly for prototyping. Besides not being efficient in mass production application, its energy consumption does not make it necessarily sustainable technology. A glance on Google Trends was showing the phrase "3D printing" as reaching peek and declining in usage in scientific as well as educational topics. However, the word “3D print” itself was and is still on the rise as well as “additive manufacturing,” which is now taking a prime position in fabrication and production contexts. It was clear to me why the Department of Product Design wanted to develop knowledge about 3D printing in the department, but it was problematic to base a research project on this so that it would produce knowledge that is new for the scientific community. In my view, a 3D printer was just a machine, a mundane piece of technology, just as a copy machine, that sits in the corner of an office or a workshop. At one point, it seemed to me more interesting to research human fascination and skepticism around 3D printers than the practices emerging around them.

However, the doctoral project ended up being about the learning that happens with 3D printers, and it was to be written on the program for educational science, which relates to the Department of Vocational Teacher Education and the Department of Product Design. On the face of it, teaching how to operate 3D printers does not seem to be an issue worth researching, and vocational education programs can assuredly handle this task. Yet, the complexity of the issue of learning with 3D printers emerges when design is included, but the design discipline has already found its use for 3D printers in the form of rapid prototyping and moved on.

The complexion of teaching and learning with these machines in the twenty-first century thus came to be a beneficial starting point for this project, while 3D printing became an exemplary emerging technology to research the issue of learning. Characterization of this topic therefore had to be broader than learning, 3D printing, or design. 3D printing is discussed in this dissertation as more than just a production or designing technique, or a method for teaching in workshops, which was changed early on somewhat contradicting the problem framing proposed in the PhD position announcement. Furthermore, even though this topic is open from the perspective of design education because it is narrated through the voice of an educational researcher and a design and teacher practitioner, the implications and generalizations have a wider audience. Based on this reasoning, the aim was to unveil what characterizes 3D printing so that research can provide a glimpse into the future of learning and education, where the technologies are perpetually becoming obsolete, rather than in 3D printing itself. In the literature review, I employed broader searches so I could frame a meaningful and relevant research question. The continuous examination and rewriting of the literature review during the formation of the research question seemed to be crucial as it informed and guided the research. My presumptions turned out to be right in many ways, but also in respect to the outcome of the research, they turned out to be substantially wrong.

Ultimately, I had to leave the conceptual approach to my research and move towards a material one.

The journey started in September 2016. At the very beginning of the research project, I refreshed my digital modelling skills, learned how to use 3D printers through online courses, and connected with online community of 3D printing enthusiasts. Further, I connected with a group of artists who use clay 3D printers, I joined them in producing 3D printed art which was exhibited at Galeri Bergman in Karlstad in June 2017. I had many interesting technical discussions about pitfalls and benefits of 3D printing techniques in clay composites and polyvinyl alcohol plastics with participants in these groups. This I saw as a preparation to develop my own pedagogical practice based on 3D printing in a course at the Department of Product Design. The journey led down many bumpy roads, trying to integrate theory into practice and take different perspectives on what I observed in the field. In that sense, this journey for me represents a story of personal change, as I had to depart from my role as design practitioner, depart from established views about learning through emerging technologies, and find my way into the field of philosophy, which I originally did not intend to do.

Over just the time involved in the process of this doctoral project, many people around the world have experienced an influx of new digital technologies in their private and work lives. In the department of product design at Oslo Metropolitan University, for example, technology has greatly expanded in the textile workshop, but also industrial-scale 3D printers have been acquired for the department, including metal sintering and carbon fiber fusion deposit printers as an extension of the 3D printing lab.

This accessibility of 3D printing technology seems to be a sufficient reason to further research this technique to understand the manifold of practices that emerge when it is put to use. However, researching these practices without discussing the broader societal impact arising from emergence of the 3D printers would not give needed answers for technological education and pedagogy. At this point, 3D printers should not be understood as an isolated technological development, rather as a perpetuation of the informatics revolution. In the context of education, it would be difficult to avoid the discussion on the effects of this revolution in the way society educates, learns, and works (Brown, 2000, pp. 11-14). Thus, the vantage point of this dissertation is the technological disruption, its effects on education and what it means to learn in the context of perpetual technological change. The informatics revolution, which started with the advent of the internet, has now disrupted the way society consumes immaterial goods and services from books and movies to banking and communication. There seems to be an analogic expectation by both the business and scientific communities that 3D printing will disrupt production and distribution of material goods in a similar way for better or worse. This seems to be generating an exceptional amount of research on applications of 3D printing from the position of a variety of social actors, including those involved in education, business, technology, and other domains. Thus, many enterprises in our society want to know how to prepare for the coming changes by educating competent staff to confront them.

Technological disruptions from the perspective of education is the issue this research strives to explore. Technological disruption refers to abrupt changes in practices due to the implementation of new technologies. For example, lately, "technological disruption in the labor market has attracted a lot of attention specifically because of automation, driven by machine learning, which has taken its toll on "highly skilled 'cognitive' and 'non-routine' occupations, such as in accounting, medicine and the law" (Healy, Nicholson, & Parker, 2017, p. 157).

Application of 3D printing in the context of product design education is a representative case of the phenomenon of this disruption. This is because 3D printing technology has already disrupted product design practice through computer-aided design (CAD), rapid prototyping methods, and education through the maker movement. However, this technology is still in the process of disrupting the manufacturing industry. The design studio environment is representative of this because it is the meeting point between formal vocational education and knowledge work where the issues of educating and learning emerging technologies and connecting theory and practice are at the forefront. Furthermore, the design studio's formal pedagogics resembles a free learning informal pedagogical approach in makerspaces, which disrupts the traditional approaches to formal education. The research question which will be further developed in section 2.3.2. is:

How can resilient learning be assisted by emerging technologies in product design education?

This research follows the logic of an instrumental case study (Stake, 1995, pp. 63-66), where the researcher selects the usual or typical cases to generalize from them. This research method is based on broader philosophical underpinnings, and often concludes with contributions and changes to those. This means that the case itself is an instrument for studying a phenomenon.

In an instrumental case study, participants and the setting are not necessarily the focus of the study, instead it is a phenomenon that is very well represented in that particular setting. This is in contrast to explanatory or exploratory case studies in which the goal of the study is to explore and explain how the participants and the setting have contributed to certain outcomes.

This project was consequently designed to uncover and discuss concepts around learning and educating *to, by, and through* technologies by researching the phenomenon of learner-medium relation. As such, the dissertation was written in an iterative manner. The literature review informed the research titles for this work, and the emerging issues for the research, in turn, informed the literature review. The findings from the review are described in detail and will reveal to the reader the key concepts that were integral to the research. The conclusions derived from the review were used to develop the research question for this dissertation

1.1. Key concepts encompassing learners' relations to emerging technologies

In this section, I introduce key concepts and describe how they relate to what I discovered in the literature review in order to thematically and theoretically define the knowledge gap. To understand learning in the context of emerging technologies, the object of this research is learner – technology relations. These relations are thematized in this section at different levels of human experience such as instrumental, group, and societal aspects of technological disruption. The learner – technology relation is therefore researched throughout the articles in this dissertation in different settings of product design education and was crucial for theoretical relational approach in this thesis.

I use the concept of *affordance* to explain possibilities of new technologies. Gibson coined the word affordance to explain the complementary nature of the relationship between living organisms and their environment: "The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does" (Gibson, 2014, p. 127). Throughout this work, affordance is used to explain what 3D printing as a technological environment set up affords to different actors, particularly those who must respond to societal demands. This term will be further explained and theoretically integrated in the method section of the dissertation. The emerging research question will be then developed and described based on these concepts and theories.

The basic premise of this dissertation is that the continuously changing work environment due to technological innovations has a wide range of effects and is a significant issue that must be considered. The series of ongoing technological disruptions as the consequence of information technology and the rise of the internet are transforming and expanding the service sector and are disrupting the production sector. The disruption, it has been argued, will bring significant socio-technological change and invention. This disruption involves not just technological interventions but is also manifested through organizational and business innovations, and the way society is organized (Troxler & van Woensel, 2016, pp. 186-189). Therefore, preparing future lifelong learners for this environment should be an important discussion topic in the context of education. In the technological production sector, the ongoing fourth industrial revolution, or industry 4.0., is based on automation but is moving towards cyber–physical systems. The drivers of this revolution are, among others, interconnected automated machinery, also called the *internet of things* platforms, which include smart sensors and advanced human–machine interfaces, such as augmented reality devices, big data analytics, advanced algorithm monitoring, comprehensive supply chains, and digital modelling and manufacturing using 3D printing (Roblek, Meško, & Krapež, 2016, pp. 2-4).

1.1.1. Operative aspect: How 3D printers work and what it means

Today, numerically controlled machines are the primary way of fabricating almost every commercial product, by either producing the products directly, or producing tools, which then are used to manufacture them by molding or stamping. Digital fabrication includes digital modelling and using that information to control tools numerically in 3D space. These tools, such as laser cutters or milling machines, can subtract from the materials or add layers of materials through processes including sintering or fusion deposition (Gershenfeld, 2012, pp. 43-45). 3D printing is therefore an additional digital fabricating technique. It is a layer-based automated fabrication process for making scaled 3D physical objects directly from CAD data without using part-dependent tools. The process is therefore replicable, enabling reproduction of the objects (Gebhardt, 2011, p. 2).

Originally, the 3D printing technology was conceptualized by Charles Hull in 1984. Hull's method was stereolithography, based on merging layers through the use of UV lights, which was the predecessor of the modern stereolithographic apparatus (SLA), or powder-based stereolithographic sintering (SLS) printers (Lipson & Kurman, 2013, p. 37). In 1988, S. Scott Crump was working on another concept using deposition layers of thermoplastic materials, something similar to a robot-navigated arm with a hot glue gun. This concept was the predecessor of fused filament fabrication (FFF), or fused deposition modeling (FDM). It took 10 years for the technology to escape the restrictions of patent law protection and become commercially accessible and open for anybody to improve it (Lipson & Kurman, 2013, p. 68).

The industrial applications of this technology are still claimed to be unprecedented in many areas: the aircraft industry, healthcare, biotechnology, architecture, products, fashion, and parts replacement for mechanical systems, among others (Lipson & Kurman, 2013, pp. 3-5). Yet, 3D printing is currently establishing its own niche outside of mainstream technology. It has applications for small production series in a diverse range of industries. In order to gain further recognition for its industrial usage, research, and development, there needs to be a better understanding of the following factors: designs, materials, novel processes and machines, process modeling and control, biomedical applications, and energy and sustainability applications (Guo & Leu, 2013, pp. 237-238). The biggest obstacles to its wider adoption are equipment cost, material cost, accessibility, and manufacturing cost. The manufacturing cost addresses energy and time inefficiency of 3D printing in comparison with the other specialized mass production techniques such as injection molding (Velenis, Stucchi, Marinissen, Swinnen, & Beyne, 2009, pp. 148,149). Stereo lithographic sintering has been used for fabrication of clay, concrete, and metal parts. Also, 3D printers have been expanding in size and diversity of application and are seeing their first commercial uses, such as in housing projects (Boffey, 2018).

Digital fabrication has, however, also become a means of personal fabrication. In this context of small-scale production, energy inefficiency and system integration are not crucial issues (Gershenfeld, 2012, p. 44). Numerically navigated milling machines and laser cutters can now be commonly seen in workshops, and 3D printing can be even seen in libraries and classrooms in the form of desktop equipment commonly called *3D printers*. Personal fabrication by means of 3D printing is also then often called 3D printing (Mota, 2011, pp. 16-20). This term is now being used colloquially. However, as 3D printing is being commercially adopted in industry, additive manufacturing as a term has reemerged and is slowly gaining wider usage.

Prototyping in product development does not demand scalability of mass production either. Therefore, 3D printing has found its use in the context of initial product development. Product developers used it to modify digital models and quickly gain access to a full-size model with all the features and functionalities the final product would be expected to have. This process of iterative incremental improvement of the products through their physical demonstrations is called *rapid prototyping* and has been used for different types of testing in the research and development phase in industry (Jacobs, 1992).

Moreover, 3D printing is a sequential but not prescribed use of a series of technologies. Its process consists of modeling and manipulation of virtual 3D digital models, which a learner has to convert into data that will enable a 3D printer to generate layer depositions using specialized software. The principle of generating digital files for creating objects by deposing layers of material differs from mechanized production processes as well as manual processes (Vayre, Vignat, & Villeneuve, 2012). In fact, 3D printing differs from the manual processes in the sense that a learner does not have physical or haptic contact with the material or an object throughout the process of creation. The effect is also temporal because the immediacy of handmade modification of the object is lost, as the learner has to wait for a 3D printer to generate a material 3D object in order to interact with it. Also, 3D printing differs from other mechanized production processes as it is versatile but less effective in carrying out the production process. The process of deposing layers at the current stage of this technology can be time-consuming, depending on the complexity of the object. However, the object produced by 3D printing is not bound by many geometrical constraints or complexity, which is usually the case with mechanized processes such as injection molding. This puts 3D printing somewhere between mechanized and manual processes because it is possible to reproduce objects, but is also possible to modify and customize them, albeit on a small scale (Berman, 2012, pp. 160-161).

Therefore, the properties of 3D printing that are of interest to research in the context of learning are the following: sharing and modification of files and output, generation and use of complex geometry, unpredictability of outcome due to temporal–physical inaccessibility of objects and software settings, and the range of applications and study disciplines due to its versatility. These properties of 3D printing and their learning affordances have already been researched, and I will further discuss them in the literature review subsection

The revolutionary affordances of digital fabrication are therefore “not additive versus subtractive manufacturing; it is the ability to turn data into things and things into data” (Gershenfeld, 2012, p. 44). Consequently, it is now possible to streamline small-scale production and produce modular and part replaceable solutions. Further, because of layer building, it is possible to produce shape complexity, never previously possible through manipulating material by hand or analog machines. The complexity and modularity do not require additional tooling or machine skills. In fact, the same production procedures can be applied in all circumstances, which is contrary to the modelling and production procedures used with analogue machines. This does not require safety training and can be used anywhere, making it exceptionally accessible to many leaners. Finally, and most importantly, ideas for prototypes can be shared, easily iterated through manipulation, and multiplied through file sharing on the internet without losing detail. As digital fabrication has become personal, these prospects represent the future learners' technological environment, and these affordances of digital fabrication are becoming their learning affordances. As these affordances are versatile, they are developing further attributes according to different actors: educators perceive them as *educational technologies,* makers as *maker technologies,* technologists and businesses put them in the broader context of *emerging technologies*, and designers call them *design media*. Finally, in this project, these affordances are represented through the term *emerging technologies* because each of them brings ambiguity in applications and unknown implications.

1.1.2. Learning aspects: Informal and formal learning with emerging technologies

Commercialization and affordances of personal digital fabrication have spurred the maker movement. This is a grassroots movement of garage and kitchen tinkerers, hackers, designers, artisans, and inventors, and it has been radically expanding. "Since the first Maker Faire in 2006, making festivals, spaces, activities, conferences, and studies have multiplied" (Vossoughi & Bevan, 2014, p. 2). The maker movement is also known for organizing non-formal learning spaces where enthusiasts gather their digital tools and knowledge to launch their individual projects (Dougherty, 2012, pp. 12-13). Hence, "*Makerspaces* are informal sites for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" (Sheridan et al., 2014, p. 505). In the language of the literature, but also colloquially, other expressions are also used such as hacker spaces and fab labs.

The emergence of these self-organized environments of informal learning represent to some researchers, but also politicians, the promise of a shift in culture, education, business, and workplaces. The potential consequences are, among others, significant social impacts, such as democratization of manufacturing, empowerment of users, mass customization (Ratto & Ree, 2012). The optimistic view about the maker movement comes from politicians who "see the promise of users being the makers of things, and not just the consumers of things"(Obama, 2009). Similarly, Hatch (2014, p. 10) viewed this process as democratization of consumption and innovation and the emergence of a proactive user. According to Lee (2015, p. 31), makerspaces as self-organized environments are based on three pillars: first, the accessible personal digital tools, particularly rapid prototyping tools and microcontroller platforms; second, community infrastructure, particularly online resources and in-person spaces and events, which allow peer learning and cooperation or collaboration; and third, the maker mindset, which allows for the tolerance of failure and learning for the sake of play. In that sense, learning in makerspaces is oriented towards problem-solving rather than a curriculum. Because of this, it is *contextual*, meaning *transdisciplinary* as it is primarily dependent on resources and participants rather than on institutional and academic boundaries. Further, because it is based on practical work knowledge and learning, it is highly *applicable*. Finally, it is highly *autonomous*, self-driven, and self-motivated, so what and how it is learned is decided through participants' sense of what is interesting and fun (Petrich, Wilkinson, & Bevan, 2013, p. 65).

However, Halverson and Sheridan (2014, p. 498) argued that the makerspaces and the maker movement are not necessarily so original and revolutionary as these values and characteristics of learning are already present in the formal educational pedagogical concept of *design studio* that was traditionally used in architecture arts and design education. Namely, designers are learning how to design in a practical sense, as well as how to navigate the process of designing, not only how to apply specialized knowledge to a design problem. In his observation of design studio, the philosopher D. A. Schön (1985, p. 6) explained this:

Given an architectural program or brief and the description of a site, the student must first set a design problem and then go on to solve it. Setting the problem means framing the problematic situation presented by site and program in such a way as to create a springboard for a design inquiry. The student must impose her preferences onto the situation in the form of choices whose consequences and implications she must subsequently work-out all of the field of constrains.

Schön also explained that the knowledge coming from this activity is rather inductive, contextual, and relevant for the problem at hand. This is unlike the scientific approach which he describes as an adductive process which has rigor, is factual and robust, but also lacks relevance for a practitioner in the actual problem-solving process (D. A. Schön, 1985, p. 15).

The design pedagogy theoretician Tovey noticed that “there is a greater emphasis on being able to do it (design) than on designers being a repository of specialist knowledge.” He further claimed that designers are “generalists in as wide range of content as possible” (2015, p. 37). This studying of the process allows for design process mastery that is then used to discover knowledge fields, according to Owen (2007). In his article about design thinking, its nature and use, he noted the following:

Common wisdom today holds that the trend of expertise is to greater and greater specialization and, therefore, success will come more readily to those who choose to specialize early and plan their training accordingly. *Design thinking*, to the contrary, is highly generalist in preparation and execution. In a world of specialists, there is real need for those who can reach across disciplines to communicate and who can bring diverse experts together in coordinated effort. For inventive creativity, the wider the reach of the knowledge base, the more likely the creative inspiration. A designer is a specialist in the process of design, but a generalist in as wide a range of content as possible. (Owen, 2007, p. 24)

The design studio is also a social setting in which designers mediate between stakeholders, such as clients, users, and other professionals, but also artificial sites and technology in order to reframe problems (Orr & Shreeve, 2017). The other important aspect of learning in the design studio is critique (Gray, 2013; J. J. Gross, 1998). Design learners present their work which is followed by critical discussion with the master practitioners and, almost more importantly, with fellow students (Goldschmidt, Hochman, & Dafni, 2010). Design studio learning topics are therefore not only defined by personal interests, but by other stakeholders. The process of learning is not only peer-guided but also supervised by an experienced practitioner, making design learners less autonomous but more interconnected than maker learners. Finally, designers are bound by *design media,* which have been considerably altered by the digital revolution.

Design discipline has itself been disrupted by the affordances of digital fabrication, which have moved design discipline from vocational towards knowledge work. Rapid prototyping has become a customary design process, speeding up the conceptualization phase in design and, in turn, *design conception*. By digitally augmenting affordances of design media, the focus of design work is moved from material skills towards conceptualization (Kempton, 2019, p. 139). In many instances, design work does not finish with a material outcome, but rather a digital file or a system intervention. Technological advancements have also made design problems more complex, thus expanding design discipline into many new fields.

Simultaneously, the mastery of the process of designing has become relevant to other disciplines. Design is now a way of solving problems, which has made design discipline a fluid concept. This is because design discipline now takes on complex challenges and deals with the emergence of completely new industries (Rodgers & Bremner, 2017, pp. 21-25). This can also be seen in the way design consultancy professionals adjust their specialization. Instead of automotive, graphic, fashion, and industrial design, now expressions, such as design for sustainability, system, service, experience, emotion, or interaction (Sanders & Stappers, 2008, p. 11), are the key design offerings. Accordingly, design is not characterized any longer by the industry in which it is used, but by the design process and knowledge gained through this process. Design discipline therefore embodies different directions within the design profession itself as well as multiple additional professional fields where design finds new roles. These roles are reflected in businesses which are either inhabited by designers or are teaching design thinking skills to their employees (Kolko, 2015, pp. 68-69). Thus, design competence of the future should rely much less on specialized knowledge of the field or particular skills and more on design thinking.

1.1.3. Societal aspects: Learning for resilience and sustainable education

The previous section provides a summary about the impact of personal digital fabrication tools. Affordances of these tools are directly or indirectly causing changes in informal learning practices. Some of these changes are the need for learning that is more context than curriculum oriented, more practically applicable than procedurally prescribed or declarative, more transdisciplinary than specialized, and finally more autonomous than steered. However, the full societal impacts of the information revolution, internet, and current cyber–physical systems is difficult to anticipate in respect to all the positive and negative sides. Researchers are striving to understand and develop conceptual frameworks and methods for how to educate future participants in the work life built on these premises. In addition, policymakers of many institutions are openly calling for autonomous and problem-solving oriented learners.

The Organization for Economic Co-operation and Development (OECD) in its Education 2030, for example, describes the abilities of future students in this way: “Students will need to apply their knowledge in unknown and evolving circumstances. For this, they will need a broad range of skills, including cognitive and meta-cognitive skills (e.g. critical thinking, creative thinking, learning to learn and self-regulation); social and emotional skills (e.g. empathy, self-efficacy and collaboration); and practical and physical skills (e.g. using new information and communication technology devices)” (OECD, 2018, p. 5).

The World Bank, discussing the global issues of employability in their report "The Changing Nature of Work – World Development Report 2019," put it this way: ". . . technology is reshaping the skills needed for work. The demand for less advanced skills that can be replaced by technology is declining. At the same time, the demand for advanced cognitive skills, socio-behavioral skills, and skill combinations associated with greater adaptability is rising" (Stromquist, 2019, p. 6).

The Department for Economic and Scientific Policy of The European Parliament in its report entitled "Industry 4.0," described the demand that will be faced by the future workforce: " . . . this means that there are significantly higher demands placed on all members of the workforce in terms of managing complexity, higher levels of abstraction and problem-solving. Employees will be expected to act more on their own initiative, have excellent communication skills and be able to organise their own work" (Smit, Kreutzer, Moeller, & Carlberg, 2016, p. 47).

This development seems to be blurring the borders between knowledge work and vocational work as even the simplest technical jobs will demand a certain level of autonomy and problem-solving skills. Other boundaries between theory and practice but also between disciplines will be less distinct. The knowledge will be dominated by cross-industry, transdisciplinary application and experience, and the constant need to develop an understanding of information technologies (Xu, Xu, & Li, 2018, pp. 2955-2956).

These policies therefore address the need for future vocational education not only to adopt new educational technologies but also to educate learners who can cope with new technologies or work circumstances. This will demand from learners the ability to adapt their workflows to these technologies or even to generate new practices and workflows that will benefit their social and physical environment, internet community, organization, or company. The need for this development has been the focus of the discussion over the last two decades in higher education about the need for knowledge workers in a knowledge society (Young, 2007, p. 18). Young, an educational theoretician, outlined the need to close the gap between theory and practice – meaning academic and vocational studies – and making them more accessible as education becomes the norm (2007, p. 32). Other researchers and theoreticians have outlined similar demands from higher education: situated or contextualized learning (Eraut, 2000), participatory learning (Knight, 2001), and transdisciplinary, interdisciplinary, and cross-disciplinary approaches (Choi & Pak, 2006) as well as continual learning through professional life (Candy, 1991). The new role of school is also being discussed as the schools are no longer bearers of information but places for meaning-making of readily accessible information (Edwards, 2010, p. 68). This demand for different kinds of knowledge and learning represents an overarching predicament that this dissertation aims to explore. The existing concepts emerging to describe this future education are expressed not only in terms of what it should do but also, often, in terms of what values it should esteem.

Open education has also emerged as a concept stressing inclusivity and *accessibility* of education as well as lifelong learning, which is commonly considered in the literature on adult learning. Similarly, open learning implies that the learning should be open to "people, places, methods and ideas" (D'Antoni, 2009, p. 4). This means that learning should extend outside the classroom into organizations and companies and that it should be open across educational institutions allowing for the transdisciplinary character of education which is defined by new contexts and demands by actors (Peters, 2017, pp. 4,5). The openness includes educating everybody, thus becoming, by definition, lifelong and free. Seely Brown and Adler emphasized the participatory factor in open learning, where the learning is emerging through interconnectivity (2008, pp. 22-24). Likewise, inspired directly by studying makerspaces, Martin (2015, p. 37) called for a more integrated education as opposed to that which is isolated, meaning integration of theory and practice, integration of different disciplines, and integration of knowledge in work life with stakeholders.

Education for sustainability is a broader concept addressing education for the fast-changing society. The concept of sustainability has been discussed in an educational context that includes thinking, teaching, and learning for the sustainable future (Cortese, 2003, pp. 18-22) and includes two concepts: first, education for sustainable development addressing the kind of knowledge that will be needed and second, sustainable education addressing how the knowledge is obtained. These two concepts can be then merged in education for sustainability or sustainability education (Sterling, 2010, p. 512). In the context of learning for sustainable development, teaching and learning of 3D printing can bring into focus the social and economic impact of the technology: savings on process-related waste, shortening supply chains, optimizing material use, localizing production, spare parts for extending product usage, and modular or customizable design (Gebler, Uiterkamp, & Visser, 2014, p. 166). It will also bring into focus critical thinking about 3D printing in the context of unsustainable practices such as inefficiency of energy use or the danger of low life span products (Armstrong, 2014).

Sustainability, according to educational theorist Sterling (2010, p. 512) implies survival, security, and well-being, and it requires that learners take into account economic viability, social cohesion, and ecological integrity. This relates to the focal topic of this project, namely, sustainable education, that which educates *resilient learners*. According to Sterling, the teaching for sustainable education cannot be transmissive, such as learning by listening, or instructive but has to be transformative and enable a shift in the learners' views and perspectives. It has to enable a learner to be critically reflective and autonomous when coming to conclusions and making decisions. Sustainable education emphasizes the ability of a learner to have a contextual understanding of the situation in which she learns and to critically reflect not only upon her own understanding but also upon that of the other stakeholders in learning situations as well as the role of new technology and its implications (McLaren, 2012, p. 257).

However, learning in a sustainable paradigm must be continually self-managed in order for learners to keep being relevant in their changing technological, economic, and societal environments with their uncertainties. Seeing a resilient learner through the lens of design media brings a series of issues to this research. One is the ability of a learner to master technological media, but also the ability to abandon it as the media or situation changes. Another is the sense to use technology responsibly and having *integrity* to apply it in line with sustainable practices. In this way, the concept of sustainability allows for value judgments of and critical views on digital technologies.

The topic therefore has an international context, as higher education is preparing a mobile workforce to be employed at jobs that never existed before, probably for markets that never existed before. This dissertation addresses this by help of the idea of disruptive workplaces (Pavel et al., 2020). The transdisciplinary and applicable knowledge needed for this kind of work is addressed through design education which already has a transdisciplinary character but is also awaiting to be prepared for the coming disruptions (Pavel & Zitkus, 2018).

1.2. Literature review of the key concepts encompassing emerging technologies and learning

> Technology alleviates the tyranny of human material constitution, its physical limitation, its spatial and temporal constraints, and its limited capacity to perform actions. Yet technology is not only fabricating instruments for a purpose. . . What turns instruments into technological objects is neither their level of complexity nor

> their function – but rather the meaning associated with them. An instrument becomes a technology when it takes on a symbolic dimension, when it is charged by meanings beyond its immediate purposes and, often, beyond its creators' awareness. (Mordini, 2007, p. 544)

In this section, I present the literature review, its research design, and its findings. From that, the knowledge gap is revealed in the context of the technology of 3D printing as a learning medium. The research questions for the dissertation will also be presented which are based on the emerging concepts related to the newly defined knowledge gap.

As mentioned in the introduction section, the topic that remains to be discussed is formulated within the context of what teaching and learning with the emerging technologies in the twenty-first century can or should be. The purpose of this literature review was therefore to give an overview of the existing *central concepts* around emerging technologies in education in general and 3D printing in design education in particular. I approached this literature review from the necessity to scrutinize the characterization of 3D printing, the learning concepts related to it, and the theoretical approaches used in these contexts as presented in the literature. I used a content analysis approach in order to pinpoint the perspectives of the key actors who are invested in 3D printing and its utilization. The characterization and contexts in which the technology is discussed show the meaning which these actors assign to 3D printers in the context of education and preparation for jobs of the future. The outcomes of this approach were the discovery of meanings, characterizations, and perspectives that are not adequately addressed and the definition of the knowledge gap within that conceptual space. The research question for the literature review was therefore:

What are the central concepts in characterizing emerging technologies in general and 3D printing in particular in education, learning, and designing, and how are they addressed in the existing scientific literature?

The summative character of this literature review was derived from the need to obtain an overview of the *central concepts* related to how current research describes this phenomenon (Hart, 2018, p. 19). This meant that an outcome of the research would be a presentation of the current body of knowledge and recommendations for further research for this dissertation. In the review, I did not scrutinize the methods of empirical research in selected empirical studies. The reason for this was that it might have taken attention away from the main purpose of the study, which is to reveal the central concepts in the field. Another reason for this is that the topic of the study is the living experience of learning activity in design studios, for which the application of qualitative methods is arguably most beneficial.

A variety of qualitative interpretative approaches, such as hermeneutical text analysis, case study content analysis, action research, and postphenomenological case study, were used throughout the articles in this project. As such, the dissertation includes this variety of qualitative methods to be methodologically diverse, and a detailed explanation for this choice will be given in the method section of the dissertation. The choice and organization of findings represent the basis for the formation of the research question for the study. The research categories are therefore defined by the above-stated goals of the review and are sorted through the Cooper's taxonomy of literature reviews (Cooper, 1988) in Table 1.

Table 1

Organization of the Review Based on Cooper's Taxonomy of Literature Reviews (Cooper, 1988)

Characteristic of the review	Researched categories in the review
Focus of the review (what is extracted from the selected articles)	-Theories surrounding emerging technologies and 3D printing in learning, education, and design -Pedagogical approaches derived from these theories
Goal (what should be the findings)	Identification of the central issues in the field
Perspective	Espousal of position for the dissertation
Coverage	Review covers central or pivotal work in the field
Organization	Organization is conceptual and is guided by content analysis and findings in order to identify a knowledge gap
Audience	For readers of the dissertation, the literature review has to introduce concepts and then use them to inform readers about the knowledge gap

1.2.1. Narrowing concepts through iterative searches

The literature review was based on iterative direct string search rather than snowballing methodologies. This was because its summative character required a wider scope of articles rather than tracing development of concepts and theories through articles and authors. Even though the literature review was limited to certain search strings with a limited number of words, the readings I had to undertake included many other articles. This reading included existing literature reviews on the use of theories with emerging technologies, maker movement, learning through makerspace, design studio, learning with 3D print, artefacts, medium, boundary objects in literature, among other topics.

The protocol of the research was planned according to the goal to research theoretical approaches to the topic (Flick, 2015, pp. 63,64). The review was therefore limited to purposive samples and was conducted to define central issues. The exclusion criteria were therefore limited to international dissertations and journals. Proceedings and reports were excluded due to lack of significance, as they tended not to rely heavily on theoretical concepts. The research included both theoretical texts and empirical studies. The sources chosen for the study were the Teacher Research Center (TRC), Education Source, ERIC via EBSCO host, and Google Scholar. The choice of sources was slanted towards education but also included social science data sources such as ERIC and Google Scholar for an overview. The data sources selection was based on perspective of technological disruption and its effects on education from the educational science point of view.

The review had three iterations of search, each one informing the next but presented here successively for a better overview. The first iteration focused on revealing current concepts educational researchers use to discuss disruption, and the second one on how these proposals were characterized in the research. In the third, I probed for the concepts I wanted to write about. The initial string therefore followed the models: for the first iteration ((phenomenon), (wider context), (setting)), and in the second and third iterations ((phenomenon), (wider context), (setting), (proposal or intervention)).

1.2.2. Insufficiently addressed concepts in current literature

Iteration 1: Revealing current concepts educational researchers use to discuss technological disruption

After the exclusion process, 634 titles emerged as relevant, out of those 143 abstracts, and out of those 37 articles. The classifications used for coding the abstracts and articles were theoretical perspectives, key concepts, and rationales/implications. In many of the selected abstracts, the theoretical approaches were not as pronounced because the research methods were directed towards either quantifying results or describing emerging topics. The review did include the key concepts from these abstracts and implications but not the theoretical perspectives.

The findings showed that the topic has been extensively researched in different contexts as well as being discussed as a theoretical and key concept around learning in relation to emerging technologies. However, I found a dominant presence of different constructivist theoretical approaches and key concepts both qualitatively and by the number of articles, as well as predominant learner-centered pedagogical approaches. The most pronounced theoretical and pedagogical approach was problem-based learning, followed by authentic, inquiry-based, and experiential learning. Here, the research focused on how learning is contextually constructed and how emerging technologies take a role in it. The behavioral approach was visible in concepts, such as using tutorials and training and gaining practical capabilities including psychomotor and spatial abilities. The biggest disclosure of this research concerned game theory, which was not often present in literature among the learning theories with emerging technologies. The presented cases were about gaming as a way of learning as well as designing games as a way of getting familiar with emerging technologies. Cognitivism in these articles was represented by explanations of how learners interact with technological interfaces. Connectivism and networked learning were often related with "open learning" to explain how learning happens over the internet, often in massive organized online courses.

The key concepts of learning with emerging technologies revolved around social factors such as collaboration and participation, technological factors such as prototyping and mastering technological tools, and individual factors such as motivation, self-direction, and creativity. The most predominant topic in the classification of rationales/implications was the effectiveness in delivering curriculum, teaching, or student performance when using emerging technologies. The next most significant topic was how the emerging technologies can be integrated and implemented in the existing curriculum. This was followed by the topics concerning methods and theoretical developments, quality of education, change in pedagogical practice, and student satisfaction. The increase in learners' motivation was also often reported as an outcome of using emerging technologies in the classroom. This increase was argued to be initiated through improved learners' performance when using emerging technologies in learning situations.

Most of the abstracts represented a positive view of the implementation of emerging technologies in the educational contexts. Some of the qualitative research outlined the success factors and issues emerging in this kind of learning. Only one article denied any positive outcome for learners using emerging technology.

The expression 3D print was used more than 3D printing in this data set. The theoretical approaches connected to 3D print were mostly constructivist ones as well, but in one abstract, a behavioral approach was discussed which underlined the use of tutorials to increase performance in the use of 3D printers. The emerging key concepts were in line with the general findings where collaborative, technological operative and individual aspects were present. Also, 3D printing was often noted as being associated to life-long learning and creativity in this literature.

Iteration 2: How are the interventions for learning with technologies characterized in the research

The second iteration scanning produced an extremely poor data set with only 97 relevant titles, out of those 26 abstracts, and out of those seven articles. Once the research strings were supplemented with societal issues around emerging technologies, such as "knowledge work" and "obsolescence of skills," the scanning process took a different route. The formulated topic seemed to be ongoing in the research fields of organizational science and management more than in educational science. The articles scoped in this scan were oriented towards learning at work, management of knowledge, and innovative processes in companies. Many of these articles were filtered through exclusion criteria as they were missing the components of design or education. Still, the topics of learning in work context were predominant after the exclusion. As the topic moved towards the organization of learning processes at work instead of pedagogical approaches in education, the theoretical approaches became too dispersed for many common topics to emerge. Most of the used theories related to participatory (3) and networked aspects of learning (3). Less pronounced but present are dialogical learning and socio-technological systems theory. The most common concept emerging in the abstracts was lifelong learning (4). Less pronounced but still present were design thinking, creativity, self-determination, and transdisciplinary learning.

The most pronounced rationale and outcomes of the research were managerial and organizational. The topics of enhancing workers learning at work, knowledge transfer within an organization, and improvements in the quality of work such as innovation, enabling lifelong learning, and development were the most common topics. This was followed by the topic of implications of technological applications in organizations through evaluation and proposals for changing policies, curriculums, or managerial practices at work and in education. Finally, only a few articles included theoretical elaborations and development of concepts as their main purpose. The search produced more matches that included the term "emerging technologies" than "3D printing" together which included only two, and "3D printing" which included only one match.

Iteration 3: Examining the concepts of interest for this dissertation

The search yielded only 11 results of which seven abstracts and four titles remained after the exclusion criteria were applied. None of the proposed articles included concepts such as sustainable education or postphenomenology, empirical studies in the design studio setting, or 3D print and 3D printing as a learning medium. This scanning process therefore indicated a noteworthy knowledge gap about the proposed topic described through the concepts of resilient learning, learning media, and 3D printing.

1.3. Defining a knowledge gap: Informal learning qualities in formal learning settings

The knowledge gap presented itself in practical–pedagogical and theoretical areas. In a practical–pedagogical sense, the research worked to bridge the issues of adoption and redundancy of the technology. The adoption of technology as described in the previous section is not a linear process of training in 3D printing. The knowledge gap can be seen in the conflicting demands in the kind of learning that is accessible, contextual, transdisciplinary, applicable, and autonomous. The redundancy of the technology has been addressed through teaching with the plan that technological skills will become obsolete, particularly focusing on learning for resilience. The theoretical issues emerge in the gap between understanding of learning as networked and personal as well as a practical technological utilization on one side and individual development of the learner on the other.

Many educational researchers have discussed how emergent self-organized learning settings caused by digital fabrication can be harnessed in the university context (Barrett et al., 2015; L. Johnson et al., 2016; Wong & Partridge, 2016). The application of the technology is a topic in both scientific and practitioner papers which envision the changes and transformations that 3D printing will bring to the society and consequently to the classroom as an educational technology (Terner, 2015, p. 4). 3D printing seems to be especially triggering interest across these educational disciplines: science, technology, engineering, art, mathematics (STEAM) (Vossoughi & Bevan, 2014, p. 2). Many articles, as confirmed by the literature review, have shown how teaching, learning, and curriculum can become more effective. Many papers underlined how learning happens as sub-product of making and how students in interaction with the new technology develop self-efficacy, motivation, and interest. Some researchers claimed that there is an positive impact of the makerspace setting in education (Forest et al., 2014) .

There are also researchers who have called for a more balanced view on learning through educational technologies. Thus, instead of focusing on the state of the art practices with educational technologies, where the best practices have been selected, scientists should research the state of the actual, presenting real issues and challenges with introduction of the technologies (Selwyn, 2011, p. 715). Therefore, the balanced view can be achieved by researching not only the incompatibilities of the educational systems, but also those of the technologies. The critical issues of emulating the maker movement in formal education have also been addressed in the context of different educational agendas of learning with maker technologies, theoretical issues of understanding learning through maker technologies, and roles of curricula and pedagogues in formal education (Godhe, Lilja, & Selwyn, 2019, p. 12).

Finally, to have a realistic outlook on what is happening in makerspace education is necessary if there are to be systemic changes. Designing curricula is a complex process that includes multiple actors and dimensions. Using the principles of makerspace in formal education would have to consider noteworthy changes in how ideological curricula is understood (Goodlad, 1979, p. 60). In other words, this would mean a change in what the key societal actors perceive as what are the ideals of the new way of educating with technologies. Good information has to be provided in order to allow for informed decisions on various dimensions of curriculum design, such as civil interests, cultural norms, client interests in vocational training, knowledge fields and disciplines, communities of inquiry and professional interests such as those of teachers and administrators (Goodlad, 1979, p. 351).

1.3.1. Emerging technologies in education: Curriculum, tool, and process-centered education

The pedagogical knowledge gap is evident in the incongruities existing between the formal schooling demands and the principles of learning in the maker movement. Also, aside from the focus on quality through grading and accreditation of knowledge through curriculum in formal education, the incompatibilities are conceptual.

The incompatibility lies in the maker movement’s purpose, from which it draws its ability to be self-organized and provide autonomous learning. The ideals of makerspace are built on the premise that the learner’s own goals, interests, and sense of what is fun and cool are primary in the learning project (Petrich et al., 2013, p. 61). This means that learning can be highly autonomous as well as applicable in a practical technological sense but not necessarily in a societal sense, suggesting that it does not necessarily directly address societal demands for sustainable development. Formal education, on the other hand, is striving to prepare learners for the future workplace.

The maker movement is seen by some researchers as being created by individuals who already share an interest in technological topics and have the resources to do this (Dunbar-Hester, 2019). It has therefore been criticized by some researchers for not being inclusive enough and being dominated by "male geeks"(Grenzfurthner & Schneider, 2009), whereas inclusivity is a priority in formal education. This inclusion means accessibility to technology but also making this kind of learning attainable for those who have not had an opportunity to participate in it.

From the perspective of formal education, it would be a gross generalization to assume that all students are self-motivated, and that learning happens spontaneously as it does in makerspaces. Engaging with a 3D printer in itself does not necessarily mean learning how to use the technology or having an interest in learning about the topics related to using the 3D printing technology. The research about casual users of 3D printing in the printing centers outside of the maker community has shown the predominant reliance of the users on professional operators of the machines (Hudson, Alcock, & Chilana, 2016, p. 393). Owning a 3D printer *per se* might allow users to gain operative procedural knowledge without necessarily transforming them into designers or makers or enabling them to acquire technical or other competencies.

Adoption of 3D printing technology occurs in three specific ways in three loose groups: "end users," "early adopters," and "developers," according to the maker movement researchers (Moilanen & Vadén, 2013). They explain how end users are printing already developed content that can be found online but are not involved in making developments in either 3D printing software or hardware. Early adopters consist of people who buy 3D printers and assemble and use them with the help of the community of users, often making contributions to the software or hardware and to that community. Finally, developers are people mainly concerned with the development of 3D printing, either in terms of software or hardware. Contrary to the claims of some makers, many 3D printers are used by end users to consume ready-made content, which has already been created by early adopters and developers in the 3D printing online community.

Without a community of learners who are genuinely interested in making, self-motivated, and autonomous in choosing their level of involvement, it is challenging to emulate a makerspace learning setting in formal education. Introducing a makerspace in formal education carries risks of losing its attributes of autonomous learning because of tool-centrism and curriculum-centrism (Halverson & Sheridan, 2014, p. 500; Martin, 2015, p. 37). Likewise, in design studio education there is the issue of the process-centric approach to learning. In each of these, certain issues arise. Introducing educational technologies in the curriculum-centric program carries a risk that the technology will simply be neglected as it may not be possible to integrate it into existing curriculum. The learning keeps being accessible but often little is applicable in the technological context. There are studies showing how technology was purchased, but simply not put into use by the educational institutions (Cuban, 2009, pp. 188-193). Introducing 3D printers into a tool-centric program can simply turn courses into a skill training where the technology is used with predefined procedures and expected outcomes. Learning becomes applicable, but the potential for autonomous learning becomes diminished in this setting.

The process-centric approach of most design studios does not seem to always be motivating for the learners. Here, learning is applicable, transdisciplinary, contextual, and, to large extent, autonomous but not necessarily accessible or attainable, especially in mass enrolment education. Namely, asking learners to gain contextualized and transdisciplinary expertise on their own as they go with the process of critical reflection and to trust in their own judgment, especially early in higher education, can be a daunting task. A recent qualitative study of architecture students in a design studio (Hokstad, Rødne, Braaten, Wellinger, & Shetelig, 2016) directly investigated the transformative properties of the design studio setting and the difficulties this educational concept brings to design learners. The qualitative study addressed the individual voices of learners and their struggle when coping with the ambiguity of the design learning process. Moreover, the individual struggle that comes from the free learning process of design studio was also earlier described:

The studio deliberately fosters an engagement in a kind of creative play—a process in which a directed outcome is not available. The ambiguity of the process, the requirement that the student begins before being clear on what is to be done—the nature of acting, then reflecting, then acting again—all this tends to engender a level of uncertainty and vulnerability that is often accompanied by a level of frustration. (Ochsner, 2000, p. 201)

In the design studio, project-based learning is put under pressure by precise intended learning outcomes. The accessibility and attainability of this kind of learning is questionable as it asks learners to have high tolerance to ambiguity and work inductively early on, in the studies. This topic is further developed in the article included in this dissertation (Pavel, in review)

As content knowledge is widely accessible on the internet, and technology is now readily available to individuals, some researchers have questioned the way future learners should be educated. They have claimed that informal learning practices based on voluntary participation call into question teaching practices in formal education. This brings into focus the role of the institutions and teachers in the empowerment of students (Halverson & Sheridan, 2014, p. 500). I do partly agree with this, but stress that the issues involve both an educational perspective and the nature of teaching practice. I have formulated this issue as the feasibility of *free learning* in formal education. Free learning can be characterized as learning freed from the curriculum and instruction, while still maintaining the most important features of the formal demands of education, such as practical relevance, societal applicability, inclusivity, and academic quality, or better said, how to use technology-based education to bridge the gap between applicable and accessible learning, on one hand, and still allow learners' autonomy on the other. This research has striven to gain a perspective on these issues from the standpoint of design studio education. The concepts of learners' autonomy, free learning, instruction, technological mediation in learning will be further discussed.

1.3.2. Pedagogy that prepares learners for technological redundancy

As the informatics revolution is changing working and living practices, the newcomer learners are adopting and navigating the manifold technologies. These technologies embody the way in which they access and modify information and interact with the material environment. In their lifetime, the technological changes affecting them will be even more substantial, demanding additional adaptation to the way they live and work. The phenomenon researched in this study then has not been 3D printing or 3D printers *per se*, but their methodological or technical applications in the design studio. The phenomenon researched here concerns the continuous influx of technologies in learners' environments and their coping with them to achieve their individual purposes. The emphasis has been on the obsolescence of skills due to technological change and preparation for lifelong learning. In this dissertation, therefore, 3D printing is not perceived as a technology of the future that should be introduced to the curriculum. It is rather perceived as one of many technologies that future learners will adopt and probably abandon due to new technologies replacing it, or due to demands they will meet in their future workplaces. In their lifetime, learners will requalify, or might simply, by advancing to higher positions, neglect their technological abilities, but the accomplishments they achieved by using them will constitute their competence.

This research stressed the importance of the process of embracing technologies by learners. This process has steered pedagogical approaches, which are both immediate and long-standing. The immediate one is to find the way to realize the potential of the technology for particular purposes, and the long-standing one is to recognize the potential of emerging technologies and be able to embrace and work through them for sustainable development. This can be called resilience.

The literature review indicated that, even though learning by means of 3D printing has been extensively researched in the context of education as shown in iteration one, the topic has not been sufficiently discussed in the context of continuously changing work environments as shown in iteration two in the literature review section.

The issue therefore ceases to be implementation of 3D printing in educational situations for the sake of curriculum goals. Rather, it becomes of interest to explore how to repeatedly and continuously adopt new technologies in professional practice. Furthermore, how learners adapt their practice to the emerging technologies and new circumstances that technology affects are key issue. Finally, the exploration is essentially about what kind of pedagogies can assist learners in becoming accustomed to the continuous process of interchanging technological environments. Thus, 3D printing can be understood as a representative technology for this kind of exploration. This formulation of the predicament for research is thematically different, as it does not seek to manage the effectiveness of the curriculum, teachers, or students. Instead, it has the goal to provide a new perspective on learning which is mediated by technology. This perspective should shed a different light on general educational issues around emerging technologies as well as practical pedagogical issues demonstrated in the context of design education.

1.3.3. Searching for theory that recognizes the technological impact on learning

The theoretical knowledge gap can be found in the discrepancies involved in how the current body of research approaches emerging technologies, but also in terms of learning at work and in education as shown in the literature review. While constructivist views are dominant in education, in the field of organization and management, the network-oriented theories seem to be predominant. Preparations for lifelong learning by means of technological alteration is not only an organizational and managerial issue but a momentous educational and pedagogical challenge. My research represents an effort to bridge technological theoretical views and longstanding learning theories. This gap between social systemic, group dynamic, and individual understanding of learning were addressed through the research. Here, the gap in question will be addressed through discussion about separateness between technology and operative capacities of learners.

Further, this research examined the dominant constructivist approach to learning. This was done from the perspective of the design studio by scrutinizing current pedagogical theoretical approaches applied in the design studio such as reflective practice and constructionism (D. A. Schön, 1985). This also meant a departure from the originally announced and conceptualized PhD project based on workshop learning (Mjelde, 2006). Consequently, the issues of technological adoption and redundancy prevailed over the application of 3D printing technology as initially presented in the project announcement. The PhD program announcement directly addressed the manufacturing side of the technology in the context of vocational training of design students for the future ceramic printing work market as you can see in the preface of this dissertation.

There are two types of ceramic printers available on the market. One is based on the FDM technique and the other is based on the SLS technique using clay dust sintering or blinder jetting (Yoo, Cima, Khanuja, & Sachs, 1993). Both are used in niche markets. The first one is found in the artistic community which uses this technique to produce small-scale series of unique or slightly modified pieces (Chau, 2017) , and the other is used in manufacturing for producing small-scale complex parts for various industrial applications. It is uncertain whether and how some of these technologies will become mainstream in ceramic production and what purpose they will serve. The department of product design at Oslo Metropolitan University currently employs two FDM printers of different sizes with different nozzle sizes and accuracies but has also newly acquired a metal 3D printer. This development at the department exemplifies the progression in development and adoption of 3D printing and shows its diversity of use. Moreover, the PhD project summary addressed the learning aspects of using 3D printing and its potential for use in different professional contexts and its role in development and change, treating 3D printing as an educational technology.

This conceptual framework of sustainable education moved the topic of this research project towards a consideration of the preparation learners for the expanding design discipline, rather than simply the application of this technology in the context of learning or curriculum for certain vocations. Therefore, the conceptual framework did not focus on following the concepts from the description: *application of (creative, artistic, digital, ceramic) production techniques, workshop learning or practice, workshop learning in practice, professional knowledge, and experience.* The sustainable education perspective refutes that there is a conclusive or definitive 3D printing technique, practice, or training process to prepare students for a specific job or field in the 3D printing industry, for example, the ceramic artistic field. Instead, the framework of learning for resilience emphasizes concepts in the same text such as *change processes, various or different professional contexts, prototyping and experimentation, occurrence, or emergence of learning.*

Table 2

The Evolution of the Research Topic through the Structure of the Research

	Setting	*Theoretical perspective*	*Participants*	*Intervention*	*Outcomes*	*Evaluation*
Initial	Ceramic Workshop	Workshop Learning	Design Students	Vocational Teaching	Expertise in Production Techniques	Design & Technology Competence
Evolved	Design Studio	Post-phenomenology	Design Students	Context Facilitation	Expertise in Adopting Technologies	Resilience

Concepts such as expertise and competence also changed their meaning in this conceptual framework. Competence is not understood as an efficient or successful deployment of particular technique or applied knowledge in the field of 3D printing, but rather coping with new circumstances and finding meaningful use for the technology in new contexts. Expertise is not expert skill or knowledge in applying 3D printing on ceramics in artistic field, but instead the ability of the learner to adapt their knowledge to a new situation or even rapidly learn new skills and knowledge. In Table 2, these concepts are contrasted across the research structures to illustrate the conceptual framework. In the imminent economy, the question will not be the proficiency of skill but sustaining interest and motivation despite the ambiguous process of finding the way to utilize new technologies. This is why the conceptual framework emerged for me as one that does not confront the issue of 3D printing as a vocational training tool or as a learning technology directly. Instead, I focused on the context in which transdisciplinary contextual, applicable, and autonomous learning occurs and how it occurs, with the understanding of 3D printing as one of many technological disruptions resulting from the advent of educational technologies, which has prompted the need of resilient learning in education.

From that perspective, learning how to use 3D printers and learning about the world through 3D printing means utilizing design and this learning medium not only for technological competence but also the ability to cope with the uncertain and disruptive technological and societal developments. It is therefore important not to see this technology only from an instrumental viewpoint as a technique and set of procedures that will allow for efficient adoption of knowledge or effective manufacturing of objects in vocational education.

2. Theories and research designs

The PhD topic summary provided by Oslo Metropolitan University outlined learning and 3D printing as main concepts. Thus far, I have explained 3D printing processes and outlined a conceptual framework of sustainable, integrated education that has emerged as a reaction to the rapidly changing technological and societal environment and the need for acquisition of transdisciplinary, contextual, and applicable knowledge, which is represented in this PhD project through 3D printing. In this section, I will consider what learning means from the theoretical standpoint and how it applies to 3D printing and product design education, especially in design studio as a research setting. The section contains my revision of learning theories with a rationale for their suitability for this research, as well as an explanation about why the postphenomenological approach is beneficial for investigating the defined knowledge gap.

In sum, the knowledge gap can be found between learning media affordances and learning for resilience. Media affordances provide insight into the challenges of contextual and applicable learning, while learning for resilience offers new insights into autonomous learning. Furthermore, this gap can exist among individual, group, and networked theories of learning, which address accessible, transdisciplinary learning.

2.1. The need for revision of theoretical approaches in the light of learning "to, by, and through" technologies

Learning can be described in a psychological sense, in general, as a "process by which experience produces relatively enduring and adaptive change in an organism's capacity for behavior"(Holt et al., 2015, p. 268). The concept of learning itself is open to the interpretation because "learning is a hypothetical construct, it cannot be directly observed, but only inferred from observable behavior"(R. Gross, 2015, p. 351). The construct of learning for resilience by means of technology is therefore holistic and involves views of learning "to, by, and through" technological medium. First, there is the "learning to 3D print" dimension of learning which is operative and instrumental and addresses issues of a learning medium. Second is "learning by 3D printing" which can be described as an outcome of established practices where this technology is used, in which a learner is using a 3D printer to participate in them. Third is "learning through 3D print," which describes learners' individual experiences of learning about the world they inhabit through technology. Further, these theories are categorized according to their foci and viewpoints: theories that present learning as transformations of the individuals, theories that present learning as an outcome of social and systemic structures, and resilience theories.

2.1.1. Social and systems theories

> Resilience thinking is about understanding and engaging with a changing world. By understanding how and why the systems as a whole is changing, we are better placed to build capacity to work with change, as opposed to be a victim of it. (Walker & Salt, 2012, p. 12)

The issue of learning for resilience has been thus far discussed in the context of individual and family development, especially in the field of social work and social systems. The social system also includes the ecological context of resilience, which emphasizes relationships between factors such as disruption and reorganization. Its focus is on innovation and organizational adaptive capacity (Folke, 2006). Thus, the discussion revolves around how social ecological systems in the face of change precipitate reflection, learning, and progressing towards more desirable situations. The concept of resilience has therefore been used to explain how communities cope with disruptions such as natural catastrophes. Here, the issues of resilience are integrated in various systems theories as well as in complexity theory and are related to the natural resource management and system resilience.

This approach was considered at the very beginning of this research project. For example, *general systems theory* could have been used in connection to action research (Greenwood & Levin, 2006, p. 57) to systemically and deliberately induce change in the community of design studio practitioners in order to research how learners and educators cope with new technology. The affordances of 3D printing technology to share, modify, and reproduce ideas opens the space for *connectivism* (Siemens, 2004) as a learning theory. Connectivists see learning as networked, in which a connected learner makes sense from readily accessible information in different kinds of networks. The learner therefore possesses actionable knowledge, which allows her to create or modify objects through 3D printing that further affect other networks. Connectivism has been considered as a way to research how affordances of 3D printing could cause emergence of knowledge networks inside and outside the classroom as a resilient property of the community.

In sociology, learning is also explained as an outcome of social interactions and technology's influence on these. Learning through the use of 3D printing can be explained through *practice theories* (Bourdieu & Nice, 1977; Kemmis, 2009; Schatzki, Knorr-Cetina, & Von Savigny, 2001). The first generation practice theories could reveal how the introduction of 3D printing in a design studio or a makerspace changes participants' practices and worldviews through modification of their *habitus* (Bourdieu & Nice, 1977). The second generation of practice theories could reveal what participants using 3D printers perceive as *intelligible* to do with them (Schatzki et al., 2001), or what makes sense to do with this technology from the viewpoint of the participants. *Activity theory* has been considered as a way to reveal how cultural and political influences shape production and the use of tools in organizational settings (Engeström, 1999). In this respect, this project could have taken the route of researching cultural and political meaning of design studio education in context of technological disruptions.

Material oriented theories were also considered as truly relevant for this project. They provide a framework for critical and non-deterministic understanding of technology and materiality. Consequently, they could reveal whether free learning is feasible in an existing educational setting of the design studio, and how resilient this setting is when new technology is introduced. Theories such as the *actor-network theory* (Latour, 2005), *science and technology studies, sociomaterial theory*, and *pragmatic constructivism* (Karagiorgi & Symeou, 2005) could have revealed valuable topics on how technological introduction in an educational organization can change the decisions of the actors involved and impact the structure of the learning network. These sociomaterial theories are suitable for studying new learning contexts built by machines and humans that have emerged through the influence of 3D printing. Furthermore, they could provide an understanding of the materiality of learning, especially patterns in emerging human–machine network structures that lead to learning. These structures are accordingly established by human and non-human actors and include artefacts, tools, technologies, bodies, environments, and nature. Further, they can reveal how the artefacts or tokens produced by 3D printing can affect learning as they create new networks. Overall, social theories put social interactions, systems, and patterns in the center of the research and are not principally concerned with the individual experience of learning or development but rather see it as a consequence of it.

As shown in the literature review as well as in this very brief overview, learning in the context of these theories is directed towards explaining organizational topics which could provide valuable understanding about the feasibility of free learning in an existing educational setting of the design studio from a structural point of view. However, the scope of this PhD study was focused on pedagogical practice and, in that, the relationship between the technology and learners' experiences. By focusing on learner–technology interaction, the new understandings of pedagogical feasibility of free learning can be achieved. The issue is also practical because, even though some of the studies follow multiple actors, the primary focus of this research was conceptualized around learning media and learners. Further, the multidimensionality of "learning to, by, and through" technologies does not seem to have been captured through social theories. The "learning by" dimension could be very well developed, but the full-scale pedagogical issues and the role of the pedagogue in the technological setting is therefore not directly possible to contemplate through these theories. However, social and system theories do provide relevant vocabulary for this topic and are actively enabling state of the art understanding of issues that 3D printing can bring to learning. Even though they were not suitable, the underlying logic of the network is necessary in order to understand the link between learners and technology. This is why the relational ontological view has been used to further discuss the phenomenon of learning by means of technological media. Some of these theories will therefore be referred to in the discussion section.

2.1.2. Resilience theories

One of the key qualities of the effective real-life learner is surely the ability to stay intelligently engaged with a complex and unpredictable situation, a property we might call 'resilience'. Resilient individuals will be more inclined to take on learning challenges of which the outcome is uncertain, to persist with learning despite temporary confusion or frustration, and to recover from setbacks and failures. (Claxton, 2002, p. 28)

The concept of the resilience of individuals and families has been prominent in the context of social work. Some of the theories have lately been coming from the field of positive psychology. The theories that directly address resilience are often complex constructs and are presented as measuring scales. Some of these theories have been taken into consideration as a way of explaining resilience in a broader context.

The key issue with these theories has been that most of them cannot explain learners' involvement with the material world. Furthermore, many of them deal with the issue of resilience in an indirect way and as a personal trait. I have not found either an ethical or fruitful way of approaching this pedagogical field, especially in researching my own practice, but also in pedagogy in general. This is why, for example, *self-determination theory* (Ryan & Deci, 2000) was not taken into consideration as the very concept is identified as a consequence of human motivation and personality. The same can be said for the concept of *grit* (Duckworth, Peterson, Matthews, & Kelly, 2007), which is a personality trait. Two concepts that I, on the other hand, took into consideration are a sense of coherence and self-efficacy.

The *sense of coherence* is a predisposition that can be activated. The term sense of coherence was coined to explain the philosophical approach to health known as salutogenesis that focuses on factors that support human health and well-being, rather than on factors that cause disease, which is known as pathogenesis (Antonovsky, 1984). Antonovsky (1998, p. 8) explained sense of coherence in the context of how humans affect their material environment for their own well-being: "The person with a strong sense of coherence. . . will select what is believed to be the most appropriate tool for the task at hand." Accordingly, they will believe that they understand the challenge that it is worth doing and possible to master and then distill core resources from their environment to achieve a solution. Sense of coherence therefore includes three dimensions: manageability, meaningfulness, and comprehensibility. Manageability is a component that describes the extent to which an individual feels that resources are at her disposal to help meet the requests posed by the stimuli to which she becomes exposed. Meaningfulness is about whether an individual can sense life as emotionally worthwhile and is therefore willing to commit to the challenges and devote time and effort to coping with difficulties. Comprehensibility relies on whether an individual can "perceive the stimuli that confront them as making cognitive sense, as information that is ordered, consistent, structured, and clear" (Antonovsky, 1987, p. 19).

Self-efficacy is also a concept that does not present a personality trait, but rather can be described as self-confidence or a personal judgment of "how well one can execute courses of action required to deal with prospective situations" (Bandura, 1982, p. 122). This perception of one's own ability can be crucial in making decisions on whether to take upon oneself certain tasks, and it is characterized through four factors: enactive attainment, vicarious experiences, verbal persuasion, and physiological state. Enactive attainment relies on previous success in similar tasks in the past. Vicarious experiences involve seeing others that are judged as similar to oneself succeeding at something. Verbal persuasion, although limited, can improve one's performance as one tries harder in realizing the task. An estimation of one's current physiological state or arousal will then have consequences on how well an individual performs.

Sense of coherence is a useful concept in explaining to use of tools such as a 3D printer to attack a challenge, especially in a situation of open learning with ill-structured problems where tasks are not easy to comprehend. The concept of self-efficacy is especially helpful as a pedagogical method, which gives a framework for instructional design. These concepts were used alternately throughout the articles I examined, and I refer to them as resilience in general.

2.1.3. Learning theories

Psychology and pedagogy put the learner in the center of the theories of learning in the classical learning theories. This perspective can be useful to explain many different aspects of learning, also learning technologies, such as 3D printing (Antonova, 2013).

Behaviorism views learning as a function of external stimulation of the learner, who responds to an external positive or negative stimulus. In the behaviorist view, preexisting knowledge is not crucial for new learning, and the process of learning is mainly based on external factors. The behaviorist approach has its application in skill acquisition, especially in the type of skills that can be learned through reinforcement and practice (Ertmer & Newby, 1993). In the context of 3D printing, behaviorism is useful as a learner is following a series of procedures from generating to printing digital models (Sachs, Cima, & Cornie, 1990). Learning each of the following processes is dependent on the ease of user interface. The vulnerability of seeing 3D printing through a behaviorist approach lies in the instrumentalization and streamlining of the learning process. However, knowledge gained through it might help in creating better interfaces and human–machine interactions.

Cognitivism can explain learners' general understanding of the technology, materials, and processes to produce predictable artefacts with 3D printing. This also applies to the transfer of this knowledge to machine settings and maintenance. In the cognitivist approach to learning, learners gain a schema or symbolic mental construction, and change in a learner's schema is necessary for learning. The vulnerability of cognitivism is in its lack of an explanation on the practical issues of usage of 3D printing. The approach, however, can help explain the acquisition of declarative knowledge that contributes to effortless processing. Effortless processing is explained (Bransford, Derry, Berliner, Hammerness, & Beckett, 2005, p. 43) as a phenomenon where learners with certain expertise can memorize the expertise related knowledge content more effectively than those without it. This can further explain resilience as an adaptation of learners to new circumstances. Cognitivism, especially gestalt theory, has been used for the design and development of machine interfaces so that they minimize cognitive load and enhance perception abilities in the users, as noted in the literature review section.

Both behaviorism and cognitivism were discarded early in the research process because of their one-dimensional view, lacking the social context or "learning by" aspect and oversimplifying "learning to" contexts as a set of procedures.

2.1.4. Constructivism and constructionism

As we move into the next century and more technologically sophisticated industry and service sectors, work becomes more abstract, depending on understanding and manipulating information rather than merely acquiring it. New forms of skill and knowledge are required. There is a growing consensus pertaining to the essential understandings, skills, and dispositions required for an adult learner to become an effective member of the workforce of the future. Economists recognize that resources should be directed toward creating a workforce that can adapt to changing conditions of employment, exercise critical judgement as it manages technology systems, and flexibly engage in more effective collaborative decision-making. (Mezirow, 1997, p. 8)

Individual construction of knowledge is the main concern in *constructivist* learning theories. Constructivism is a dominant theory in research about makerspaces and design studios. Derived from Dewey's concept of learning by doing and being part of a community of actively participating citizens, constructivism is represented in the ideas of social learning theorists such as Vygotsky (1980) and the developmental ones such as Piaget (1964). They have described very well the learning that can be observed in a self-organized community of learners such as those of the maker movement or the design studio. However, the theory that resonates the most with makerspace research is constructionism (Papert & Harel, 1991), a theory based on learning by making. Constructivist views are quite dominant in the discussions about the design studio but also learning for resilience. The design studio can be often recognized in the ideas about reflective practice (D. Schön, 2003) and learning for resilience in the ideas of transformational learning (Mezirow, 1991).

The constructivist view proposes the individual construction of knowledge through individual experience. Learning therefore happens as learners are making sense of their own involvement in learning inquiries. In this context, the 3D printer can be seen as a tool for learning inquiry as it generates learning experience in the process of the creation of artefacts and further by examining the consequences of the 3D printed artefacts in the real world. In the context of sustainable education, it is relevant to examine how 3D printing can facilitate resilient learners. Resilient learners should be able to shift perspectives or change the ways in which they make sense of their experiences.

Because constructivism is a dominant theoretical approach in the research about 3D printing in education, I have considered how this dissertation can contribute to the existing constructivist understanding of learning by making and design. The article "How Designers Learn, Objects of Representations as Means of Knowledge Transfer" (Pavel, 2017) utilized constructionism to explain the medium as an object of representation of the knowledge which happens in the minds of learners. Similarly, Mezirow's transformative learning theory was singled out to explain learning for resilience in the article "Norway-UK Comparative Analysis of Sustainability in Design Education" (Pavel & Zitkus, 2018). In this section, a brief summary of constructivist theories is presented. In the summary, three constructivist theories: constructionism, transformative learning, and communities of practice, have been considered for this dissertation as being possibly suitable for answering for the research question. These three theories were chosen because they address different aspects of learning with 3D printers. Constructionism supports the instrumental aspects of learning, communities of practice involve social factors, and transformative learning theory explains individual resilience.

Mezirow recognized the importance of critical reflection through the observation of adult learners, specifically through his observations of adult women who entered the program for requalification. The issues of autonomous and contextualized learning have often been captured in adult learning in the fields of andragogy and heutagogy, where adaptation to new circumstances is in focus. Mezirow explained that fundamental perspective shifts happen occasionally and arbitrarily in a lifetime, when a person meets disorienting dilemma. Accordingly, this dilemma is imposed by external factors such as personal crises or random experiences through art or argument which will then force a person to challenge her own views or belief systems or habits of mind (Mezirow, 1993, pp. 145-146). He also stated in an interview that certain perspective shifts can happen within the framework of the present habits of mind that are smaller, while citing Schön's metaphorical thinking (Mezirow, 2015). Moreover, transformative learning theory clearly provides the framework for understanding resilience. It gives both theoretical and contextual background for researching university students' use of technologies and the need for vocational education to focus not only on practical skills, but also on critical thinking: "In the absence of fixed truths and confronted with often rapid change in circumstances, we cannot fully trust what we know or believe" (Mezirow, 1993, p. 4).

Wenger, inspired by anthropology and social learning theory, explained learning as meaning-making in the production of practice. He defined practice as the process of participation and reification (Wenger, 2010). In participation, members create events, activities, conversations, and reflections, and in reification, they generate physical and conceptual artefacts – words, tools, concepts, methods, stories, documents. Wenger described the process of participation and reification as the creation of a common memory or history of learning. This learning is not locked but always changing through negotiation of meaning among members. The negotiation of meaning allows members to understand what important or what matters in this community of practice is and define and develop their role and regime of competence (Wenger, 2010, p. 1). Learning, for Wenger, therefore, happens in a social context in which members of the community of practice define what kind of knowledge and competence is useful for their practice. Deployment of 3D printing technology in a classroom and the formation of the community of practice around this reification tool might give new insights into the implications for participation and communities' negotiation of meaning.

Seymour Papert, on the other hand, put the creation of artefacts in the center of constructionism (I. E. Harel & Papert, 1991). For Papert, a learner is a creator who constructs "objects-to-think-with." Accordingly, learning happens as a creator internalizes actions that lead to creations of those artefacts. Papert focused on the formation and transformation of ideas through media and culture that might support or halt these activities. Constructionism primarily focuses on individual situated learning and the projection of one's own ideas and feelings onto the process of creation. However, constructionism does recognize the influence of the environment, as Papert calls culture, that emerges around certain activities or tools, such as in the computer culture (I. Harel & Papert, 1990). Using additive manufacturing for construction as media might lead to new patterns of internalization and forming of a different climate or culture in the classroom or the design studio.

When discerning given theories from the point of view of the knowledge gap, they all seem to be relevant to a certain extent. Constructionism explains the instrumental aspects of learning through 3D printing; communities of practice explain these in the context of the application of 3D printing in a design studio, makerspace, or classroom setting; and transformative learning explains learners' resilience and perspective shifts when using 3D printing. Still, all three theories give an explanation in different ways about producing objects and social interaction.

Constructionism emphasizes making and the group culture, communities of practice stress reification and participation, and transformative learning theory addresses how learning happens in instrumental and communicative domains. These theories then describe individual learning as an individual's adaptation to these circumstances. For constructionism, it is the internalization of the activity of making; for communities of practice it is meaning-making of what is said and done; and for transformative learning, it is a critical reflection gained through disorienting dilemmas.

Yet, the issue with the constructivist approach to understanding learning by 3D printing is not its irrelevance, but rather its lack of recognition of learners' material environment and embodied experience in how learning occurs. There is an understanding in constructivism that learning, even though situated and individual, is constructed in the minds of the learners. Learners therefore possess knowledge that is tacit, explicit, procedural, or declarative. The very role and properties of the medium are not of particular concern in the constructivist perspective. This does not provide grounds for a holistic exploration of the role that technology might have as a part of the everyday embodied learners' environment. Additional explanations for why constructivism as a theoretical approach for the study was replaced by postphenomenology will be presented in the discussion section.

2.1.5. Postphenomenological epistemology and inter-relational ontology

> The illiterate of the 21st century are not those that cannot read or write, but those that cannot learn, unlearn and relearn. (Toffler, 1970)

Phenomenology does not focus on the activity of making as crucial for learning. Instead, learning is explained as bodily situated and therefore happening in relation to the environment. Merleau-Ponty (1996, p. 164) explained that physical and social embodiment shapes meaningful learning. Embodied learning means that human bodily capacities, such as the mental, emotional, and physical, in relation to environmental affordances and constraints, are the preconditions for learning. The focus here is therefore on the relationship between the environment and learner and the connection they establish that changes them both. Accordingly, learning is a process in which previous knowledge allows participation in an embedded situation. Each additional act of learning modifies the entire horizon of experience and expertise. Learning means to change and transform oneself or, as phenomenologists express it, as being and becoming. The phenomenological method calls for observation that suspends habitual modes of analysis and readymade interpretations, such as cultural construal.

Husserl described this technique of phenomenological research as *bracketing* (Husserl, 2012, p. 110). This technique is also crucial in learning as it enables learner investigative and reflexive revelation. This adaptive view of learning corresponds with the concept of resilience.

Learning can be seen as an outcome of the relationship between learners' intentionality and the object they are directed toward, resulting in the constitution of meaning. Learning is situated in not only what learners think about it, but also what they live through with their operative intentionality (Merleau-Ponty, 1996, p. 18). The learners' impression of what they can and cannot do conditions their impression of what they know (p. 137). Therefore, affordances of 3D printer emerge as a key factor in learning. Seen through a phenomenological pair of glasses, learners should divest themselves of the preconceived notions of what the 3D printer is and should use it in an embodied situation in which these affordances will guide their inquiry.

Phenomenology from Heidegger onward proposed a relational ontological approach. "The basic contention of relational ontology is simply that the relations between entities are ontologically more fundamental than the entities themselves. This contrasts with substantivist ontology in which entities are ontologically primary and relations ontologically derivative,"(Wildman, 2010, p. 1). Sterling (2010) explained the relationalist perspective of learning as one that overcomes dichotomies between the intrinsic and the instrumental, which is crucial for learning for resilience (pp. 521–522). He described the relationalist learning paradigm as follows:

> Learning is seen as an essentially creative, reflexive and participative process. Knowing is seen as approximate, relational and often provisional, and learning is continual exploration through practice, whereby the meaning, implications and practicalities of sustainable living are continually explored and negotiated. (Sterling, 2010, p. 523)

Relationalist ontology gained significant recognition especially in the works of Merleau-Ponty. In his book on the phenomenology of perception (Merleau-Ponty, 1996), he described humans as not being separate entities from the environment but rather part of it. He gave a more systemic and ecological relationalist perspective in phenomenology. Relational ontology in phenomenological philosophers becomes inter-relational in postphenomenology. The postphenomenologist Don Ihde explained the relationship between objects and humans as reciprocal. Namely, humans are changing the environment through technology, which in turn changes them, which Ihde presented in his concept of homo faber (Ihde & Malafouris, 2019).

This section contains explanations of key postphenomenological concepts, ranging from those of the phenomenologists Heidegger and Merleau-Ponty to current developments of the ideas of Ihde. The history of the genesis of this narrative will be brief and thus could lose some detail and depth due to its brevity. Still, I believe it is important to present the concepts from their original source. This is not only for the convenience of the reader but also to enrich the discussion section where the postphenomenological ideas from the pedagogical perspective are discussed. Concepts discussed by phenomenologists are not new. Aristotle explained the distinctions among the five intellectual virtues. The virtue coined *Technê* can be simply translated as craft but is far more comprehensive. Aristotle explained it as a disposition to perform activity to achieve something in a practical sense, meaning that technê is an ability to recall, perform, and improvise to create a product.

Heidegger's transformative reading of Aristotle produced a critical view on Husserl's transcendental phenomenology (Crowell 2005, p. 49). Heidegger moved away from the usual philosophical questions such as "Do the body, mind, and world exist?" and asks, "What does it mean to exist, or what is being?" The following concept of German word *Dasein* (Da-sein: there-being) is used to uncover the primal nature of "Being" (*Sein*) or also existence, meaning that Dasein is always a state of being engaged in the world: neither a subject, nor the objective world alone, but the coherence of being-in-the-world, making Dasein preontological. The interpretations of other philosophers simply include the way of life of a certain community or human openness or embeddedness in their environment. Heidegger saw it as a philosophical challenge to discover modes to encounter Dasein with entities.
In Heidegger's view, Dasein reveals itself as humans encounter mundane and ordinary ways of using, for example, equipment for certain tasks. Humans have a primordial relationship with equipment, meaning nobody theoretically studies it, but rather skillfully manipulates it. In fact, he claimed that the less a human studies it, and the more she seizes a hold of it and uses it, the more primordial the relationship becomes. The hammering itself therefore uncovers the specific "manipulability" of the hammer (Heidegger, 2010, pp. 82,83). This manipulability can be also called affordance as coined by Gibbson. Dasein has no conscious experience of the items of equipment in use *as* independent objects. Thus, a carpenter does not consciously recognize the hammer and nails. Hammer and carpenter constitute hammering, and for a carpenter, this equipment becomes *transparent*. The carpenter becomes

absorbed in her activity in such a way that she has no awareness of herself as a subject over and against a world of objects. Dasein further reveals itself in the way a carpenter does not think about the purpose of this activity. Even though she is producing the construction for a house, which will provide shelter for someone in her community, for the carpenter, this is something that is just part of what that community basically does (Heidegger, 2010, p. 97).

Ihde took the concept of transparency in order to explain inter-relational mediation between humans and technologies. He described these mediations as enacted when humans and technological artefacts are in interaction as human–technology configurations. Here, Ihde described two extreme types of configurations, embodied and hermeneutic ones, which he also called alterity relations. It is important not to understand these relations as categorical but rather as a continuum where the different technological artefacts can take the form of one or another or anything in between, meaning being more embodied or related more to alterity (Ihde, 1990).

In embodiment relations, humans relate to technology to see and affect the world. In alterity relations, humans are related to the technology as the "other," or a part of the world; yet, this technology changes the way the world is perceived by humans (Ihde, 1990, p. 79). Ihde claimed that this happens as humans tend to approach technological artefacts in anthropomorphic ways, by projecting human properties on the artefacts, or attaching certain feelings for them. The other reason they are "other," rather than embodied, is that these technologies have some kind of independence and can afford "interaction" between humans and technologies. Ihde considered robots and ticket machines as examples of alterity relations (Ihde, 1990, p. 97). To take part in these relations, humans have to interpret technologies, for which he coined the expression *hermeneutic type of mediations*. A ticket machine will provide tickets if a human interprets it properly and takes the right steps to purchase a ticket. Further, Ihde noted that, in different contexts, humans will perceive technological artefacts in different ways and use them in different ways. This multistability of artefacts in their use and perception by humans can also be culturally enacted, so that in one culture an artefact is used in one way and in other culture in another. Similarly, if the culture changes, the meaning of artefacts will as well.

Rosenberger (Rosenberger, 2014b) expanded the concept of transparency to the field of awareness He used the term *field of awarene*ss to explain how human experience changes with technological mediation in respect to "what is attended to, what is ignored, what stands out as significant, what instead constitutes the backdrop for those significant things, etc."

Rosenberger (2014b, p. 22). Field of awareness, which is composed through interaction with environment, is accordingly altered by technological mediation. Rosenberger also introduced another term he coined as *field composition*, which signifies a state in which the user's field of awareness is somehow significantly reconfigured by technological mediation. As an example, Rosenberger took the experience of watching a movie in a theater. At first, the user's experience is defined by the interior, smells, and the size of the room. As the movie starts, the experience changes, and the content of the movie occupies the majority of the overall space of which the viewer is aware.

Merleau-Ponty (1996) in his book *Phenomenology of Perception* has developed a phenomenological understanding of human perception that Ihde later adopted in his postphenomenological work. These ideas were spawned by following Heidegger's relationalist phenomenological approach. Merleau-Ponty refuted the separation between bodily and intelligent conduct and introduced the notion of corporeality. Accordingly, corporeality can be seen in the unity of behavior that expresses the intentionality and, therefore, the meaning of the conduct. Hence, corporeal existence constitutes a third category that unifies and transcends the physical and psychological. In corporeality, the body adapts to the intended meaning through habits, giving itself a form of embodied consciousness (Merleau-Ponty, 1996, p. 102). For Merleau-Ponty, perception and making meaning are closely connected as they are linked to human intention and interpreted through that prism. Accordingly, humans do not receive passive sensory stimulations that are then interpreted, but rather they operate through "creative receptivity" in which the relationship between subject and object perceived is not one of exclusion. An example would be that of an exhibition visitor whose body is preconditioned to make meaning of what she sees. In her interaction with exhibited pieces, the visitor is influencing what she sees through her intentions. She is reciprocally influenced by the exhibition, as her body is moving unconsciously in accordance to exhibited items to provide her the best experience of the scale, texture, and shape of what she is observing.

This phenomenon that humans see the whole through attaching meaning to what they see rather than the parts that create the understanding has been confirmed by cognitivist science. In cognitive science, gestalt principles demonstrate that humans do perceive the figures as a whole and then become aware of what constitutes them. An example for this is the illusion that makes the viewer switch between seeing a rabbit and a duck (see Figure 1). The phenomenon of instability in perception is what phenomenologists and later postphenomenologists call *multistability*. It is referred to as human ability to change the meaning of technology and give it a different purpose and even cultural connotation. A hammer can hammer or pull nails, but it can also keep stack of paper from being blown by the wind.

Figure 1. Demonstration of the phenomenon of multistability through gestalt principled visual Illusion. Taken from the October 23, 1892 issue of *Fliegende Blätter*.

Technology not only influences humans when they are using it, humans are changed by its presence or the notion of its usage.

> Technologies that are not in actual use—either as being invisible or as merely being idle—is taken for granted when we organize our daily lives; they are intentionally present in their potentiality. As such, technologies both in their actual use and in their possible use constitute the technological presence in our lifeworld. (Kiran, 2012, p. 79)

The technologies therefore present themselves to humans in their actuality, but as humans are able to contemplate their actions through these technologies, they are seeing the potentiality of the technology. By realizing these potentialities, humans are giving new actualities to the technologies.

> Technologies' potentiality reflects on how we conduct ourselves, and how we see ourselves as being able to act. We become the kind of subjects that we are through throwing ourselves into projects. The projects we regard ourselves to be able to undertake, to throw us into, is very much related to the technological possibilities we recognize in our lifeworld. Therefore, it is the potentiality and not the actuality of technologies that points us to future actions. And furthermore, in understanding the future through the possibilities offered by technologies, we come to understand our own possibilities as well. Understanding our possibilities means understanding ourselves. (Kiran, 2012, p. 79)

Ihde's work builds directly on Merleau-Ponty's concepts. Merleau-Ponty (1996) claimed that "man is a network of relations" (Merleau-Ponty, 1996, p. 456). Thus, humans are interdependent with the objects surrounding them. For him, humans are not fully transparent to themselves, and objects are given over to us, influenced by us, just as we are influenced by the objects that surround us. Ihde took these ideas to explain human–technology relations in an evolutionary sense. To him, humans and technologies are inter-transforming and making each other. He went on to note that "*Homo faber* refers to the special place that this ability has in the evolution and development of our species" (Ihde & Malafouris, 2019, p. 195). Further, Verbeek (2015) very effectively incorporates postphenomenological ideas in his mediation theory. Inter-transformations happen through technological mediations between humans and their environment, not only in the sense of what things do but what kind of meaning humans give to technologies both empirically and conceptually (Verbeek, 2015, p. 191). Through his theory, Verbeek described mediation as the ability of technology to enhance human perception and action in one way and prohibit it in another. Verbeek supported his mediation theory with ideas earlier developed by Akrich and Latour (1992) where they claimed that technological artefacts pose a *script* which invites users to use these artefacts in a certain way. Accordingly, designers delegate specific responsibilities to artefacts. For example, the responsibility that drivers do not drive too fast in populated areas is delegated to speed bumps.

Postphenomenology is then "modified hybrid phenomenology" (Ihde, 2009, p. 26) which "analyzes human relationships with technologies, while integrating philosophical commitments of the American pragmatist tradition of thought"(Rosenberger & Verbeek, 2015, p. 2). The concepts of technology, medium, and affordances are interconnected. Technology is a medium that allows mediation, which affords certain activities and prohibits others. Technology is therefore seen as an extension of human capabilities.

Postphenomenologists research mediation between technology and humans and their configurations through concepts such as multistability, transparency, or technologies' actuality to analyze how humans and technologies interact. This approach takes the issues discussed by material, network aware social theories to the situational level, and are therefore helpful for studying pedagogical issues and understanding learners' experience. The postphenomenological concepts presented in this section were used extensively in the articles and the rest of the project summary to explain learning through technological mediation.

Returning to the beginning of this section, phenomenological learning is defined as an outcome of human bodily capacities meeting environmental affordances and constraints

(Merleau-Ponty, 1996). It is therefore useful to consider technology as a mediating factor in learning, by taking the postphenomenological perspective. This exploration should give a better understanding of how human directedness is mediated by technologies and what kind of factor they represent in the human-environment constitution in learning. It should also give a more holistic understanding of human learning unlike behaviorism, cognitivism and constructivism, which describe particular aspects of the learning experience.

2.2. Research design: Case study and action research

This section details the research design for the dissertation that revolved mostly around the situational context and pedagogical issues in the design studio. In order to preserve authenticity of the work, the description in this section presents a more descriptive than normative account of the research (Bell & Newby, 1977). By this, I mean that the research design emerged from the processes that could be characterized as being evolving and iterative rather than as streamlined. Presenting it this also shows the conceptual progression of the study.

The research was planned from the beginning as a research in and of practice. It was designed to be an action research project that would reveal the practical challenges 3D printers bring to the material design practice. Normatively, it was planned as a series of workshops with master students at the department of product design at Oslo Metropolitan University who are already experienced in using materials and workshop tools. This series of workshops was supposed to reveal how their practice changed with the use of 3D printers and provide insights into the issues of learning that they encounter through this change. As the research question matured, moving away from the issues of applications of 3D printers in teaching and designing so did the research design. The interest became rather how design students learn design by the help of 3D print, as well as how they adapt technology in new situations. This made me decide to study freshmen students as well as cross-disciplinary settings.

2.2.1. Exploring the instrumental, social, individual, and societal aspects of learning through media

This initial approach brought numerous challenges, which started immediately as I explored the literature and worked at defining what learning means in the context of 3D printers. It was necessary to first explain why it is important to research the phenomenon of 3D printing in this formal educational context. This was especially relevant as there is already a weighty volume of literature on this topic. However, I realized that there is a need to specifically examine the meaning of this technology for the department of product design and, more broadly, for design studio education, which exemplifies open and free learning in higher education. It became apparent that a thorough explanation is required for what makes design and learning media different from one another. Thus, the issue became why learning through digital medium should be researched separately, or to reformulate, what makes learning with digital media different.

My concern was that perceiving digital media as different from analogue ones from the learners' perspective could be a false premise for researching pedagogical approaches for learning with 3D printers. From this reasoning came an important insight gained through reading the literature and analyzing the design process which was that digital media were designed to be used individually and were usually implemented in the latter phases of design process for testing and detailing, while the conception phase was usually reserved for sketches and mockups (M. Tovey, 1989).

This is why, instead of organizing workshops at once, I decided to explore the issues of learning media. Therefore, the first article related to this dissertation "Supporting Collaborative Ideation Through Freehand Sketching of 3D-Shapes in 2D Using Colour" (Sandnes et al., 2017) was one that explored the problem that most of design media are meant to be used by an individual. To explore this concept, along with a group of authors from a computer science background and design colleagues from Brazil, I wanted to determine how a design digital medium could be used in collaborative practice in the conceptualization phase of design and be integrated into the digital fabrication process. In the second article for this dissertation "How Designers Learn? Objects of Representations as Means of Knowledge Transfer" (Pavel, 2017), I explored the aspects of collaborative learning through media in general for which I believed I should first study analogue media in the preconceptual phase of the design process. The article was meant to introduce a theoretical and conceptual framework for future research but yielded mixed results. Still, the article was a pilot article in which I established my research setting and applied case study methods.

The first two articles (Sandnes et al., 2017; Pavel, 2017) inductively brought into focus the design process issues in the context of media. The challenge that emerged from this investigation and was worth researching from both design and teacher perspectives was how design learners can be unconstrained by the media, so that they are able to keep their own intentionality in the particular situation. This means that they have to be able to collaborate so that ideas can develop rapidly but still produce an applicable concept that can be scrutinized for its intention. The issue of learner autonomy is therefore intricately connected to the constraints of the medium, meaning that learners' ability to switch the medium and then utilize its affordances for the task at hand is the key issue of design pedagogy.

In the third article "Norway-UK Comparative Analysis of Sustainability in Design Education" (Pavel & Zitkus, 2018) involved in this dissertation, my intention was to study how educational design programs address this issue. Through that article, I introduced the concept of learning for resilience and sustainable education into the argument. The concept of resilience allowed me to explain the issues of learning and pedagogy. The concept of resilience captures the ability of learners to cope with learning in context and in response to the situational demand, rather than applying or merely transferring preexisting knowledge.

The first three articles (Sandnes et al., 2017; Pavel, 2017; Pavel & Zitkus, 2018) were explorative, meaning that their roles were to discover concepts, issues, and theories around design media, emerging technologies, learning for resilience and the current understanding of these issues in education. This phase helped in formulating the research question for this dissertation and in defining the aspects of learning that are worth researching. The first article in this research project (Sandnes et al., 2017) examined the instrumental aspects of the medium by studying how humans create technologies to fit them. The second article (Pavel, 2017) explored the social and individual aspects of how any media, digital or analogue, becomes a technology for learning and influences learning outcomes. The third article (Pavel & Zitkus, 2018) investigated the societal aspects by introducing the concept of learning for resilience and discussed how certain design schools normatively perceive these kinds of skills in their programs.

2.2.2. Research Question and Overview of the Articles

Based on this exploration, the aim of my dissertation became to provide a perspective about learning and teaching in light of the disruption caused by emerging technologies. The main research question therefore was defined as:

How can resilient learning be assisted by emerging technologies in product design education?

This question then opened the discussion about possible pedagogical approaches to address the issues of learning for resilience. The development of the theory therefore presented itself as an important issue in the research design. The part of this theoretical exploration was abandoning the constructivist paradigm and moving towards the postphenomenological one throughout the research. There were practical and theoretical reasons for this. The literature review showed clearly that the constructivist approach to learning has already been well explored. At the same time there was a knowledge gap in the way literature described learning with technologies, which pointed the way for further theoretical development from phenomenology to postphenomenology as explained in section 2.2, and the postphenomenological approach enabled holistic understanding of learning. Finally, and most importantly, my practical pedagogical experience showed difficulties in implementing constructivist pedagogies in the design studio, which I thoroughly described in the fourth article noted in Table 3 "Postphenomenological Perspective on Free Learning with Maker Technologies – An Action Research Study of 3D-Printing" (Pavel, in review). In that article, I described how, through circles of action research, I developed new theoretical approaches that helped me understand learning through media from another perspective. Throughout the process of implementing 3D printers in design education, I tried to overcome the challenges of fully utilizing this technology while at the same time making learning attainable for the students and respecting their autonomy. In the last article, I document my study of an open learning situation with 3D printers and how postphenomenological concepts can help define pedagogy with emerging technologies.

Table 3

Overview of the Articles Sorted by the Development Phases

PREDICAMENT: 3D printing is one of many new media that will enter work life and schools. It will demand greater flexibility and adaptability from future learners. Does education have the suitable pedagogical approaches for this? What are the possible options? How can resilient learning be assistedby emerging technologies in product design education?		
What is the role of media in learning through design? (How do different media influence learning?)	How is design education currently addressing learning for resilience?	How can education incorporate emerging technologies in a sustainable way?
ARTICLE 1. Instrumental aspects RQ: How can sketching framework allow designers to quickly represent imperfect 3D shapes? **"Supporting Collaborative Ideation Through Freehand Sketching of 3D-Shapes in 2D Using Colour"** Published: CDVE17/conference Co-author Perspective: Information science	*ARTICLE 3. Societal aspects* RQ: How can design skills address the challenges of education for sustainability ? What changes can be made to curricula to enhance this? **"Norway-UK Comparative Analysis of Sustainability in Design Education"** Published: E&PDE18 Lead author Perspective: Curricula text analysis/exploratory case study	ARTICLE 4. *Developing pedagogical approaches* RQ: If learning is free from curriculum and instruction, how do learners know what to learn? What is then the role of pedagogy? **"Postphenomenological Perspective on Free Learning with Maker Technologies – An Action Research Study of 3D-Printing"** In review process: *Technology, Pedagogy and Education Journal* Author Perspective: Relationalism /action research
ARTICLE 2. Social and individual aspects of learning RQ: How can designers facilitate the choice and transfer of knowledge for problem-solving in a teamwork context? **"How Designers Learn? Objects of Representations as Means of Knowledge Transfer"** Published: E&PDE17 Author Perspective: Constructivism–constructionism/exploratory case study		ARTICLE 5. *Examining pedagogical approaches* RQ: How can human–technology mediation facilitate resilient learning? **"Multistable Technologies and Pedagogy for Resilience: A Postphenomenological Case Study of Learning by 3D Printing"** Published: *Journal of Design, Education and Technology* Lead Author Perspective: Postphenomenological case study/instrumental case study

As a result of all this, the project has grown in complexity. While the first article was about the research on digital media and third article on documents, the other three articles were based on the research of the living experience of designing. This was highly relevant because the complexity of today's design setting is always changing and constantly involved in capturing and developing new concepts of what learning by means of design media is. My insight into this started with a small workshop, which is described in the second article (Pavel, 2017), and proceeded with a series of design courses that was detailed in the fourth article (Pavel, in review) and ended with exploring the open learning context documented in the fifth article "Multistable Technologies and Pedagogy for Resilience: A Postphenomenological Case Study of Learning by 3D Printing" (Pavel, at. al, 2020). Hence, the last two articles were then used to develop and examine concepts developed in the exploratory phase of this research project. The action research methodology was used to examine existing theoretical concepts in practice and develop a new pedagogical practice. The case study was used to examine new theoretical concepts in an open learning context where I served as a participant observer in order to gain a more objective view of the phenomenon of learning with emerging technologies.

2.2.3. Participatory processes and direct content analysis

The research design was developed to find a theoretical explanation, or in this case, an explanation drawn from the field of philosophy that could provide the most likely or viable understanding of the phenomenon from the data sets. Derived from the open and generalized research question, the overall research design was instrumental. This meant that both its exploratory and examination phases would be conducted to conceptually and theoretically explain the phenomenon of learning through media and emerging technologies. In other words, the study for this dissertation was not intended to explain the workings of a particularly important incident. Instead, it aimed to study casual, everyday usage of a medium in the context of designing and learning in the design studio to indicate key issues that emerge in learning and teaching that occurs when these media are put in use.

However, unlike the initially planned research design, where the same methodological approach was to be used throughout all of the articles, this research design included a pragmatic approach. Methodologies therefore ranged from design science in the first article and different types of case studies to action research. The research design thus took on different methodological positions through the articles to discuss the phenomenon of learning through a design medium, but for the purposes of this dissertation, it was positioned in a pragmatic paradigm as it assumed all the methodologies as being valid. This research design became more complex and demanded more effort to provide a congruent argument. Yet, I believe it is more authentic and credible because the intentions and outcomes of the research were reflected in methodologies. It could be also argued that it is richer in its explanation as it includes a perspective shift and documents an evolution of understanding of the researched topic over time.

Different methodological approaches in the different articles have also allowed for diverse positionalities of the researcher and multiple perspectives. They varied from complete participation as in the action research article to moderate and even passive participation in the case study articles (Musante & DeWalt, 2010). In the action research, the active participant role was embraced, and the issues of reflexivity and positionality were highly important.

2.2.4. Data collection methods: Artefacts, recordings, participant observations

These different methodologies bring with them different data collection methods. However, except for the first and third articles, the rest of the research was conducted with the same data collection methods, namely, artefacts, sound recordings, and participant observations. The first article differed in that it was written in the positivist tradition and used an experiment to test its hypothesis. The third article was a text analysis based on a case study, which used certain criteria to select documents for analysis. The next section presents these different methodologies and explains the data collection process in order to address the credibility of the research.

"The design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts," (Hevner, March, Park, & Ram, 2004, p. 75). While the scientific method often offers results as descriptions, explanations, and predictions, design science is based on a prescriptive method (Aken, 2004). Inspired by Herbert Simon's (1969) work *The Sciences of the Artificial*, this method is called design science research. Design science is a "solution incubation" which proposes prescriptions which are then evaluated by different parameters and aspects (Holmström, Ketokivi, & Hameri, 2009). The process often includes procedural steps such as a problem, solution, development, evaluation, value addition, and communication (Hevner et al., 2004). The process ends with evaluation, which considers the utility and viability aspects of the proposed artefact in order to demonstrate its validity, in an academic and practical sense. In order for this method to be scientific, an artefact has to achieve objectives proposed by a researcher. The objectives need to be achieved thorough a satisfactory solution, rather than an optimal one, showing the pragmatic side of the design research science (Çağdaş & Stubkjær, 2011). The knowledge provided by this method is about the purposefulness of the measures taken by the deployment of an artefact (Hevner et al., 2004). The knowledge also needs to be generalizable to a certain class of problems allowing for other researchers or problem solvers to apply this knowledge (Dresch, Lacerda, & Antunes Jr, 2014).

Design science methodology is pragmatic, in the sense that it draws conclusions from both the field of information and organization science to develop artefacts. The scientific rigor is then achieved through testing and evaluation in comparison with initially specified needs by the organization. Finally, the evaluation is then also a matter of consensus by the individuals in the context of use (Hevner et al., 2004, pp. 80-84)

The first article (Sandnes et al., 2017) relied on this methodological structure. In the first part of the article, the programming code that was used to develop a piece of software was presented together with the user needs. In the second part, a usage case was presented where the task analysis is conducted by experimental methods to indicate the complexity of usage by the number of attempts. This was an initial experiment, and even though the issues of replicability were open to discussion, the results showed that novice learners are able to grasp the software functions for simple tasks. The research was limited as the new software was conceptually different and could not be compared with any existing one. However, it showed indications that the new software could improve the simple digital sketch creation for beginners and be used for their simple sketches.

As a co-author on the first article, my initial intention was to gain more experience and possibly adopt this methodology in order to study different user learning styles and issues emerging from the human–software interaction. Nevertheless, I had to abandon this approach because it would have affected my explorations about long-term effects of learning and learners' applications of the learned technologies.

The **case study** approach, in contrast, proved itself useful for studying the phenomenon of 3D printing in the design studio, especially as the boundaries between this phenomenon and context of the design studio are not explicitly evident. According to Yin (2009), case study is a suitable research format when a researcher asks how or why questions about a "contemporary set of events over which the investigator has little or no control" (2009, p. 9).

The case study method was useful to explain how 3D printing mediation affects learning, through units of analysis derived from postphenomenology. As it is flexible in its form, I also used case study for the purpose of exploration of the theoretical concepts in real-life settings as well as in text analysis of the design education curriculum.

In the third article, (Pavel & Zitkus, 2018), the design program's curriculum was compared with the governmental policies for sustainability. The documents were selected through a protocol defined by the exploratory conceptual construction of the case study. Two countries that were showing interest and making moves towards sustainable development were to be selected to study whether their policies were reflected in their curricula. To ensure that similar challenges were addressed for both countries, we chose countries from the same region, northern Europe. To ensure that a wide range of issues were addressed, we chose countries of different size, population density, and economic structure, and therefore different priorities in sustainable development. Thus, the United Kingdom and Norway were ultimately selected. As the study was exploratory, we, as the authors, strived to obtain enough saturated data to reveal the issues rather than to make definite conclusions about the faults of the curricula. Our goal was to find where and how the issues of learning for resilience are situated in the context of design education in the normative language of program planning.

In the research of the lived experience in design studio practice, case study and action research were used. These methodologies allowed me to participate in the confined contexts of design courses and workshops. In these contexts, I took on the dual role of a researcher–facilitator, which proved to be very demanding and markedly engaging. This role varied through the context and therefore required a different use of methods and approaches for mitigating the dichotomy of these two diverse roles.

In the second article, (Pavel, 2017), the documented research was confined by the context of two groups' experience in a three-hour **workshop**. Here, workshop is defined as "an arrangement whereby a group of people learn, acquire new knowledge, perform creative problem-solving, or innovate in relation to a domain-specific issue" (Ørngreen & Levinsen, 2017, p. 71). Workshops are organized events of a limited duration and scope, targeted to participants who share a mutual interest or domain (Jackson, Joshi, & Erhardt, 2003). They were suitable for this research for several reasons. They are easy for participants to comprehend and ensure the recruitment of a particular participant group that is motivated to learn through practical work. They keep the groups small allowing everybody to participate and be heard. Participants are willing to actively participate and change the course and outcomes of their workshops. Participants expect to practice something, as well as gain insight from it. Workshops are designed with the idea to fulfil a certain purpose, but that purpose is not predictable and, therefore, gives the participants the power to negotiate the meaning of their experience (Ørngreen & Levinsen, 2017, p. 71)

Workshops are a common means of teaching in product design and are used to allow students to exercise application of theory into practice in a safe environment. The workshop in question was conducted as an extension of a context mapping course, which students were already attending. The case study protocol (Yin, 2017, p. 93-104) is written in the line with the case study purpose to follow the real-life event and therefore followed the workshop protocol. The workshop was organized around the topic of communication in design work. The goal of the workshop was to study how different media influence discussions and decisions participants make throughout the workshop. This is an important issue because meetings where ideas are created and important decisions are made, can be influenced by the media used on these meetings. Media can present the information in such a way that certain issues are perceived as important, and the feasibility of certain ideas are increased. In this way, media amplifies certain conversations and diminishes others. Moreover, as media become everyday professional tools for designers, design education has to take this media usage as part of the learning and pedagogical strategies. The premise for this study was that the medium could lead towards different discussions among participants and different experience of designing. The research strives to understand underlying principles behind this phenomenon and give a framework that can allow for better organization and handling of these meetings.

The protocol also had to take into consideration the educational context in which it takes place, taking care of both data collection and education of participants. According to a literature review by Ørngreen and Levinsen (2017, p. 72), workshops have been researched as a means of achieving a goal, a solution, as a particular practice of processes and creation, and as a research methodology. As a research methodology, the workshop fulfills two roles simultaneously. It allows participants to achieve something related to their own interest and realize their expectations from the group and the facilitator. Student participants and workshop organizer -researcher are the key stakeholders in the study in this article, which means the protocols had to be adjusted to address the interests of both parties.

The students were therefore invited to an “experimental workshop” in which they could test and develop context mapping techniques as an extracurricular activity. In that sense, this workshop can be characterized as collaborative, where researchers and participants work together, but the researcher is in control (Darsø, 2001, p. 216). The interest here was therefore the development of new techniques of context mapping. The students could benefit from learning different techniques to utilize this method, and my motivation as a researcher was to examine the feasibility of these techniques inspired by constructionist theory. The friction between the facilitator and research roles has been described in workshops as a contradiction between the "clinician" and the "ethnographer," where the clinician has the best interests and needs of the clients in mind, while the ethnographer has the motive to objectively and uninterruptedly collecting data (Darsø, 2001, p. 216). The way to mitigate this issue for me was by creating a workshop protocol where the instructions were integrated in this plan. This was done to ensure that both groups had the same instructions, but also so the students got enough attention and information to work with. I tried to balance the two contrasting roles by enabling discussion after the workshop and interviews were over. At that point, the researcher role ended, and I engaged students in discussion comparing the different results that emerged from the two different techniques. The data were collected throughout the workshop where students were working independently and from the group interviews that occurred right after the activity. The interviews were organized around the artefacts produced during the workshop. This was done to avoid false interpretations and recalls. The workshop as research format was useful as it provided a controlled context that allowed for voluntary participation. The protocol can be found in Appendix 2 in this dissertation.

In the fourth article (Pavel, in review), where I led an **action research** inquiry**,** this advantage was not present and different strategies to ensure data credibility had to be applied. Action research as a form of research demanded a high level of reflexivity from me, and the questions concerning researcher positionality emerged on daily basis. The goal of action research is change, and the validity of the research, among other aspects, is evaluated in what is changed and how. Here, the conceptualization of what should be changed is a matter of values, moral evaluations, and ethics (Feldman, 2003, p. 27). The action research therefore often has an emancipatory character and is used for the empowerment in a participatory worldview (Boog, 2003, p. 428). This kind of research inquiry brought into focus the values according to which the change had been implemented. The values were, however, intricately connected to my insider insights and deep immersion in the field of design. Here, the fact that I had spent so much time studying and practicing design, generated a specific personal epistemology. To me, accessibility of free forms of learning is an emancipatory project that is at the core of sustainable education and represents the paradigm of open learning and education.

From this perspective, the emergence of makerspace represents an educational disruption that actors in formal education have to take into consideration, scrutinize, and understand. Also, 3D printers are seen as both a potential threat and an opportunity for sustainable education and development, but also as a chance to exercise the ability to adapt to continual technological disruption on individual, group, and societal levels. This worldview also reflects itself in my critical perspective of makerspace and design studio as I believe the way these pedagogical forms are conceptualized today are not going to be convincing or applicable for mainstream formal education purposes. The action research was conducted therefore by imposing somewhat paradoxical demands on one's own practice in design studio education. On one hand, learning has to be autonomous, applicable in the context of learning, as well as transdisciplinary, while on the other, it has to be attainable, possible for novice learners to grasp, and be of a certain quality. This kind of learning should not be something accessible only for the most technically or creatively inclined, and it should definitely not be elitist, but rather inclusive, which is in line with formal education demands.

In everyday practice, these values are met with immediate scrutiny when introduced into a school system defined by accreditation, grading, and inert curricula. However, as it often happens, the contextual and applicable learning comes out of what is predicted by the program, if left to creative individuals. In the daily environment of the design studio, these values were put to examination by learners with different levels of motivation. Daily, I had to reevaluate if my pedagogical approaches were allowing students to be autonomous and ensure that my wish to make learning accessible and attainable was not standing in the way instead of helping. By autonomy, I mean the freedom to learn autonomously, but also to choose the level of involvement one wants or is capable of achieving. For this, trust was one of the important topics that was discussed between me and students. They were therefore asked to report weekly about problems they encountered in their groups and report these to their representative. This was done to secure that any coercion exerted upon participants was identified and eliminated before the trust was put into question.

To enable my position of a researcher–practitioner, a group of experienced colleagues were recruited to lead the grading process. In addition, a *critical friend* (Kember et al., 1997) joined this team and was present at student presentations and discussions. This often put me in the position of having to defend student interests against criticism from the outside. This also was done to prevent misinterpretations from what was happening in the meetings.

The data that were included as valid in NVivo were the only data that enabled equal coverage of all students and were from different sources, such as milestone meetings, course evaluations, reflection notes and artefacts. Individual tutoring or informal discussions were not included as data sets.

For the fifth article (Pavel et al., 2020), a case study methodology was conducted in the confined context of a course in inclusive design. Here, the researcher–facilitator dichotomy was also explicit when planning the research design. The case study protocol (Yin, 2017, p. 93-104) was based on the course plan in order to research how learners use 3D print as medium in real-life educational settings. The protocol was planned and modified according to the particular circumstances of collecting data in multiple locations and three languages. For example, data collection through participatory observation was somewhat obstructed due to the language barrier. It was for that reason that the captured data were collected only from common discussions that were held in English and in the presence of the other groups and often the rehabilitation center staff. Meetings with patients were simultaneously translated tome on the site. The challenge with this was that my access to the field was somewhat limited to deep insider insights. The positive side of this arrangement was that I had to rely on the other author and students who spoke English to check if the information for peer debriefing and the member checking process was continual (Houghton, Casey, Shaw, & Murphy, 2013, pp. 14,15). I also believed that, for postphenomenological methods that rely on interplay of artefacts and humans, this arrangement was quite appropriate. The other side effect was that the opinions of the members were evenly distributed, as the time was equally limited which allowed for easier planning of the case study protocol as described in part A of the protocol in Appendix 2 of this dissertation.

The protocol also addresses the political background of this thesis as it was financed by Board for Internationalization and quality development in higher education through the UTFORSK program. The program is part of a broader development of quality in higher education through establishing academic and consequently economic cooperation between Norway and Brazil. The faculty of technology, art and design at Oslo Metropolitan University has applied for this funding as part of the strategy to OsloMet 2024 which explores the issues of technology and wellbeing. The intention in the study was therefore to examine 3D printing as a new manufacturing method for the purpose of assistive technologies, which students haven’t studied before. Concerning also international and transdisciplinary character of the educational research setting, where students had to collaborate across cultures and disciplines. The research setting was described as disruptive workplace. For detailed information about research setting see the article (Pavel et al., 2020) and in the part B of the case study protocol in the Appendix 2 of this dissertation.

The protocol was used to direct the questions towards the object of this research which is the relationship between the learner and the medium. This was done through both participant observation and participant reflection. The questions are set from the position of a moderately involved participant observant where the other participants adapted to my presence as a guest lecturer. Still, from the perspective of a student, teachers are not their peers, which puts them in the position of outsiders (Herrmann, 1989, p. 4). Further, it also puts them in a position of power over the students (McNay, 2004, pp. 71–75). We mitigated this through a clear theoretical framework, source triangulation, and member checking to support the validity of our claims (DeLyser, 2001, pp. 442–450). This position possibly allowed me a sufficient balance of the insider and outsider roles. To secure the ethical standards of the research, we applied for and were granted authorization by the Norwegian Council for Research Data according to the ethical standards that include participant consent, anonymization, and secure data handling for all the research settings.

2.2.5. Analyzing data through content analysis

These different methodologies bring with them different data collection methods. However, except for the first article the rest of the research was analyzed through content analysis. Directed content analysis is described as content analysis in which research categories or coding schemes are predefined by certain theories. The goal of this approach is to validate a theoretical framework or theory. Contrarily, the conventional content analysis starts from blank categories and codes and allows them to emerge from the process of reading and interpretation (Hsieh & Shannon, 2005, p. 1281).

This represents a good normative description of directed content analysis and is methodically congruent with what was to be achieved through this research design. It also did serve the purpose for the second and fifth articles wherein I used case study methodology. However, what happened in practice in the fourth article with the action research methodology was the process of what I would call matching and assessing theoretical directions for content analysis. I tried distilling categories and codes from different theories, but many of them would not yield meaningful results or would not match the research question. In other words, I ended up distilling categories from multiple theories and then trying coding the transcribed material through all of them sometimes simultaneously, sometimes separately and from different data sets. After a while, one theoretical framework emerged as the most plausible to apply to data sets and the most valid for the formulated research question, and that was then chosen as a dominant theory through which categories the rest of the data material were coded. This was a practical procedure of conducting theoretical triangulation and fine-tuning the research question in order to describe the phenomenon in a more precise way.

I chose this approach rather than conventional content analysis for two reasons. First was a concern with interpretative subjectivity as I, the researcher, was an insider in the research setting. The emerging categories could easily be a product of my predetermined understanding of design process. Second was a concern that, even though the categories would reveal what happened in the particular situation where the phenomenon occurred, it would be difficult to lift it to the theoretical level and generalize it to other instances of phenomenon occurrence.

This method for analysis was useful in the action research methodology where the data were collected through active phases, and theories were examined and discarded in reflective phases of the research. Similarly, these methods can be used through case study methodology where stating and discussing competing theories is a common practice.

All of the articles except the first one relied on qualitative direct content analysis, in which the research was directed by theoretical assumptions, and then examined for possible explanations of the phenomena researched. However, the series of these iterations led to the development of a postphenomenological explanation. This shift is thoroughly detailed in the discussion section.

2.3. Publication strategy

The first three exploratory articles were published as peer reviewed conference proceedings. The first article was “Conference on Cooperative Design, Visualization and Engineering” (Sandnes et al., 2017). The conference was chosen because it focused on information technologies as tools to enable human cooperation. This way of approaching the topic enabled uncovering the technical underpinnings on which the 3D printing functions. Furthermore, it revealed the necessity for researching the socio-technological background to better understand the phenomenon of digital modeling and printing. The second and third articles (Pavel, 2017;

Pavel & Zitkus, 2018) were published as proceedings in the Engineering and Product Design Education Conference in organization by Design Society in 2017 in Oslo and 2018 in London. This conference brought together representatives in education and industry to share new ideas and future requirements for design education. The topics ranged from innovation in cooperation with industry to design curricula and assessment as well as issues of sustainability in design education. Attending this conference enabled a deeper understanding about design pedagogical issues and the problem of medium in design pedagogy, but also sustainable forms of teaching design which is in rapid change and expansion.

The last two articles were sent to two different peer reviewed journals. The fourth article "Postphenomenological Perspective on Free Learning with Maker Technologies – An Action Research Study of 3D Printing" (Pavel, in review) is still in the submission process. I wrote this article as the sole author and have submitted it to *Technology, Pedagogy and Education*. This journal is concerned with the impact information technology has on education in general. This includes the potential innovations technology could bring to professional development and the socio-cultural, political, and economic aspects of learning and education. The fifth and last article in this dissertation (Pavel, Medola, Berg, & Brevik, 2020) was published in *Design and Technology Education: An International Journal*. This journal focuses on educational technology in design contexts, but especially on developing practices and theories around the issues of technology education.

Thus, this dissertation covers a very wide field of research which encompasses technologies, technological media, issues of "hands-on" learning and teaching as well as the societal contextualization of these topics. In the exploratory phase, the publishing channels were chosen as a result of the need to explore these topics separately. These topics included the informational technology underpinnings of digital modeling and printing, use of media for learning in design, and sustainable design curriculum. As the ideas for this paper became more conceptually mature in the next phase, the goal was to put developed concepts into action. The journals chosen in this phase therefore were those that discussed the challenges and benefits that technology provides in education and its consequences for practical pedagogical and theoretical approaches. This publishing strategy enabled attention to be directed to each of these topics. The exploratory approach at the start of the study was needed to understand the technical underpinnings on which the 3D printing functions and the socio-technological background to better understand the phenomenon of digital modeling and printing. This was necessary because it enabled ideas to grow and merge organically and for concepts to grow from understanding the wider body of research.

The set of these five articles together generate a whole as they connect concepts of learning for resilience by using technological and material artefacts. They do this by examining this topic from different researcher and thematic perspectives. It starts by depicting it from the perspectives of computer science, collaborative design activity, and design curricula. It finishes by taking this topic and changing the teaching and learning practices and introducing new theoretical concepts and vocabulary in the pedagogy of design education.

3. Findings on how technologies mediate learning

The dissertation is structured as a response to the predicament using three research questions. The main predicament of the research is that 3D printing is one of many new media that will enter work life and schools. It will demand greater flexibility and adaptability from future learners. Thus, I explored suitable pedagogical approaches for this development in context of open and sustainable education. One research question can be seen from the point of view of the needs of education as to **how education can implement emerging technologies in the classrooms.** Similarly, from the teachers' perspective one question can be formulated as to **how pedagogy can assist resilient learning through emerging technologies in formal education.** A related question from the learners' point of view would be **how learners can be educated so that they are accustomed to the continuous process of interchanging emerging technological environments.**

To answer these research questions, three topics needed to be developed in the context of the research setting of the design studio and design education. The first subject was to develop an understanding about what constitutes emerging technological environment, and what this means for learning to determine **what the role of media is in learning through design.** The second subject was to provide an answer about what education should do to allow this kind of learning through media, that is, **how design education is currently addressing learning for resilience.** The third and final subject was to offer perspectives on how pedagogical approaches can be used to support learners' adjustment to these environments, in other words, **how education can integrate emerging technologies through pedagogical approaches.**

The last question can be seen as directly answering the main research question which was the basis of the structure of this dissertation. The first three articles answered the first two research questions and represented the exploratory part of the study. The last two articles answered the last question and represented the explanatory part of the study. The exploratory part was used to define topics and the research questions as well as the research settings and terminology that would be used throughout the next phases of the research. This is why the reader will find concepts and terminology that are often derived from constructivist paradigm in the articles, especially constructionism and transformative learning theory, while in the summary, the same findings are discussed through postphenomenological concepts. The changes that occurred over the course of writing the articles will be found in the discussion section where I present the reasoning behind this move.

The research was designed to capture diverse perspectives and to investigate pedagogical practices, curricula, design media, and design learners' everyday practices. Also, this research was situated in particular settings, bounded by one professional discipline and was therefore limited in its findings. Rather than seeking truth and definite answers, I used conclusions accumulated through the articles to provide the best possible and most relevant explanation for the setting and context from which it emerged. The relevance of the findings is therefore the new perspectives and terminology provided from which educational actors can benefit when discussing technology in education. The relevance of this unique setting can be found in relation to the introduction of certain technologies that are disrupting other important professional fields.

3.1. The role of media in learning and designing processes

This subsection covers the synthesis of the collected findings from the first two articles. To provide explanations about this synthesis, the chapter provides a further clarification of the concepts *technological environment* and *media* through postphenomenology.

Postphenomenologists assume that humans and things "exist in mutual interdependency, beyond the nature and culture distinction" (Ihde & Malafouris, 2019, p. 199). By "things," the authors are referring to a broader formulation which includes material forms and techniques, such as mundane objects, but also tools and modern digital or analogue technological artefacts. Thus, this view assumes coevolution of humans and things: "We change the world and make things that transform the way we experience and make sense of it. We in turn change during this process" (Ihde, 2009, p. 44).

The matter of this study is the *relations* between humans and things, with a focus on the many ways in which technologies help to shape relations between human beings and the world. The things are mediators of human experiences and practices (Verbeek, 2015, p. 190). Mediations are emerging through human interactions with things, which then become media. A thing, a medium is usually a technological artefact that is meant to mediate human experience in a certain way or for a certain purpose. Media was described by Marshall McLuhan (1994) as the amputations and extensions of our bodies and senses. McLuhan was particularly interested in communication media and practices that these media afford. Correspondingly, design media can be described as things adopted by designers to mediate their experience of designing or augment their abilities to design in a certain way. It can be said therefore that things afford certain mediations and prohibit others, making them suitable or unsuitable as media.

Furthermore, things often embody and actively mediate relations by becoming media. They are not neutral or passive but shape and transform human experience in unanticipated and unintended ways. Because of this unpredictability, technological change is not necessarily progressive and linear and cannot be controlled. Extensions and augmentations of human capabilities generate dependencies and changeovers. Human–technological coevolution in the sense of becoming is not directional but inherently creative, continuing, and therefore incomplete (Malafouris, 2016). I refer therefore to the technological environment as a series of emerging technologies that are yet to become media and where the coevolution of humans and these technologies is still unpredictable. Therefore, there is nothing inherently good or bad about emerging technologies. However, given the impact that they have on human life and human thinking and culture, it is beneficial to study the specific effects they might have on humans, such as the impact 3D printers have on design learners.

To refer to Heidegger's phenomenology, the phenomenon can be studied in the way Dasein reveals itself as designers encounter different media. From the perspective of Merleau-Ponty, a phenomenon is how corporeality manifests itself in designers' intentionality through media. In postphenomenological terminology, the phenomenon is a designer–medium relation, which allows the coevolution of the design learner and technology she uses. To understand learning "to, by, and through" 3D printing from the viewpoint of postphenomenology, it is necessary to study how the manifold technologies around 3D printing mediate learners' intentions. In other words, we must determine what a 3D printer affords to learners and how this is done, or in other words, how it augments and prohibits learners' abilities in different situations and according to their directedness. Furthermore, it is important to understand learning through a medium in a wider sense than that of a 3D printer. By doing this, we can understand the unique affordances of emerging technologies which are different from any other design medium.

The articles one and two (Pavel, 2017; Sandnes et al., 2017) took two very different approaches to the issue of coevolution of the designer and media and the ideas about what learning could be. The purpose of this approach was to be able to study technological and material mediation through the activity of prototyping in a holistic way. The topic in both articles was the reappropriation of things to become different media for specific designing purposes. The first article explored how the manifold technological media can be integrated with the intent to augment designers' ability to conceptualize and communicate ideas. While in the second article, we investigated how the existing artefacts could be repurposed to produce the same outcome. The findings showed how both augmentations come with certain prohibitions.

The basic assumption then is that the designing process is often put together from several media which afford different activities to design learners. The design practice of prototyping can include sketching and mockups, sometimes 3D scanning and digital modeling, and can end up with animation or digital manufacturing for the purpose of prototyping. For a thorough explanation of this, see the first article (Sandnes et al., 2017). In this way, a developed practice emerged from the designers' experimentation over time, rather than the technology being initially designed to support it. As the software companies have been further developing their software, many functions have been included, and operations have been adjusted to fit into the designers' workflow, enabling coevolution of the designers and their medium. Yet, at first glance, commonly used 3D software can appear to be an opaque technology to a novice learner as it may present multiple choices and directions which can be confusing. For the experienced design practitioners, on the other hand, these options, together with hidden menus and software plug-ins, constitute a powerful medium for expressing ideas in detail and precision that articulates their intentions in the best possible way. To these practitioners, this technology is transparent. This means they are not seeing the screen as something with an overwhelming number of tools. Instead, they are seeing a directed intentional trajectory or strategy for building their digital model. As they are modeling, just as Heidegger's carpenter is hammering, they are not systematically applying theoretical concepts; instead, they are becoming a part of a modelling activity that is constituted by the designer and the modeling software.

In the first article, (Sandnes et al., 2017), the simplification of CAD technology was addressed as a further adjustment for designers. In this adjustment, the goal was to make digital modeling technology more transparent to novice learners. By doing this, authors hoped the technology could afford a more collaborative process of designing. This article demonstrated the development of design media technology from the usability standpoint and the potential for rapid acquisition of design skills, such as sketching and digital modelling, by merging them. The article questioned the current media and practices that designers use to translate an idea into a digitally manufactured model. It especially addressed the time designers spend on sketching where ideas are not accessible in 3D for collaborative discussion. The problem of media for learning was addressed through proposing a different CAD experience for designers and for the acquisition of modelling skills. The proposed interface would allow designers to work on an object only from the top view. In this way, the medium would afford a designer to intervene with the color on the background surface by a digital pen in the same way the 3D printing nozzle would intervene on a building plate.

This is expected to enable the designer to simultaneously conceptualize an object through sketching and building a digital model in line with affordances and prohibitions of a 3D printer. This also would enable instant 3D rendering of an object, allowing for the creation of virtual models that are immediately suitable for 3D printing and exposing flaws of design for a design team to discuss. As the additional steps such as plane sketching and then using multiple commands to generate form are eliminated, the ability of the team to discuss and interact as the form is being built is significantly expanded. This should, in practice, speed up the design process, thus allowing the designer to move more rapidly to a collaborative phase and possibly facilitate the collaborative creation of sketches, models, and 3D prints.

In this way, conceptualized 3D printing activity is much closer to a hammer as it becomes transparent to designers. This was also confirmed in the initial experiment where the novices without any previous skills managed to generate simple objects from their first attempts, which is not commonly done with the most often used digital modeling software. However, this was not necessarily a worthwhile outcome. As conceptualized in this way, the process becomes streamlined and sedimented by the diminishing multistability of the medium. Thus, the coevolution of the designer and medium is suspended as the technology becomes stabilized in its actuality. This means that the medium prohibits a designer from contemplating outcomes that would be possible if the medium stayed split into its three original forms, namely, drawing, digital modelling, and 3D printing. It therefore prohibits a designer from exploiting all the affordances of the multistable 3D printing technology, including forming complex and enclosed shapes. This article demonstrated, in a practical way, the operative and instrumental aspects of the medium. The concepts of transparency and multistabilty provide explanations on how this medium compares with others.

Understanding designing and learning as the coevolution of the media and the designer can be illustrated not only by digital media but also through analogue media that designers can invent by themselves. The second article, (Pavel, 2017), examined how designers use concept mapping techniques to conduct design research for a service design project. Context mapping is a method that enables designers to construct cognitive schema of the information they collect, or they already know. These mappings also afford visual communication among members of the team. In these assignments, they can exchange ideas and form a common but multifaceted understanding about the task at hand. This is a crucial step in the investigative design phase of the project.

The researched phenomenon in that study was the enhancement of mediation that concept maps can provide to designers by embodying visual elements and making them three dimensional. The case study was directly inspired by the workshop held on Relating Systems Thinking and Design 6 in 2013, on which topic the authors of the workshop have later published an article (Aguirre-Ulloa & Paulsen, 2017). In this case study of a workshop, two groups were assigned the same task, which was to provide an analysis of a possible service including stakeholders. One group was given the freedom to choose its own medium to discuss the assignment, which ended up being the whiteboard and marker. The other group was given pins, threads, and a Styrofoam board. Pins were used to represent the stakeholders. Students were instructed that threads of different materials should represent relationships among the stakeholders. Finally, the distance between the stakeholders and the tightness of threads were used to represent the quality of the relationships.

The whiteboard group drew a circular target pattern with the client in the middle and placed their stakeholders in the form of institutions into different circles in accordance with their importance to their client. They considered a wider array of options than the pin and thread group and created more generalist solutions that did not include the existing institutions, but rather new stakeholders that directly provided help to the client. The participants stated that they experienced the task as too abstract and that they had to spend more time finding principles on which they could base their solutions. The pin and thread group, however, provided a more detailed solution where the stakeholders would be encouraged to take responsibility on their own, discussing different stakeholders' motivations and roles in the problem. The members of the group said that they had experienced the task as concrete, that it was easy to remember what was said and decided, and that they felt they had good overview of the task.

Here, designers turned things or mundane artefacts into design media. Both the whiteboard–marker and pin–thread methods augmented the students' abilities to immerse themselves in their design task. However, they augmented different abilities. While the whiteboard–marker medium directed the learners to think in terms of principles, the pin–thread medium augmented their ability to focus on stakeholders and their relationships. The affordances of the media were, in both cases, crucial for the way the design and learning process unfolded.

Postphenomenological concepts of transparency and multistability are also beneficial when assessing affordances of the medium and, therefore, their suitability for a certain purpose. The pin–thread design medium was less transparent to start with but more stable and easily sedimented in practice. The whiteboard–marker medium was more transparent but also more multistable, allowing for ingenuity in meaning-making by the learners. It is important to note that the pin–thread medium had to be explained to the learners, and common conventions about its use had to be established for it to become transparent. Transparency occurred when learners became immersed in their activity, as they stopped seeing threads and pins and started seeing their stakeholders. It can therefore be said that the pin–thread medium afforded sedimented practice, while the whiteboard–marker medium did not.

By comparing these analogue media to a 3D printer that is comprised of digital modelling software, slicing software, and a 3D printer interface, it could be said that this medium is both opaque and multistable. Furthermore, opaqueness and multistability characterize every step of usage often to the point that most of the affordances of the software are not used in each occasion. To be used to full potential, it usually becomes dependent on the learner's intentionality and, even more, on the contemplation of the medium's potentiality. Often, this requires a learner to choose the right software and right operations in the software for their intentions. Further, it demands that the learner experiences that this process is worth implementing for their given intentions. Finally, the learner has to be able to perceive that this makes logical sense and that the activity is structured. These are the issues that teaching this highly multistable and opaque technology has to consider so that the learner can be resilient when meeting new technologies.

3.1. Learning for resilience in today's design education

There was a need to understand how the current design education supports this kind of learning with technologies and technological adaptation for two reasons. The first was to frame the topic so that concepts, such as resilience and education for sustainability, could be applied to the issues of design education and therefore understood in that context. The second was to determine what kind of pedagogical approaches could be used for this kind of learning and how design schools normatively aspire to manage this kind of education. The third article scrutinized design curriculum and the existing literature to address the issue of resilient learner and sustainable education and the use of 3D printing technology in higher education. The third article, (Pavel & Zitkus, 2018), and the literature review provided in the Introduction section therefore described the knowledge gap that was eventually identified before the next phase of the project.

This initial exploratory study examined Norwegian and British design school curricula from the perspective of learning for sustainability through a hermeneutical approach. The study uncovered the challenges in how curriculum addresses current technical skills, critical reflection, and especially aging society. The article represented a contextual background for other articles in this dissertation. It introduced concepts such as sustainable education, resilient learner in contexts of technological skills, and societal changes. The study was structured in the context of the comparison of the policies that two countries have issued and their respective curricula. The curricula were examined for their content and learning forms. From the hermeneutical perspective, the verbs that are used show how the makers of the curricula understand what kind of skills and learning should normatively happen in the classroom.

The research showed that procedural knowledge is very pronounced in the curricula with verbs such as plan, utilize, implement, develop, and so on. In British curricula, emphasis is placed on critical thinking skills, which is expressed by verbs such as critically reflect, analyze, interpret, and evaluate, and the importance of declarative knowledge is expressed by verbs such as understand, recognize, comprehend, and describe. However, in Norwegian design schools, this seems to be the other way around as critical thinking is the least represented in curriculum. However, in both of the British and Norwegian design curricula, the essentialist approach is very much represented by verbs such as have, acquire, know, and demonstrate.

Even though technological skills are very pronounced as integral to procedural knowledge, there seemed to be a mismatch with how students could actually apply them. This conclusion emerged when we looked at other research that clearly showed that it is difficult to recruit for technical skills. It proved to be a challenge to conclude what the reasons were for this mismatch. Yet, this showed that, in general, the ability of learners to adopt new technologies and adapt to the new technological environment is a relevant topic in design education. Further, inclusive and universal design, especially in the context of aging, were found to be misrepresented in the curricula in comparison with governmental policies. This was also an indication of the type of content design education should pay more attention to. These findings directly contributed to research design for the fifth article that explored how 3D printing has been used for production of assistive technologies.

3.2. Integration of media into pedagogy

The last two articles (Pavel, 2017; Sandnes et al., 2017) demonstrated how relational ontology and postphenomenological epistemology can be practically applied in pedagogical contexts. In the fourth article, I took the role of researcher–practitioner with the goal to reconcile free and accessible learning. The action research method was used with the goal of introducing digital technologies, especially 3D printing early in the learners' practice, but also to provide a basis for teaching practices at the department of product design. The action research explored and was aimed at overcoming contradictions that emerge when the makerspace pedagogical postulates are applied in formal learning settings.

Through three cycles of action research, a course for the freshmen students was developed. Throughout the cycles of action, the data were collected from my own practice. In reflection cycles, the goals of the course plan were revised based on the content analysis and by relating the emerging issues to the existing literature. The contradictions between free and accessible learning were resolved by altering the course plan and running it again. The contradictions in free learning emerge when the teaching is lacking instruction as it becomes difficult for a learner to comprehend and manage learning. On the other hand, if the instruction becomes overly formulated, the learner loses autonomy to organize their own learning and apply critical thinking.

The inability to achieve happens as the learner does not have enough experience to organize practices and not enough practice to accomplish particular tasks. Thus, this experience and practice have to be pedagogically sustained. The solution for this issue emerged when I stopped looking at the phenomenon of learning as an acquisition of skill and accumulation of knowledge through experiences and rather focused on the embodied connections and activities of the learning environment. From this changed perspective, I realized that technological mediation, design media, and the technological environment in which this embodiment occurs are essential to understanding the phenomenon of learning. Finally, the proposed pedagogical concept moved from designing instructions to providing experiences and moved further towards understanding learners' coping with technological mediation. The premises for pedagogy became supporting learners' intentionality and its modification that happens in mediation in a situated technological environment.

In the fifth and last article, (Pavel et al., 2020), I put these new approaches to learning and teaching into the context of open learning. Furthermore, I discussed them using the terminology of a disruptive learning environment where learners need to grasp on their own what is important, formulate issues, and generate practice. The article provided a research basis, theoretical perspective, and terminology to discuss learning for resilience with emerging technologies as well as to make recommendations for how to think of them in a formal education context. The article illustrated the coevolution and multiplication of technologies in a networked setting.

4. Revised conceptual framework for technology-mediated learning and pedagogy for resilience

Using media for teaching and learning is an established and widely researched topic. As digital technologies are filling classrooms, media have become a focus of many researchers in educational settings (Hakkarainen, 2009; Henrie, Halverson, & Graham, 2015; Oliver & Herrington, 2003). However, to know how media affect learning, it would be necessary to clarify the very idea of learning. If learning can be described as the acquisition of declarative knowledge, then learning and media can be seen as two different issues. This suggests that knowledge is content and that a medium is just that, a means of conveying that content. Thus, it could be easy to dismiss a medium as not being a vital part of the way knowledge is formed (Clark, 1994), or see the medium in the context of the effectiveness of teaching. If knowledge is a construct accumulated through individual experience, then a medium is more important. How a learner uses a medium will affect what is learned. Still, knowledge is constructed by a learner through engagement with media (Papert & Harel, 1991) or critical reflection (D. Schön, 2003), and this is inevitably a matter of meaning-making which happens in a learner's mind. Learning is constructed by the learner's mind, while engagement with media is a way for the knowledge to be constructed. These are basic postulates of instructionism and constructivism, which I will return to in the discussion section, but let us now consider an alternative view.

In the relationalist view, learning and knowledge are enacted and generated only in learners' relation to their environment. Learning and knowledge are provisional and situational and cannot be expressed or understood outside of the context of relation between learners and their environment. As an environment becomes technological, this perspective suggests media as a key factor in learning. The question stops being what is learned by using media and becomes what kind of learning does this medium enable to emerge. Learner and medium are part of the environment, which they are changing, and through that, they both become transformed. This transformation through coevolution can be seen as learning and knowledge, which is reflected in the augmentation of human capabilities and agencies. Skill can be then explained as the extent to which learners' social, natural and technological environment is susceptible to their intentionality (Pavel, in review).

Following the phenomenological premise of learning as becoming by being embedded in the social and physical lifeworld, postphenomenological learning can be described as becoming by being embedded in a socio-technological environment. Similarly, the postphenomenological premise is that a homo faber uses technology to improve their own environment, but through that process changes themselves, as described by Ihde and Malafouris (2019). Learning by designing, and then 3D printing in particular, can be seen as the process of new technology conception through prototyping. Learning happens through repeated processes of conception and reception of design, which are bound by the technological affordances of 3D printers and by individuals, groups, and communities. The human–technology relation has a goal to rearrange material environment and conceive new technologies or technological artefacts. In other words, a learner or a group of learners use 3D printing to conceive a new technology that will rearrange the human–technology configuration for some particular purpose in their group, community, or organization. The reception and potential adoption of this new technology by the community determines what and how they will learn.

4.1. A revised understanding of technology-mediated learning

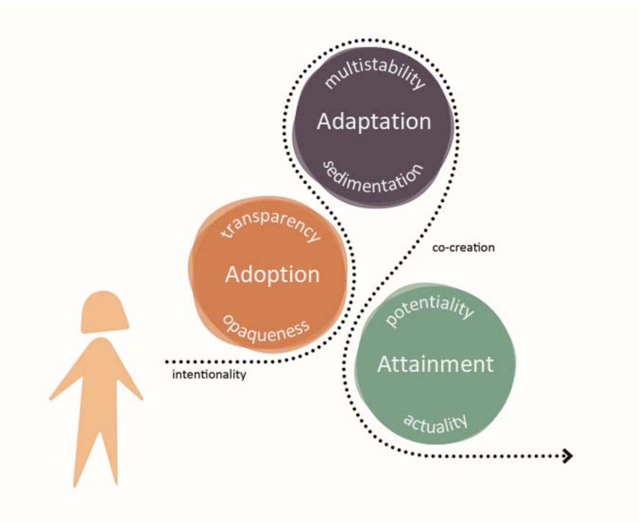

Figure 2. Technology mediated learning- The figure shows different manifestations of learning with technologies

Embodied learning assumes human bodily capacities, such as those that are physical, mental, emotional, in relation to environmental affordances and constraints as crucial factors for learning (Merleau-Ponty, 1996, p. 164). Learning by the means of technological media can also be explained through learners’ use of their bodies, perceptions, and mental capacities to relate to technology. Learning 3D printing in a postphenomenological sense can be described as a change in the learner–3D printer mediation. It can be described through the postphenomenological concepts of human–technological mediation that can be observed when learners encounter 3D printers in learning settings (Pavel, in review, p. 5). This change includes bodily experience from alterity to embodiment configuration, perceptions from multistability to sedimentation, and mental processes in which learners contemplate usage of this medium from potentiality to actuality.

4.1.1. Adoption: From opaqueness to transparency

Learners often start learning to 3D print by choosing an existing digital model, which they prepare in the slicer. At the very beginning, this technology seems opaque and is experienced by the learner as "the other" entity. This entity, which is constituted by the slicing software and 3D printer's interface, needs interpretation. The slicing software exposes affordances and limitations of the 3D printing process by visualizing the route of the nozzle. The build plate and the nozzle require that the learner prepare them before the printing can start. A learner has to find out how to clean the nozzle so that the filament is extruded properly. Further, the learner has to find out how to apply the glue and preheat the plate, all for better adhesion of the printed model. Learners also have to service this machine so that it can produce what they intend.

The first couple of prototypes might not even come out as planned. The learner often discovers that the orientation of the prototype parts, supporting materials, and the layer and wall thickness as well as the route of the nozzle have a lot to do with mechanical properties and the aesthetic finish of their prototype. She also realizes that there will be long hours of waiting for a model to be finished, which often comes as a surprise.

By going through the process of preparing a digital model for 3D printing in the slicing software, preparing the machine itself, and waiting for the prototype to be finished, the technology becomes more transparent and less opaque to a learner. Learner is experimenting with different settings in the slicing software to achieve the more preferred physical properties of the prototype. She gains an understanding about whether the machinery is properly prepared to start the process of 3D printing. The configuration between a learner and 3D printer becomes less one of alterity and more one of embodiment. Learners stop seeing a complex set of screens and cogwheels and can successfully predict the route of the nozzle.

As a learner also spends time with a 3D modeling software, she stops seeing commands and menus and starts seeing steps for geometric development. As 3D modeling software becomes transparent, a learner starts integrating geometric features into her digital models to avoid limitations of the set of 3D printing technologies. The nozzle becomes the extension of the learner's hands and mind. In other words, the leaner has "learned to" 3D print. She has adopted this medium as one of many ways of rearranging her material environment.

4.1.2. Adaptation: From multistability to sedimentation

When learners are using 3D printers to print the existing models, they are using it in a sedimented practice or according to its delegated script. Yet, for a 3D printing technology to become a prototyping technology, a designing conception process is necessary. Only when meeting a new design challenge, generated by social and cultural context and demands, does 3D printing technology become multistable for learners. Multistability occurs as learners *pivot* (Rosenberger & Verbeek, 2015, p. 30) affordances and multistabilities of 3D printers in their attempt to amend the human environment with a new human–technology configuration for a potential user through a prototype and in congruence with their cultural preconceptions. Multistabilty can happen through a combination of many technologies, including a 3D scanner, multiple 3D modeling software, slicing software, and 3D printing filament materials. The combination of all of these different software and material constellations as well as the ability of a 3D printer to produce complex shapes enables learners' to pivot. Once the challenge is addressed by the acceptable new human–technology configuration and design is conceptualized, the 3D printer stabilizes its usage for that particular challenge. If the design challenge stays the same, and the most optimal prototype is chosen, then the usage of 3D printers becomes yet again sedimented. Then, 3D printers are used only to reproduce parts and not to utilize its affordances for design conception. Thus, learners learn about their own lifeworld "by 3D printing." They adapt this medium to their needs and purposes.

4.1.3. Attainment: From potentiality to actuality

Learning and design conception happen not only when learners interact with the prototyping technologies such as a 3D printer. The conception of design is influenced by the very presence of technology, in this instance, a 3D printer and its potentiality (Kiran, 2012, pp. 78-80). The potentiality found in a 3D printer shapes what learners regard as their possibilities of design conception. It enables design to be conceived in one way and prohibited in another. It also constitutes learners' being designers by showing them what they might achieve, either right there in the project, or in the future. Even when not in direct interaction with 3D printers, learners virtualize 3D printers as enablers of certain actions (Lévy & Bononno, 1998).

The 3D printer's actuality is demonstrated in printing existing digital models. However, its potentiality is in the leaners' virtualization of affordances of 3D printers that can be used to achieve new design conceptions and through that enact a new human–technology configuration. Once a learner produces a prototype that enables this new human–technology configuration, production of this new part becomes the 3D printer's new actuality. The potentiality of 3D printers and potentiality of new conceived design are closely related as the one enables the other. Once 3D printers become part of the learners' lifeworld, they are able to contemplate design concepts through 3D printers. They have learned to think "through" 3D printers. Learners' abilities to rearrange their material environment and conceive new design solutions are then augmented by the medium of 3D printing.

4.1.4. An approach to technology-mediated learning

Just as in phenomenology, the learners' intentionality can be seen as the essential drive of any learning and the reason for its emergence. This drive proves to learners that they are agents in their lifeworld, and it forces them to establish relations. When encountering their lifeworld, this relation is arbitrated by the material or technological medium they happen to have access to. On their path to realization of their intentionality, they overcome barriers by negotiating them with the medium. As the medium affords certain doings, and prohibits others, the relation is then modified. The learner interchangeably discovers new affordances of the medium, finds new purposes for these affordances, and comprehends possibilities of the medium in different scenarios. Technology-mediated learning happens through the process of design conception and reception. The outcomes of conception are new technological artefacts, and of reception, they are new mediated activities, but the learning process is essentially the same.

Adoption, adaptation, and attainment happen simultaneously, even though adoption is necessary to enact the other learning and mediation processes. When adopting a new medium, a learner strives to get hold of it and manage it. The more learners' attempts attain foreseeable results, the more this medium becomes transparent to them. However, the more it provides unforeseeable ones which obstruct her intention, the more it stays opaque.

When adapting a medium to their purposes, learners strive to develop meaningful processes and practices with this medium. They evaluate if it is worth the effort and if is it meaningful for her purposes. At the beginning, she perceives the medium as multistable with a variety of procedural outcomes, but as she keeps investigating, certain procedures stabilize while others are abandoned. Finally, the ones that keep being repeated become sedimented as part of their practice with this medium. Adaptation is about learners' capabilities to bracket by suspending delegated scripts of the technologies, perceive technologies as multistable and delegate new scripts to match their own purpose.

Once augmented by the medium, learners can comprehend the outcomes of their doings. They evaluate if their actions and results make sense and if they have structure and order. They can estimate to what extent their works affected their social and material environment and learn about unanticipated barriers created in this material reconfiguration. The more they are able to anticipate the outcomes and take responsibility for them, the more they recognize their own agency, changing their field of awareness and tapping into the potentiality of the used medium. In the opposite case, the more they rely on the existing field composition, the more they use it in its actuality. In this manifestation of learning, a learner understands her own possibilities through this medium.

Returning to article two (Pavel, 2017) in this dissertation a similar perspective on learning with media can be extrapolated with analogue media as well. In this article, learners adopt a new tool to facilitate their discussion, and they adapt it to their purpose in order to attain common understanding and new solutions for the task at hand. Therefore, the proposed model is not given only for digital technological media. However, with emerging technologies the mediation effect is not yet explored, practices established, and the medium is often more complex as it automates a series of functions making it difficult to virtualize its potentialities. It is for that reason that the postphenomenological perspective onlearning becomes more relevant with emerging technologies. In the case of 3D printing the mediation effect is the ability of learners to produce complex shapes, reproduce, modify and share their work. Furthermore, this perspective becomes relevant because the use of emerging technologies does not yet have established practices and teaching has to take this into account.

4.2. Pedagogical approach to technology-mediated learning for resilience

Self-reliance and responsibility are two aims of phenomenological pedagogy (Langeveld, 1984). Similarly, the need for awareness of one's own agency and responsibility should be a key focus in postphenomenological perspective on pedagogy. This is because human abilities are augmented through technological mediation, possibly causing dependence on unsustainable practices with technologies. Resilience as a concept is therefore twofold. It assumes the ability to adopt new technologies, which can be demanding and difficult to attain on one hand. On the other hand, it also means the ability to abandon technologies when they do not provide sustainable practices that are promoting enduring positive changes for the individual, group, and the community. The role of pedagogy is therefore wider than teaching technologies or using them as a learning medium. I would rather characterize it as assisting learners' resilience. This assistance promotes the development of sustainable practices in individual, group, and community contexts.

As previously explicated, from a phenomenological perspective, learning relies on learners' embodied enacting of experiences in these contexts. As learners are part of their environment, they will learn what the environment affords. It is, for example, impossible to fully teach assistive technologies and inclusive design to future designer without involving patients, and therapists who will use these technologies (Pavel et al., 2020, p. 11). It is the role of the pedagogue and the educational institutions to provide these environments in order to enable the most meaningful learning for their students. Furthermore, it is the role of the institutions to enhance learners' sense of coherence in this potentially complex socio-technological context. It is therefore difficult to achieve a relational approach to learning and pedagogy without the community, groups, and individuals and their physical environment. Social involvement is connected to the process in learners' technology-mediated learning, which demands different pedagogical assistances in that process.

Adoption of the medium depends on individual engagement of a learner. Here, a learner is advancing from an opaque technological mediation towards a transparent one. The pedagogical imperative for a learner is perseverance. The use of the internet to find relevant information, tutorials, learners' modeling actions of teachers and arranged use of technology is useful pedagogical assistance.

Adaptation of the medium will work best in a group. In this case, a group of learners is pivoting affordances of the medium with the goal to stabilize it for a certain purpose. The pedagogical imperative for the learner is ingenuity. Providing new socio-cultural contexts and teaching learners to suspend their judgments or bracket them can be beneficial pedagogical assistance.

For attainment, a community or an organization is central. Here, a group of learners is augmented by technologies and contemplates the outcomes of technological mediations for themselves and their community. The pedagogical imperative for the learner is integrity.

Facilitating diffractive practice and plurality of opinions and ideas can be beneficial pedagogical assistance.

When learning a new medium, the learner's resilience is reflected in how the learner's intentionality plays out through technological mediation. A learner has to utilize medium affordances while still maintaining their own intention and values. This contrasts with acceding to what is easy to do with the medium or what is delegated by the script. Through the processes of pivoting and virtualizing actualities, the medium can both augment and prohibit the learner's intentions. Learners' ability to maintain their field of awareness despite applying a medium's field composition can be seen as integrity.

For the phenomenological pedagogue Langeveld (1984), pedagogy was defined as an ethical and normative practice because it distinguishes between what is good and what is not good for a learner. Pedagogy for technological mediation therefore needs to address learners' dependency on a technological medium. Pedagogy as a method of teaching for this kind of learning has a goal to support learners' intentionality despite of the scripts that the medium affords. This means also that it shapes learners' sense and understanding of their own integrity and agency but also their own fallibility as a mere participant in relations in the social and material world. Using a medium only for what is it good for is part of the learners' autonomy, responsibility, and self-reliance in technology-mediated learning.

As noted previously, technology is rarely neutral, but the scripts are not always consciously delegated in a technological medium. They are also a matter of pivoting its multistable affordances. Being able to contemplate or virtualize the consequences of using technologies in co-creative processes within the community means achieving personal autonomy and responsibility for a learner. It is crucial for future learners to be able to take ethically responsible decisions, which are not skewed by technology-mediated field of awareness. Here, resilience means being able to choose the right tool for the right task. This means being able and willing to switch field compositions and abandon the medium that cannot yield sustainable practices.

This can be achieved through bracketing, a term coined by Husserl (Husserl, 2012, p. 110) which is often used in the phenomenological method but also in pedagogy. The aim of the bracketing is to suspend judgment by enabling a learner to "re-achieve a direct and primal contact with the world as we experience it rather than as we conceptualize it" (Van Manen & Adams, 2010, p. 452). Bracketing becomes a useful phenomenological learning technique to suspend mediated field composition and habitual observation and become aware of the actual relations happening in the socio-technological environment. Integrity in this context can be seen as a learner's ability to use the field of awareness to critically assess field compositions in her environment and choose ones with sustainable outcomes. In other words, abandonment of the technological media is an equally important part of learning as these technologies will inevitably become redundant. As the medium becomes sedimented in learners' practices and even in their identities because they feel augmented by it, this is not necessarily an easy task for pedagogy. Here, the experience of adopting a technology is more valuable than proficiently using a medium. The very experience of learning should be able to encourage learners to reengage in new technologies through enactive attainments (Bandura, 1982, pp. 126,127). Enactive attainment is the phenomenon where previous success increases perceived self-efficacy and therefore increases the chance for learning new technologies.

5.0. Discussion: Technology-mediated education

> When you hold a hammer, everything looks like nails (Maslow, 1966), when you use a 3D printer everything looks like . . .

Before we turn to the discussion section, which includes implications of the findings for pedagogy, theory, research method, and design discipline, let us summarize the topic of this dissertation. It was written following the qualitative research traditions of action research (McNiff, 2014) and case study (Robert K Yin, 2017). This research has revealed exemplary qualitative findings. The conclusions in this dissertation is therefore valid for a small sample and particular cases. They are confined to a design studio educational context which demonstrates free learning, exemplary media such as 3D printing, and specific participants, the design students. As already mentioned, this research used this data to provide a new perspective on how learning could be understood when it becomes defined by the use of media. The strength of this way of doing research is that each article answered contextual questions with multiple variables. This enabled concept utilization and formed the conceptual and theoretical generalizations (Sandelowski, 2004). These analytical generalizations are unlike statistical probabilistic ones. They are fluid ideas that facilitate sensemaking of the world and phenomena in it, according to Atkinson (2017, p. 5). The value of these ideas is in their transferability. They provide readers a conceptual vocabulary to describe their own situation when they recognize these phenomena in their own practice, but also modify them and build on them. This postphenomenological perspective on learning might be relevant outside of design teaching practice as technology enters everyday lives both privately but also in formal and informal education where free learning occurs, such as for example workshops with multiple stakeholders.

The predicament addressed in this dissertation is that emerging technologies based on digital media are readily accessible in schools and are becoming a part of their inventory. Furthermore, the technological innovation puts these media into perpetual change, making previous generations of media redundant. The inquiry of the dissertation was to find suitable pedagogical approaches for teaching and learning with these new media. The other important issue was making these approaches sustainable so that they can be used to educate learners who are resilient to changes of the technological media.

The dissertation takes design education and its teaching practices as the suitable research field because it is formal education, which is characterized by contextual, applicable, and autonomous learning. The dissertation explored the design of digital media described in the first article (Sandnes et al., 2017), the use of material artefacts as media in the second (Pavel, 2017), the concept of resilience in design education in the third article (Pavel & Zitkus, 2018), the development of media-based pedagogies in the fourth (Pavel, in review), and the application of these pedagogies in an open learning setting in the fifth article (Pavel et al., 2020). The findings indicated that the dominant theoretical approach to learning with the emerging technologies in the current body of research is constructivism. The first (Sandnes et al., 2017) and the second articles (Pavel, 2017) concluded that media sets the agenda for how and what is learned. The third article (Pavel & Zitkus, 2018) showed the mismatch between how these practical technical medial skills are taught in educational settings and how they are used in practice and that learning for resilience is partially represented in design curricula. The fourth article (Pavel, in review) suggested how to incorporate emerging technologies and media in formal educational settings so that they can allow for resilient learning. The fifth article (Pavel et al., 2020) illustrated how these pedagogies unfold in an open learning setting with multiple actors.

The dissertation offered a new perspective on learning which refuted the idea that learning is only a construct of the minds of learners. In this relational perspective, learning happens in relation to the learner and the environment. Knowledge is about how capable a learner is at manipulating her socio-technological and material environment. The proof of learning can be therefore seen not only in observable change of the learners' behavior, but also in concrete changes of their material and socio-technological arrangements. Skill can be defined as susceptibility of socio-technological environment to learners' intentionality (Pavel, in review). Knowledge is about how capable a learner is in manipulating her socio-technological and material environment (Pavel, in review). Learning occurs through four manifestations of coping with technologies and material environment through mediation (Pavel et al., 2020, p. 10): adoption, adaptation, attainment, and abandonment. In the adoption, technology becomes transparent to a learner; in the adaptation, the learner appropriates technology for her own purpose; in the attainment, the learner is augmented and can virtualize and contemplate effects of technologies; and in the abandonment, the learner finds technologies that are more manageable, and worth investing time in, and which lead to more sustainable practices. In this ecological view on learning, the focus is on human knowledge as an effect on the environment. Learning is a source of human resilience and ability to cope with an environment. We do not know what the jobs of the future will be, but we know that they will be about engaging with emerging technologies. These technologies will be multistable and opaque. This means that it will take learners' persistence, ingenuity, diffractive practice, and, eventually, openness and readiness to get involved in new cycles of technological learning. Through this view, the new insights in learning through technologies become evident, but also a new set of questions emerges.

5.1. Implications for theory of learning and pedagogy: Learning in the light of emerging technologies

I will now share my reflections on the evolution of this dissertation, as it is important for introducing the discussion. As stated previously, there is a need for more nuanced and multifaceted understanding about the use of emerging technologies in education. From the perspective of academic knowledge, it is too risky that an important issue in educational science relies so heavily on only one theoretical idea.

Constructivism and constructionism, without a doubt, provide a beneficial stance for both pedagogues and scientists when dealing with the issues of media and project-based learning in formal and informal situations. Without constructivism, the issues of learners' autonomy and ownership of learning would not be taken into consideration in the first place. Further, the very concept of minimal intervention on the side of the pedagogue and letting learners define what issues they want to invest themselves in are essentially constructivist ideas (Montessori, 2013, p. 348). Understanding learning as an occurrence that happens through the process of making would not be taken into consideration without constructionism (Papert & Harel, 1991). Therefore, it is not my intention to dismiss constructivism and constructionism, which served many researchers well, myself included (Pavel, 2017), but rather to provide another perspective which is more suitable for the changing circumstances of a massively technologized personal and professional environment and learning with multiple stakeholders. This perspective can give new insights in everyday learning that, intentionally or not, happens in human contact with technologies. It can also provide the field of educational research with a fresh view on media and project-based and open learning activities in education.

5.1.1. Changes in theoretical perspectives on learning

That said, the incapability of existing theories to explain the context of changing technological environments could be described through a critique of constructivist understanding of human learning and practice. The change is reflected in the way multistable technologies organize human work, the scope of learning, and the complexity of the socio-technological environment. This will be addressed through taking already presented ideas from Schön, Mezirow, and Papert, and further addressing their shortcomings when faced with technological learning media.

Schön's ideas about reflective practice come from observing different practitioners, among others, architects in design studios. He explained how these practitioners extract what is important in a given situation and use their own previous experience to address this situation. While observing architecture students, Schön (1985) found that a reflective practitioner operates routinized performance. Only when the practitioner enters the indeterminate zone of practice, described as "a situation that cannot be resolved by routine practice performance," does she change her perspective:

> In these zones, competence takes on new meaning. There is a demand for a reflection, through turning to the surprising phenomena and, at the same time, back on itself to the spontaneous knowing in action that triggered surprise. It is as though the practitioner asked himself, "What is this?" and at the same time, "How have I been thinking about this?" Such reflection must be at some degree conscious. It converts tacit knowing in action to explicit knowledge for action." (Schön, 1985, p. 25)

Schön was observing architecture students in a design studio education with centuries of tradition in practicing architectural design and educating architects. This education came with a predefined set of technologies, which were often transparent, stable, and sedimented in practices of the previous generations of architects. In the context of fast changing technology and society, there is a challenge posed by this view in my opinion. Emerging technologies do not necessarily come with a prescribed, standardized, or routinized set of practices or performances, as their abilities are expanding faster than practices. There is the challenge of either deploying this technology in the current practices or forming new meaningful practices around it. Most of the involvement with 3D printing, for example, becomes an indeterminate zone of practice, which is what makes this technology open-ended and inspiring in the first place. Namely, the 3D printer does not have a designated purpose. Pulled out of a makerspace or a research and development lab, a 3D printer stops being a manifestation of the established cultural and work practices. Riis effectively described this property of emerging technologies where he explained that this can lead to tension between the instability and multitude of their uses (2015, p. 169). Schön also did not recognize the premises of the situation practitioners' encounter such as the medium as an important factor in what is learned and how, which is common for a constructivist perspective where learning is an abstraction in the mind of learners (Ackermann, 2001, p. 3).

Still, constructivists do emphasize the issue of the acceleration of change in society, which Mezirow (1997) described:

> As we move into the next century and more technologically sophisticated industry and service sectors, work becomes more abstract, depending on understanding and manipulating information rather than merely acquiring it. New forms of skill and knowledge are required. There is a growing consensus pertaining to the essential understandings, skills, and dispositions required for an adult learner to become an effective member of the workforce of the future. Economists recognize that resources should be directed towards creating a workforce that can adapt to changing conditions of employment, exercise critical judgement as it manages technology systems, and flexibly engage in more effective collaborative decision-making. (Mezirow, 1997, p. 8)

Transformative theory, in its essence, is therefore a resilience theory. However, it is presented as an ability of the mind to readjust to the new situation. I would agree with Mezirow in that learners of the future should answer for themselves what is the right thing to do when using 3D printing or other emerging technologies to understand the world around them, but not once in a lifetime, rather persistently, with each iteration of the technology and each social and market change which occurs repeatedly. Mezirow put it this way: “In the absence of fixed truths and confronted with often rapid change in circumstances, we cannot fully trust what we know or believe” (Mezirow, 1993, p. 4).

This rapid change poses a question of the frequency of the transformations and the ability of future learners to keep switching perspectives. According to current understanding in transformative theory, transformation cannot be guaranteed, and educators can only provide opportunities, while experiences and reflections are individual (Fullerton, 2010, pp. 35-42). Transformative theoreticians have already discussed these questions; for example, Weimer (2012, p. 439) asked: “Can learning experiences be designed so that transformative learning happens more regularly? What sequence of activities best transforms dependent learners into independent learners?”. In the context of this research, the issue of personal transformations was differently formulated. They are intricately connected to technological mediation. For Mezirow, transformation was defined as a mental process which might happen when learners are challenged through a discussion or a piece of art, or when they meet situations that challenge their habits of mind. However, transformative learning theory does not address how the technological environment is changing or transforming learners. For example, a person might enter art studies as a student, but end up as a ceramicist, or ceramic artist. Thus, the technological mastery can become part of transformation and identity change. This is an important discussion to have as technological redundancy is inevitable, disrupting identities and generating personal relationship with work life.

In contrast to the abovementioned constructivist theoreticians, Papert (1980) considered the very process of making as crucial for the learning process in his constructionist learning theory. He also took the materiality of the engagement with the environment more seriously through his mathematic principle:

> First, relate what is new and to be learned to something you already know. Second, take what is new and make it your own: Make something new with it, play with it, build with it. So for example, to learn a new word, we first look for a familiar "root" and then practice by using the word in a sentence of our own construction. (Papert, 1980, p. 120)

Papert also took seriously bodily functions in thinking, calling it body syntonic thinking (Papert, 1980, pp. 205-221). He considered this as being most visible in the logo programming language for children, which is based on distance, angle, and variable to operate an onscreen object. Here, Papert claimed that children use their bodily understanding to comprehend these functions. In many ways, Papert's ideas are not that different from postphenomenological concepts in which learning happens in environment and is embodied.

The criticism of Papert, as I see it, is more attuned towards constructionist incongruences with constructivism, making the theory incoherent, as described by Mackrell and Pratt (2017). They criticized constructivism in the context of the Cartesian split between body and mind, in which emotional experiences are then not consequently important for learning. They argued that this is not the case in constructionism where it is clearly stated that ownership of the learning situation is a crucial factor for learning (Mackrell & Pratt, 2017, pp. 423-426). From a relationalist viewpoint, the learner is seen as one with their environment, and the experience of learning lies in the bodily relation that emerges between the learner and the environment. The issue with constructionism lies in the fact that objects of representation or "objects to think with," as Papert called them, are treated as representations of learners' knowledge or, as

Papert named it, syntactic thinking in which the human mind functions on an abstract level applying principles in different instances of objects.

I encountered this dilemma in my own research (Pavel, 2017). The issue presented itself as how to understand the properties of artefacts in learning situations, namely, if they have affordances that enable learning or are objects of representations that enable learning only in the context of meaning making by the learner. In this research, as described in findings section, I ultimately adopted a relationalist view. Accordingly, I believe that objects are not representations of abstract ideas through which learning happens when the learner is making them. What humans perceive is already conceptual in character and adequate to produce human judgement and belief. If we create experience in this way, we can see this experience not as a mediator that comes between environment and ourselves, but as reality itself. Experience discloses the world to us (Bakhurst, 2011, p. 7). Therefore, it is rather human intentionality confronted with affordances of material and technological artefacts that are inspiring or prohibiting certain actions. Enactment of these actions generates experience that represents human learning.

5.1.2. Changes in practical pedagogical perspectives

The critique extends equally to pedagogical practice as much as to theoretical perspectives on learning. Constructionism starts from the premise that there is already decided what is to be learned and taught in a pedagogical situation. As previously explained, working with new technologies in social settings in design studio demands a rather explorative approach, in which the very subject of learning needs to be discovered. The relationalist view on learning would be that it is very difficult to teach somebody something outside of the socio-material context in which learning is happening. Without direct material and social consequences in the learning environment, learning becomes detached from practice and context. Learning happens as learners are becoming part of the socio-technological environment. In this environment, relations among humans, mediated by material or technological artefacts, constitute and therefore commend what is necessary to be learned in order for the learner's participation to occur. Consequently, pedagogy is not there to decide what is to be learned, following curricula or learners' mental capabilities. Pedagogy is there to facilitate the learners' resilience and the sense of their own agency to improve relations and the environment and to establish sustainable practices. Thus, a classroom represents an insulated system that cannot accommodate the learners' full potential because its only outcome is learning in itself. This applies also to design studios where there is no external cooperation with, for example, users of products or services, and/or stakeholders, or technology that is to produce it. Similarly, the maker movement relies only on technological artefacts and makers outside of the societal context. This provides a safe insulated space for failure and experimentation but does not provide opportunities for learners to evaluate the consequences of their doings in societal contexts. The relationalist perspective therefore seems to be the most suitable for truly understanding and discussing concepts of open and free learning and education.

In the research for this dissertation, the practical pedagogical issues around applying constructivist approaches to learning was the topic of the action research project and the fourth article (Pavel, in review). In this research, the principles of open learning with minimum instruction were deployed in the design studio. Starting with constructivist practical approaches, the study showed how, through the iterations of action research, the relationalist approaches could be gradually applied. This new approach allowed for the creation of a learning environment in which learners could relate their practical work to theory in a better way.

Constructivist methods often involve the forming of learner groups, based on the idea that learning is a social construct, and giving the group a problem to solve with minimal instruction. The idea behind this is the belief that, by solving these problems together, learners will construct their own knowledge about the curriculum topic at hand (Sjøberg, 2007, p. 3). This is in contrast to instruction where the knowledge content is presented to learners and it is demanded that learners acquire it (G. M. Johnson, 2005, pp. 90-98). In Johnson's study, this approach led to a series of challenges. First, the learners found the instructions confusing and non-relatable. As previously noted, design studio education does not only demand learning by doing, it also demands that the learners conceptualize the problem and, through that, find out what is to be learned. In my own study this resulted in the task becoming unattainable for learners, as they "did not have enough practice to do the task and not enough understanding of design to organize their individual practices" (Pavel, in review). Second, the group work made some learners less active as they did not try new skills, letting other participants do that, and were rather applying what they already knew to contribute to the group project.

The discovery of these flaws in constructivist methods are not entirely new in the context of design studios. However, neither are they new for the critics of constructivist pedagogical approaches. Many of the critics have claimed that the lack of instruction misleads and frustrates learners (Kirschner, Sweller, & Clark, 2006; Moreno, 2004). The issues of working memory and the ineffectiveness of letting students find out what is already known on their own were mentioned as crucial problems involved with minimal instructions (Kirschner et al., 2006, p. 6).

The criticism of the constructivist approach to learning in groups was also already the target of the critics. This has been an issue because of the conformism to group thinking. Consequently, there is a tendency for passivation of the students by those who are dominant in the group. This causes passive students who are not gaining enough skills and knowledge in a group endeavor to lose interest and motivation (Gupta, 2011, p. 217)

Ackerman directly addressed the problem of media and technological absence in the constructivist understanding of learning. Accordingly, constructivism in the Piagetian view oversees central contextual factors in learning environments, including educational resources, integrating media into learning environments and practices, learners' individual preferences, and individual thinking (Ackermann, 2001, pp. 7-10). This criticism suggests that constructivist approaches focus mainly on cognitive factors, ignoring other contributing environmental and technological factors.

Instructionism as well as constructivism considers learning as cognitive processes rather than learners' relations to their physical and, therefore, material and technological environment. Constructionism, even though it underlines the necessity of human engagement with the physical environment through making, still considers artefacts as representations of abstractions that happen in the minds of learners. In the relationalist view, these propositions are problematic as they isolate learners from socio-technological and material contexts, and they assume the knowledge content as an imperative in teaching practices.

Returning back to the knowledge gap, the challenge of teaching with media reflects in these different approaches in different ways. In instructionism, media might be used as a means of transferring declarative knowledge in curriculum-centered education. Here, the power of media can be used for visual and audio transfer through PowerPoint presentations, educational movies, interactive boards, and quiz software, as examples. Instructionism in the context of skills related to media promotes tool-centric education where procedural knowledge takes primacy, which is especially remarkable in vocational education. Constructivists might see the media as an opportunity for scaling up cooperation. In that case, media can be used for collaborating online through different software programs and can engage learners in social learning through negotiations of meaning. In constructivism, the use of artefacts is for creating a common understanding among learners through “boundary objects” (Akkerman & Bakker, 2011), where universal ideas come to take on a local meaning in a community of practice. Constructionists see media as “objects of representation” or “objects to think with” (Papert, 1980, p. 11). For them, media is significant if it can allow learners to make products. Making is a necessary step for internalizing processes and ideas gained by making. Finally, from a relational perspective, media are material, technological, or cultural artefacts through which humans relate to their environment (Ihde & Malafouris, 2019). Learning can be explained as a result of learners’ ability to adapt to and change the environment through these artefacts, and human learning is seen as the result of bodily experiences in this process.

To conclude, it seems that media have a role to play in each of the discussed approaches to learning. Further, it seems that each of these approaches to learning has a role in certain learning situations. Constructivism, constructionism, and even instructive behavioral approaches can be beneficial in confined classroom situations where the focus is only on theory or practice and designed for answering a defined set of questions by the curriculum. Relational and postphenomenological approaches, on the other hand, are therefore beneficial in free and open learning and bring an ecological and “learning-at-work”-related perspective to educational science.

5.1.3. Ethical issues in technology-mediated learning

This relationalist perspective, however, brings into focus ethical questions about using technological media. Namely, technology amplifies human intentionality, so the actions based on mistaken premises can yield irreparable consequences. This issue becomes even more pronounced in ethical concerns in technology-mediated learning, which is a substantive and polarizing topic in the philosophy of technology. It is not my intention to discuss different viewpoints of this topic in the discussion section, especially as they capture issues of power and resistance, and inevitably lead to a discussion about capitalism. This is particularly visible in autonomist Marxist and Foucauldian perspectives. I would instead rather focus on the evolution of Dewey’s view on empowering individuals to take action. Here, the views from critical technological theory and social-technological science of Andrew Feenberg (2017) can be of use, but especially the postphenomenological mediational ideas put forth by Peter Paul Verbeek (2006).

In this perspective, inventing technologies is part of what being a human is. Humans are the outcome of the technologies they create. Therefore, rejecting or embracing technology is a false dilemma. Instead, the question should be what kind of technology-mediated subjects do we want to be, or how and in what direction do we want technology to take us. Ethical issues are not about humans or technologies in themselves, but human–technology associations (Verbeek, 2011). This is why mediated learning, which happens in the process of conception and reception, is so important to research and will be further discussed in the next section.

In Verbeek's (2011) view, subjects are constrained or produced by relations of power of which some are mediated by technologies. However, human subjects are not determined by their technological mediations, and they do have the ability to rearticulate their technology-mediated subjectivity (2011, p. 66). Out of this idea that mediation is not necessarily determined by a script comes the criticism towards technocracy. Namely, to avoid technocratic solutions, user involvement is necessary. In this user involvement, the democratic process should determine what technology users find of value and what they perceive a good life should be when mediated by technologies (Verbeek, 2011, pp. 89-121). In this way, subjects shaping their technical environments become an alternative form of democratization.

It could be, therefore, possible to describe technological affordances or scripts on one hand and technological multistability and potentiality on the other as opposites in making ethical decisions when using technologies. It is the role of pedagogy to enable learners to activate their ethical sense and change their field composition, as well as abandon technologies when necessary. Further, it is their responsibility to design technologies with ethical affordances and scripts, delegating ethics to technological artefacts (Verbeek, 2006). Ethical issues are therefore critical in both the conception and reception phases of the design process, meaning equally in designing and using technology.

Ethics in the context of technology-mediated learning demands critical reflection and, moreover, diffractive practice. In the constructivist perspective on learning, critical reflection is an essential step in the learning process. Schön and Mezirow especially singled out critical reflection as a crucial moment in which learners overcome the situation in which they find themselves. For Schön, a learner is a reflective practitioner who performs a routine practice and reframes problems when meeting indeterminate zones of practice (D. A. Schön, 1985, p. 25). Schön explained that learning happens through reflection and action. A reflective practitioner reflects in practice and on practice. Reflection in action is a process in which a practitioner reframes problems through metaphorical thinking (D. Schön, 1993, pp. 155-159).

Reflection on action is referred to as a form of metacognition that happens in reframing the understanding on one's own practice.

Mezirow went a step further and borrowed the concept of critical reflection directly from Habermas to explain how a person finds a way to cope with facts that do not fit their worldviews or "habits of mind" (Kitchenham, 2008, pp. 105,106). Mezirow argued that a person is transformed through the process that starts with a disorienting dilemma that sparks critical reflection (Kitchenham, 2008, p. 105). A learner consequently learns new skills and finds the way to incorporate new perspectives in the process of reintegration. This searching for new ways of being with the world happens in the communicative and instrumental domains. In the communicative domain, a transformative learner discusses and reflects on her experience, and in the instrumental domain, she learns new skills and masters new habits of mind through new "tools."

Critical reflection, however, is a metaphor that describes the ability to think over, reconsider certain ideas, and change action. Operating in quantum relationalist ontology and new materialism, Karen Barad provided a new metaphor which breaks the cyclic processes of reflection and action. Just as reflection, diffraction is taken from the realm of physics as a metaphor. Reflection as a metaphor for inquiry can be explained as a mirroring of reality that relies on extracting objective representations from the world and then acting upon them (Barad, 2007). In contrast, diffraction happens when the small particles of light encountering an obstacle or opening start bending and spreading waves. Diffraction as a result, as a metaphor for inquiry, signifies embracing difference and being receptive to patterns of interference and the outcomes of difference-making practices. For Barad, a practitioner should be an agential realist who understands that what she sees is not something external and preexisting, but something relational. To support this, Barad cites Brom's experiment which demonstrated that light sometimes behaves as a particle and other times as a wave, depending on the material configuration of the experiment. The reality is therefore neither socially constructed nor relative; it is rather in continuous reconstitution through material entanglements. Barad coined this phenomenon as *intra-action* which, by contrast to inter-action, involves the "mutual constitution of entangled agencies" (Barad, 2007, p. 33) where complex material practices assemble in particular ways to produce specific phenomena.

To conclude, technology-mediated learning in a relational sense is therefore very unlikely without individual, group, and community or organization actors in a technological and material environment. Awareness of our own technology-mediated agency is crucial for the ethical handling of learning and being. Further, user involvement, delegating ethical affordances to artefacts, and one's own diffractive practice should be crucial for ethical technology-mediated learning. User involvement in designing technologies is essential for this process, which also reveals issues in makerspace practices. Namely, user involvement or awareness about ethical issues around technological mediation in conception and reception of technological and material design is not explicitly expressed in makerspace practice. Thus, the design studio clearly demonstrates what the role of formal education in technology-mediated learning should be because it puts the user in the center and takes inclusion as the core of its practice. Finally, this ecological way of understanding knowledge and learning have much more effective and practical effects in terms of sustainability and, therefore, human resilience.

5.2. Implications for design theory, design practice, and design education

The ecological view on learning in this dissertation is based on Ihde's philosophy of technology. Through the lens of postphenomenology, learning in here is understood as human adaptation to its environment by changing itself and the environment. This can be explained through postphenomenological concepts of human–technology mediation. Designing is therefore intrinsically connected to human learning. As described earlier, Ihde explained through postphenomenology how humans relate to their environment through technology (Ihde & Malafouris, 2019). Human experiences and intentionalities are mediated by technological affordances. The focus here is on the way that humans change their actions as their intentions become augmented and contemplated by technologies. Technologies that were created by humans are now changing how humans do things and ultimately what it means to be a human through different human–technology configurations.

Learning is therefore not evidenced only by changes in behavior as proposed by psychologists but also in concrete social and material rearrangements. The human-technology relationship, therefore, is one of learning and designing, which is mirrored in the processes of conception and reception of technological artefacts. Conception and reception are processes of technology-mediated learning, namely, adoption, adaptation, and attainment. However, the outcomes are different: as for the conception, the outcome is a new technology or technological artefact, while for reception it is augmented action. Just as, for example, the motherboard transistor is a technology that allows personal computers and software development, so is the conception of new technologies dependent on human mediation with existing technologies. In that way, it can be claimed that technologies and humans relate for further conception and advancement of new technologies. The very concept of learning in postphenomenological terms can be seen as the human ability to adapt to socio-material conditions and designing as conceiving and rearranging material and, therefore, the social environment. The ability of humans to manipulate their environment in a sustainable way signifies their resilience. The implications of this perspective on design and learning can be potentially noteworthy for design studio education and practice. Namely, the design discipline is in need of new philosophical and theoretical outlooks. There are two reasons for this: first, because of its accelerating expansion into other fields which are characterized by technological changes and issues pertaining to sustainability and second, because of the deficiency in its academic rigor in order to be acceptable to other disciplines in a scientific manner.

5.2.1. The evolving design discipline

To explain how this relationalist postphenomenological perspective can give new insights into design discipline, let us return to the very introduction of this dissertation. In Section 1.1.2, I describe the reasons for researching emerging technologies in the context of design studio. Here, the current developments in design as a discipline have been presented. That is, design has been in expansion over last three decades and has been moving away from product generation and towards the generalist methodology of solving complex problems. Design is not characterized anymore by the industry in which it is used, but by the design processes and knowledge gained through these processes. Design discipline, therefore, embodies different directions within the design profession itself as well as multiple additional professional fields (Sanders & Stappers, 2008, p. 11).

There is a need for this development to be reflected in design education itself. The design theoretician Findeli (2001) summarized these issues in a very systematic way and called for reconsideration about the basis on which design education is developed. He criticized determinism and instrumental reason as well as the central role of economic factors in design. He claimed that this reflects in the way design topics are established. User factors are merely concerned with ergonomics and cognitive psychology as well as there being an overemphasis on material product. Aesthetics are concerned only with shapes and material qualities, while ethics are based on the culture of business contracts and agreements. For Findeli, this model is part of historical development of design discipline, which is connected to the vision of material progress (Findeli, 2001, p. 6).

He proceeded to explain that, today, design needs to turn towards understanding the complex interplay and relationships that happen between interrelated subsystems that happen in user, social, and technological environments, the complexities of which a designer has to become familiar with. Further, Findeli proposed that this approach is necessary because of the very dematerialization of design (Findeli, 2001, p. 15). Accordingly, the vanishing product and shifting to services will characterize the future of design in accordance with the sustainability imperative. I agree with this disposition in general and add that change in design education is necessary to accommodate this development. I will comment later on this to clarify my position, but for now, let us move to the other point about limitations of design studio pedagogy: the lack of academic rigor.

5.2.2. Limitations of design studio pedagogy

Thus far, I have argued that permanent technological changes demand open, free, and practical learning. I have further argued that the design studio and makerspace, as examples, are where these kinds of learning practices do happen in formal and informal education, respectively. The issues emerge when these learning practices are to be applied in other educational settings and fields. The makerspace movement originated in formal education, generating many examples where individual teachers clearly have seen its potential and are taking it upon themselves to use these approaches in STEM fields (Barton, Tan, & Greenberg, 2016; Saorín et al., 2017). There is also an understanding by individual institutions that makerspaces can spark ownership of the process of learning among students; therefore, they are opening makerspace labs under their own roofs. However, there is no major official attempt to apply the design studio model as a pedagogical approach to other academic disciplines, even though this has been discussed (Mor & Mogilevsky, 2013; Salama & Wilkinson, 2007).

The reason for the lack of this initiative was outlined by Schön (2003). He elaborated on how the design studio approach to education creates a split between design studio practitioners and other professionals as well as others in academia. The design studio takes upon itself to solve problems with a wide range of aspects and parameters which are dynamic and interchangeable (Buchanan, 1992, pp. 14,15) and provide a contextual solution, not a general truth. This inductive process collides with a positivistic abductive process, which starts with a hypothesis which focuses on specific variables of the problem (Wang, 2010, p. 175). Schön explained that the knowledge coming from an abductive process has rigor, it is factual and robust, but it also lacks relevance for a practitioner in the actual problem-solving process (D. A. Schön, 1985, p. 15). The reliability and scientific rigor of abductive processes, which are not necessarily represented in design studio education, cause a lack of respect for this pedagogical approach in academic and professional education communities, according to the design researcher Wang (2010, pp. 173,174).

There are ways out of this dilemma. For example, one is to see design as a scientific method, just like in design science, which can then incorporate more isolated research questions and quantitative approaches. The other is to see design as an emerging property of a system. In that case, design is not a predetermined methodology that can be applied to a problem in order to solve it (Wang, 2010, pp. 178-181). Here, we should once more return to Findeli (2001, p. 10) who suggested that problem-solving is characterized by the positivist paradigm, and that the design discipline should be seen as a situated change of existing systems through implementation of design competencies. Scientific inquiry in this case is carried-into, instead of applied-to the field of the design project and of practice. This is how he described the change of perspectives:

The most widely-accepted (and practiced) logical structure of the design process is, therefore, the following: 1 A need, or problem, is identified: situation A; 2 A final goal, or solution, is imagined and described: situation B; and 3 The act of design is the **causal link** by which situation A is transformed into situation B.

A new logical structure of the design process is: 1 Instead of a problem, we have: state A of the system; 2 Instead of a solution, we have: state B of the system; and 3 The designer and the user are part of the system (stakeholders). (2001, p. 9)

In this approach as Findeli concluded, Schön's concept of "reflection-in action" stops being only a methodology and is moved into the epistemological realm. Hence, Findeli explained that in the process of affecting systems, a designer or client cannot act upon a system, only within a system. In order to do that, the learning plays a critical role. He continued by explaining the notion that a designer learns the relationships, dynamics, and patterns inside the system. Clients, users, and designers together through a certain set of values transform themselves and the system. The state B is accordingly transitory, not a permanent state of the system that can be called "solution."

While design science research analyzes the effects of the design, the gap between problem definition and generation of solutions in design is explained through systems theory in another way. Complex systems are bigger than their parts and are self-organizing. This means that systems interpret the information within themselves and project "emergent properties" that could not have been predicted from the component parts (Meadows, 2008, pp. 13-17). These emergent properties then change the behavior of the system and are generated by the interactives of the system. In that sense, complexity theory is focused on explaining the relations as an internal dynamic of the system, not objects, and is limited to a study of processes, not products (Portugali, 1996; 2006, pp. 651-652). This means that design is an outcome of an accumulated knowledge and ongoing dialogue among the stakeholders in the system. This approach is demonstrated in research through the methodology of participatory design (Asaro, 2000).

5.2.3. Design studio as a conventional pedagogical approach

This dissertation contributes valuable insights in this ongoing discussion in the design discipline and design education. First, it provides nuance to the above discussed proposals for a shift in the design paradigm, and second, it offers practical guidance in implementing this new paradigm. In addition, through this contribution to the discussion, I have proposed a mode in which design studio can be seen as a conventional pedagogical approach. This approach can be more acceptable for fields other than those of architecture and design.

Systems theory allows for genuine explanations of the issues we deal with in design discipline today, especially in its focus on democratization through participatory processes. However, I would recommend some caution when renouncing materiality of human experience in our attempts at understanding design. Bringing postphenomenology and relationalism into the design discourse leads us to reconsider the notion that the vanishing product in design necessarily likewise means dematerialization. In fact, the vanishing product could make services more complex, demanding more understanding of technological mediations and material entanglements that enact human relations through these services. As we rely more on algorithms to conduct complex human relations and transactions, technological mediations through material means will become more invisible, but ever more present in the future service systems. Further, I would also be cautious in prescribing various systems theories as the only means of conducting the design process. Systems theories are varied and somewhat incoherent in their approach as they differ ontologically. When applied in natural sciences systems, theories rely on realism where the system is defined by a closed loop, which secures the scientific feedback (Laszlo & Clark, 1972). In the social sciences, it is perspectivism which is dominant in systems theories where the boundaries are not clearly defined but rather constructed. This means that the constitution of the system is rather the perspective of the observer (Midgley, 2000, p. 35) This ontological position, especially in social sciences, is problematic as it ascribes a totalistic and organizational view to the design situation. It is therefore difficult to take advantage of the systems theories and to apply them in the field for stakeholders who are not seeing the whole picture but are rather part of that same picture. In this situation, Findeli (2001) himself recommended a phenomenological, qualitative approach as best to understand the systems within (Findeli, 2001, p. 12).

However, relationalism through for example postphenomenology and material engagement theory (Ihde & Malafouris, 2019) can provide the vocabulary and personal perspective for stakeholders to relate to their environment in the design situation. Through understanding and rearranging these relationships, designers can grasp the complexity and enact change in a more systemic way. To illustrate this, I will refer to Rosenberger's (2014a) study of the bench "against" homeless people. Rosenberger brought to light the material properties or technological affordances of the bench. This bench had extra hand rests separating the bench, therefore not allowing its usage for lying, only sitting. By way of analysis, this artefact is technological, but also cultural as it symbolizes attitude and perspective. A designer at first could reconsider how the relationship between the homeless and the city management is mediated by the bench. However, we can take the project even further by mapping where in the city these benches appear and look at the habits and other meaningful artefacts that mediate the relationship between the homeless and their city. By analyzing relationships and how they are mediated, a designer gains phenomenological, experiential, and bodily knowledge of a complex landscape. Out of this, a designer is better able to provide and test ideas for improved mediations between the city and its homeless. Through these insights, a designer can also provide consultancy for the city management eventually enabling more systematic changes.

Similarly, in the fifth article (Pavel et al., 2020), I showed how the mediation of technological artefacts can function in a design studio setting. In this study, a designer was part of a newly created environment where the rehabilitation center with its therapists and designers designed customized and personalized assistive technologies. Through this process of augmenting user abilities to accomplish their daily routinized tasks, the designers gained firsthand phenomenological understanding about the situation. They were compelled to provide a socially acceptable yet technical solution for mediating artefacts that were suitable for manifold stakeholders, such as patients, their caregivers, and therapists. Learning happened through the conception and reception of their designs, and the very scientific inquiry became a part of everyday practice as students tried to evaluate the impact they made in their design situation. Through this phenomenological approach, the designers became part of their environment and eventually made an impact not only on the technological solutions but also on the system in how are the services for the patients were organized.

The relationalist view in design demands a more externally interconnected design studio. It requires design education to enable access to the field where the design process can happen. This is challenging, as it is difficult to secure the time and engagement of stakeholders. For educating relationalist learners, it is necessary to have more a fluid and interconnected society where the boundaries between institutions are less strict and where cooperation is commonplace.

Relationalism in design reminds us that stakeholders participating in design process are part of the environment they inhabit, whether it is natural, material, or technological. It strips away the abstractions that appear in the complexity of design topics of today, and it promotes design as a generalist discipline. In this generalist view, it is difficult to split ideation and investigation or conception and reception. It gives primacy to authentic phenomenological and participatory inquiry instead of to the recycling of declarative knowledge and assumptions through post-it notes and infographics. It focuses on critical and diffractive practices with design media, which is possible only through a hands-on approach. This is contrary to the current practices where the very process of making is outsourced to technicians. For example, in many design schools, digital models are designed by students, while 3D printing is done by workshop staff.

5.2.4. A relational researcher pedagogue

The relationalist approach also changes the role of a pedagogue. Returning to the introduction of this dissertation, the main topic of the emerging makerspace is the democratization of information and tools due to technological development. The main characteristic of this way of learning is substituting peer learning for the pedagogue. Contrary to this, the design studio setting often characterized by a master–apprentice relationship. Schön, in his work “Design Studio: An Exploration of Its Traditions and Potential” described this:

> With distant origins in the apprenticeship of the medieval guilds and more recent origins in the Ècole des Beaux-Arts of the late 19th and early 20th centuries, architectural studios are prototypes of individual and collective learning by doing under the guidance and criticism of master practitioner (Schön, 1985, p. 6).

Similarly, today, design studio masters are those that connect the community of design practice and newcomer practitioners (M. M. Tovey, 2015). Design studio has been used for over the hundred-year long tradition to educate designers and architects. Even though the topics in the studio have changed and branched out, there is no substantial change in the apprenticeship pedagogical model.

Besides the obvious issues of power balance, the critique pointed out that design learners might fall into the trap of copying a masters' approach to the design process (Glasser, 2000, pp. 251,252). This is a direct danger to the core competence of design. Further, this very personal master–apprentice relationship generates risks for the design process mastery and exploration of the possible new topics of design. As both knowledge about the process and design topics come from the masters' own experience, certain processes and methods can become arbitrary. In educational action research, contrary to this, the idea is that "teachers' practices should not be opaque or private and must be made the subject of systematic, documented research and development" (Hiim, 2015, p. 151). This power position of a design studio pedagogue can be questioned by both critical and pragmatic epistemologies (Hiim, 2015). In this study, the critical epistemology outlined the democratic capacities of a pedagogue to sustain critical discourse and inquiry as well as questioning current practices in the design studio. The pragmatic one outlined the ability of a design pedagogue to spot problematic concepts in everyday teaching practice and facilitate an experimentation process in order to improve them.

In today's design studio, pedagogues can be either design practitioners or academic staff. Both roles are challenging for the relationship with design learners and for the diversifying competencies the design studio should provide. Practitioner–pedagogues are skilled in practicing design, but in fields or topics and in media that can become obsolete and further block the transdisciplinary character of design studio education. Academic – pedagogues, on the other hand, are knowledgeable about design practice and topics. However, as time passes, they become more qualified as researchers of design discipline or phenomena than as practitioners of design activity.

Relationalism changes the role of a pedagogue in the design studio because the pedagogical or design situation is not constructed by the pedagogue. Thus, the feedback for learners is not coming from the master–practitioner but from the unpredictable interplay of social, technological, and material factors that constitute the design situation. The instruction does not come from the master–practitioner either but emerges through participatory processes that are enacted by design learners themselves. Still, the role of pedagogue is more important than before, but now in facilitating learners' resilience. This can be done by supporting learners' perseverance through complex inquiry, teaching them to suspend judgment and engage in diffractive practice, and by insisting on multi-vocality of ideas and designs. In this way, formal education ensures inclusivity of different kinds of learners and relevance of knowledge and skills for society, without putting the pedagogue in the position of power. These important characteristics of education are something that makerspaces are not providing. Furthermore, and most importantly, this kind of education provides exercising awareness of one's own agency and responsibility which is also not a central question in makerspaces.

In the relational approach, a pedagogue is part of the study environment. The pedagogue therefore has to be a researcher because only then is their ethical position justifiable. Namely, the pedagogues' own practice depends on critical discourse and inquiry, as well as on spotting problematic concepts and experimentation, which are happening in the design situation. Thus, research occurs on many levels such as in the very practice of designing, in the practice of teaching, and in the practice of stakeholders involved in learning situations.

The relationalist approach to teaching and learning also brings outstanding ethical challenges in a pedagogical situation. Unlike PowerPoint teaching, for example, where most of the aspects of pedagogical situation are predefined, the relational approach raises the issue of managing the expectations of participants. In the last two articles, these issues became pressing. In the fifth article (Pavel et al., 2020), the ethical issue was managing the expectations and privacy of the patients. We held a discussion about ethics with the students and therapists to ensure that the students understood how to conduct interviews with patients. We were also explicit that the students would deliver prototypes of which some would be functional, and some would need further adjustments, possibly by other student groups. However, we were also explicit that students had the right to fail, delivering prototypes that were not usable. The benefit in this project was not only in the delivered assistive technology prototype but also in the learning process that the staff and the patients had. Yet, the most important benefit of this project for the patients was in the way assistive technologies reframed the understanding of their capabilities in their material environment, thus giving them some form of empowerment.

It is questionable to what extent the patient involvement was justified in this case. If we take into consideration the ideological perspective of relationalist learning and the benefits for the society, this approach was certainly justifiable. This was because it is necessary that we as educators have to teach design where conception and reception are explicit to all stakeholders involved, rather than through PowerPoint presentations or imaginary projects. By doing this, we can ensure that the generations of students are prepared for meeting real-life challenges after they finish their education. However, from deontological and teleological perspectives (Macdonald & Beck-Dudley, 1994, p. 616), ethical issues in this research study seemed to be more complex. From the deontological ethical perspective where the judging of the nature of action is right or wrong regardless of consequences, this is justifiable because the intention is to provide customized functioning prototypes to the patients. From teleological ethical theory perspective where the downsides and upsides for patients are measured, it can be justifiable to a certain extent. I would say to the extent at which we are sure we can provide functional prototypes to our patients.

In the fourth article (Pavel, in review) the issues emerged as the research was part of the educational setting, making the courses uneven in quality and treating student groups differently from one year to the next one. Here, I was guided by the principles described by Stephen Kemmis (2006). This research was aimed to critically assess current dominant practices; it was done independently of governmental policies and programs; it included voices of participants and described their copings with the program rather than only focusing on professional ones; and it was done in wider cooperation with stakeholders at the Department of Product Design. Finally, this research was intended to address wider topics than only the immediate ones of that particular classroom. The research examined the existing issue of unattainable pedagogical instructions. This was tackled by introducing free learning in one course early in the curriculum, but also challenging the constructivist conventions in design studio education. Issues of unattainable instruction are neither new or unknown in either design studio or constructivist pedagogy, as discussed both in the article and in the previous section. It was therefore not clear that the first student group was placed in a disadvantaged situation for the benefit of the coming generations. The benefit of using this approach was that the students had a chance to develop independence early in their design studies, which they should have benefitted from throughout their studies and careers.

The relationalist approach therefore required stern ethical evaluations as it often involves many parties. In many cases, some form of negotiation will be needed to decide the optimal outcome for those involved. Design pedagogy should be able to accommodate these demands in different design situations. Furthermore, it should be considered that the affordances and prohibitions of the media could also present ethical challenges.

5.3. The way forward: possible implications for teaching practices and curricula

Aside from these demands on design pedagogy, technology-based curricula pose contradictory demands on education in general. On one hand, there is a need for more specialized curricula as the technology becomes complex. This also means perpetual refreshing of the curricula as its content becomes obsolete rapidly. On the other hand, there is a demand for autonomous employees who can think critically, but their general competence might be of higher priority. There is a massive enrolment of students in higher education that demands insurance of better quality in the programs. Yet, at the same time, lower fees are demanded to accommodate all the enrolling students. This often leads to more automation by online systems, such as massive open online courses. These are efficient in spreading declarative knowledge but not optimal for hands-on learning, which is often necessary in technological education. To add to the confusion, the alarming reports about under-utilization of highly qualified skills have put into question ambitious educational programs as described by Bol (2015, pp. 116,117). These issues can be resolved by de-abstraction of knowledge and skills and relying on them to be learned through concrete work and learning situations concerning actual socio-technological environments.

For many educational programs, the existing and emerging online systems are optimal for good educational practices. These systems provide reduced pedagogue involvement, while relying more on videos, online tests, and even training through virtual reality programs. In the instructionist pedagogical paradigm, this way of educating seems to fill most of the needs of both learners and educators. However, to teach a generalist resilient learner a different approach is needed. These learners must be able to participate in and assess situations, extract what is of importance for the given situation, formulate steps of actions to change it, and then follow them up and modify them as they go. Presently, education relies on the content of the curriculum, a classroom with its physical limitations, and the pedagogy based on the construction of knowledge in learners’ minds to achieve this. For a true open and free learning, it is necessary that education provide human–technology assemblages that will provide context to any meaningful learning.

Even when this learning is still finding its place in the right environment, different wording in curricula could be beneficial. These new ways of expressing intended learning outcomes might enable educators to discuss their curricular activities in open and free modes. Instead of describing knowledge and skills by the curriculum demands in an abstract way, they could be described in relation to the social and technological environment where they take place. It would therefore be beneficial to describe learning outcomes in a relational way to better connect the theory and learning outcomes to the context of learning. A relational description should include the roles learners take and the learning settings that describe their socio-technological environment.

Following is an example of the changed course for the second-year master's studies program in product design at Oslo Metropolitan University, which matches European qualification level seven. The differences enacted are both in content and form. In content, it has demonstrated a shift from a deterministic economic view on design, as criticized by Findeli (2001, p. 6), towards a more sustainable and system aware approach. Further, the form of the description has substantially shifted from theoretical academic approach towards a relational one, which is more relatable to learners' immediate experience of reality and gives a better idea of their role in it. The descriptions have changed while keeping the same academic content and literature.

The purpose of this chapter is to illustrate, rather than demonstrate how the relationalist approach to learning can change perspective and the language used in the curriculum and through that potentially give educators a different vocabulary on knowledge and learning when discussing open and free learning activities. The following course descriptions therefore are an illustration of how the presented theoretical approach can be used for course planning and description to better match learning outcomes with the reality of designing and working with technologies. The change in formal curricula is a cultural, political and above all administrative process that involves many stakeholders (Goodlad, 1979, p. 61) which is neither the topic nor the enterprise of this dissertation. The dissertation instead focuses on changes in perspective on learning in light of emerging technologies, which may give different fallout in situations where open and free learning takes place, and as a consequence possibly curricula. This description therefore is not a finished and negotiated document where all the actors in the curriculum design have had their say so that it can be turned into a formal curriculum. Further research and more comprehensive effort with many stakeholders would be needed to assess the feasibility of this perspective for a different kind of curriculum. That said, the next two subsections describe the original and the modified course description of the course Technology and Design for Health.

5.3.1. *Existing description of the course "Technology and Design for Health"*

In the current course , the focus is on design in innovation with the following introduction: innovation does not necessarily proceed linearly from basic scientific research to product development; it is an iterative process of both matching market needs to technological capabilities and conducting research to fill gaps in knowledge, whether during product conception, product engineering, manufacturing, marketing, or other phases of the innovation process. The course explores how design can be strategically used as merging the abovementioned factors for commercialization of the new technologies.

Learning outcomes are described in terms of knowledge, skills, and general competence.

Knowledge is described as the students' capability of using design theory and methods concerning user experience and user engagement to commercialize new coming technologies; handling transdisciplinary processes in order to utilize new coming technologies for user experiences, products and services; and analyzing market viability of products and services concepts for commercialization of newly developing technologies. Skills are described as the students' capability of facilitating and running multidisciplinary design projects within the area of technology and design; linking various fields of technology to entrepreneurship and innovation; and linking theory and methods attained in the specialization courses, to various fields of technology. General competence is described as students' capability of discussing ethical sides of technology and implementing technology in new contexts.

The content of the course is described in these terms: reading and workshops that handle the relationships among design, innovation, research and technology; artificial (autonomous) intelligence; discussions concerning ethical situations that emerge by the application of technology and artificial intelligence as part of design; engagement and user experience facilitated by technology in products and services; and methods that comprise innovation and technology. Teaching and learning methods include a combination of lectures, workshops, and teamwork and a combination of theory and practice (activities related to the subject matter). The course includes presentations by student groups. The course includes no extra requirements.

Student learning and progression was assessed in this way: The evaluation is based on two parts, each contributing 50% of the final grade: 1) Written assignment: As part of the turn-in, the students will turn in text individually or in groups that discusses ethical views about design and technology; 2) Group work presentations of self-initiated work with roots in the curriculum. Both examinations 1. and 2. must be passed in the same semester in order to pass the course. Part 1) The exam result can be appealed; Part 2) The exam result cannot be appealed. There are no restrictions in permitted exam materials. The student work is assessed on a grading scale: A grading scale of A (highest) to F (lowest,) where A to E is a passing grade, and F is a failing grade. One internal examiner assesses the first part of the exam. Two internal examiners are used regularly to assess the second part of the exam.

5.3.2. Relationalist description of the course "Technology and Design for Health"

The proposal for the changed introduction to the course should include following text: Technologies play a distinctive role in everyday lives, but also in the history of human development and culture. Human relations with technologies are multifaceted and comprise the meaning-making process, which can lead to adoption of new technologies and therefore innovation or abandonment and substitution. This process is not necessarily linear from scientific invention and design conception to distinctive product reception by users and markets. This iterative process is characterized by ethical, ecological, and material engineering issues, but above all, by the imprint on human behavior in the way that technologies augment or prohibit human intentions and the role and effect they have in complex systems. The course explores how design can be strategically used as a merging of the abovementioned factors for commercialization of the emerging technologies.

The knowledge gained is described as verbs and in terms of their relation to the environment. Therefore, the course should qualify students to identify, observe, classify human–technology relations; anticipate and assess technological impact on human behavior; discern key technological, social, and operational issues in design; and plan and conduct design process that include technological and human factors. Skills are described as the students' capabilities of using facilities in 3D printing and virtual reality labs; demonstrating human–technology relations through prototypes; and leading participatory workshops within a community or organization. Responsibility and autonomy should be introduced instead of general competence and should be described as for what a student can independently do: evaluate the ethical and ecological impact of technologies and propose solutions; implement technologies in new contexts; and propose systemic answers for a predicament which achieve sustainable practices with technologies.

The content of the course including the literature is kept the same as follows: reading and workshops that handle the relationships among design, innovation, research, and technology; artificial (autonomous) intelligence; discussions concerning ethical situations that emerge by the application of technology and artificial intelligence as part of design; engagement and user experience facilitated by technology in products and services; and methods that comprise innovation and technology.

Teaching and learning methods include a combination of fieldwork, workshops in teamwork, and debates, and a combination of theory and practice (activities related to the subject matter). The course includes presentations by student groups. The course includes no extra requirements.

The assessment procedure is changed so as to present practical work as the final demonstration of learning, while declarative knowledge is considered as a means of coming to a practical solution. The evaluation is based on two parts, the first being a course requirement for the exam. The course requirement is in the form of a written assignment: as part of the turn-in, each student will turn in a text that discusses ethical views about design and technology. The examination requires practical work, which consists of group or individual prototype demonstrations and testing results. There are no restrictions in exam materials and equipment. Grading is done on a scale: A grading scale with A (highest) to F (lowest) where A to E is a passing grade, and F is a failing grade. One internal examiner will assess the written assignment. Two internal examiners are used regularly for the final exam.

5.3.3. Possible benefits of the relationalist perspective on curriculum

The changed descriptions are written according to the guidelines of the Norwegian agency under the Ministry of Education and Research (NOKUT, 2017). These guidelines were written in compliance with the national framework which again follows the guidelines by European qualification framework established through the Bologna Convention (Declaration, 1999). I have chosen a course description in higher education because there is a need to illustrate how relationalist and more systemic approaches can be described in an existing European qualifications framework (EuropeanCommission, 2018) as practical educational implications of the findings.

This particular course was chosen to be modified in accordance with the relational approaches to learning, as it is exemplary because of the topic and form. Its topic concerns technology so the new knowledge derived from this study is then operationalized in the content of the modified course plan. Further, the form of the course should fit second-year master's studies of level seven in the European qualification framework. This level demands that the courses deliver to the students specialized problem-solving, innovative approaches, and handling new situations, which is the topic of this dissertation and is best suited for the relationalist approach due to the capability level expected from a master's student.

The proposed description of the course and, consequently, the program plan potentiate tangible artefacts, human material or technological relations, and relations among stakeholders in the course. This contrasts with the previous course description where declarative knowledge seemed to dominate learning outcomes. In this way, the course description connects infrastructure, stakeholders, research, and technology. It also gives more transparency and provides a better framework for all the stakeholders to achieve tangible outcomes of the course because the learning will have material or technological outcomes with its ramifications for the learning network.

One of the benefits of describing courses and learning outcomes in this way is that it offers a more coherent overview of what the course provides to all stakeholders. This kind of coherence integrates all the aspects of the guidelines provided by NOKUT in a better way. As the outcomes are tangible and ramifications observable, the relevance for business and society becomes obvious as demanded by NOKUT (2017, p. 9). The focus shifts from abstract descriptions of knowledge and skills and is directed towards actionable contextualized objectives, such as delivering functional prototypes and writing academic texts, instead of just presentations and reports. The balance between individual and group work and practical tasks becomes more explicit and applicable (NOKUT, 2017, p. 10). The role of infrastructure in learning is outlined in the learning goals, which ensures that new technologies and media will be put into use and applied in real-world situations (NOKUT, 2017, p. 11). Further, the students are prepared to have an active role as the main enactors of change in human–technology constellations in the network in which they participate. In order to do that in the controlled way, they have to rely on the academic community and its research methods (NOKUT, 2017, p. 12). This, in itself, makes tasks and pedagogical instructions attainable for students as they can relate it to the real subjects in their network. Further, it commits the academic staff to connect to businesses and society and puts learning, infrastructure, and stakeholders into daily practice, which enables transdisciplinary exchange of knowledge. This removes dualism of expert practice vs. academic theoretical knowledge satisfying demands posed by NOKUT for relevant practice placements (2017, p. 15).

5.4. Contributions

The dissertation makes the following contributions:

- Introduces a new postphenomenological perspective on learning in design and making
- Deepens and further develops relationalist understanding in design theory and design pedagogy.
- Provides new perspectives on open and free learning and sustainable pedagogical practices.
- Provides new explanations about media as a factor in design.
- Illustrates the effect of the relationalist approach on curriculum design.

The dissertation contributes to a set of novel concepts in teaching and learning with emerging technology-based media. These concepts are grounded in a postphenomenological approach in design and making. To provide these concepts, the use of technological media in learning settings was reassesed. Research in this dissertation therefore no longer addresses the effectiveness of learning by the means of media. Instead, it considers how media influences choices learners make in their learning environments as media becomes multistable, but also how to learn for redundancy and introduction of new media. These novel concepts are the result of re-contextualization of the use of the new media. Thus, the new framework for learning arises from postphenomenological concepts and can be described through the processes of adoption, adaptation, attainment, and abandonment. This framework can assist and strengthen free learning and sustainable teaching practices.

This study has exposed the contradictions in the existing constructivist approach to learning in designing and making. It proposes an alternative approach that relies on relationalist ontology and postphenomenology. By adopting this perspective, it allows for a better understanding about the role of technology and media, which is not appropriately addressed in constructivist theory, at the same time providing an alternative explanation to constructionism.

Throughout the last two articles (Pavel, in review; Pavel at. al, 2020), the study demonstrated the feasibility and utility of the postphenomenological approach in design studio education and pedagogy. Based on these studies, in this dissertation, I have introduced novel vocabulary for discussing issues in design studio pedagogy and free learning. These concepts provide a better understanding about the role of media in learning and creative processes in design studio pedagogy. It highlights the socio-technological dimensions of learning, leading to less confusion for learners and more egalitarian design studio.

This approach can also have concrete outcomes in the way education is planned through curricula and organized through networks of teaching and research practice. The implementation of the findings described here in curriculum design, however, will require further research and modification by other actors and influences.

Further research is needed to evaluate the suitability of the described approaches to other situations with open and free learning using emerging technologies. These settings might be in STEM or art education and may include technologies such as virtual reality or machine learning. Further practical and theoretical pedagogical development is needed to evaluate the possibilities of free learning using emerging technologies for different levels of education such as primary and secondary. In these lower educational settings, the proposed perspective may be of use in workshop based learning with multiple stakeholders. Consequently, further research is needed to assess the feasibility of the approach for curriculum development. The new perspectives presented in this dissertation might also have implications for commercial design practice and further research is necessary for exploring these avenues of practice.

6. References

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Appendix 1- Literature review scanning and skimming procedures

Scanning process

ITERATION 1 – *Goal: defining the concepts in the field*

(“emerging technologies” OR “3D print*” OR “additive manufacturing”) AND (“learning” OR “pedagogy” OR “education”) AND (“design*” OR “design studio”)

- Sources-results: Google Scholar-17,400, Teacher Research Center TRC-57, Education source- 849; and ERIC via Ebsco host- 384.
- Date: 05.12.19

ITERATION 2 – *Goal: Defining predicament for the dissertation; this search also includes the type of intervention concepts that are of interest for the research concepts.*

(”3D print*”OR “additive manufacturing” OR “emerging technologies”) AND (“education” OR “learning” OR ”pedagogy”) AND (“design*” OR ”design studio”) AND (“knowledge work” OR “obsolescence of skills”)

- Sources-results: Google Scholar-2,240, Teacher Research Center TRC-0, Education source- 11; and ERIC via Ebsco host- 7.
- Date: 05.12.19

ITERATION 3 – *Testing the concepts intended for the development of the dissertation:*

(”3D print*” OR “additive manufacturing”) AND (“design media” OR “learning media”) AND (learning OR pedagogy OR education) AND (resilience OR “sustainable education”)

- Sources-results: Google Scholar-11, Teacher Research Center TRC-0, Education source- 0; and ERIC via Ebsco host- 0.
- Date: 05.12.19

Skimming process

Inclusion/exclusion and selection protocol for all iterations:

A. Selection by search:

1. Only journal articles and book chapters are included. Proceedings, presentations, and reports are excluded, as they are not likely to provide pivotal or central theoretical arguments.
2. Both theoretical and empirical articles and book chapters are included.
3. The review includes non-English language articles and book chapters.

B. Selection by title:

4. The articles that do not address design as a discipline, designing as an activity of the participants, planning of design activities of participants, or design studio are excluded. This is because design as an expression emerges in multiple of textual contexts, for example, as "research design" or "instructional design."

C. Selection by abstract:

5. Articles that do not propose or develop theoretical or pedagogical approach are excluded. In addition, step 4 is repeated when necessary.

Theoretical perspectives by appearance per abstract in NVivo:

60 constructivist theoretical approaches: Problem-based learning 12; Authentic learning and teaching 10; Inquiry, discovery-based learning and learning through experimentation 10; Experiential learning 9; Constructivism and critical reflection 6; Maker-based learning 6; Constructionism 3; Transformative learning 3; and Active learning 1.

Behaviorism 14

Skill acquisition 1

Game theory and gamification 13

Cognitivism 6

Connectivism and networked learning 6

Activity theory 1

Perception theory 1

Key concepts by the number of codes in NVivo:

Social engagement and collaboration 19; Technology-based pedagogical approaches 16 and prototyping 5 (21); Self-efficacy and autonomy 9 and self-direction 4 (13); Learning for creativity, innovation, imagination (12); Imagineering, design-fiction, story-telling (4); Motivation 12; Media and technology literacy 10; Open learning 6, Cultural aspects 5; Lifelong learning 4; Deep learning 3; Apposite pedagogic action 1.

3D printing

Theoretical perspectives: experiential, authentic (2), deep learning (1), materials to develop with/internalization (1), constructionism (1), learning by making (1), tutorials (behaviorism) (1).

Key concepts: prototyping (3), collaboration, motivation (1), apposite pedagogic action (1), creativity (1).

Additive manufacturing: effective education (1), creative processes (1), lifelong learning (1).

Rationale/implications: efficacy (28), integration of technologies into curriculum (23), methods and theory development (18), quality of education (17), change in pedagogical practice (9), student satisfaction (4), merging theory and practice (3), better course management (3).

Appendix 2- Case study protocols

Case study protocols are instruments for data collection (Robert K Yin, 2017, p. 93). Accordingly, case study protocols are increasing validity and reliability of the study by allowing the public to scrutinize the process of research in the light of presented results. They are used in both single and multiple case studies to secure even methodological collection of data in the field. The structure of the case study protocols should inform the public about both objectives, collection procedures but also the structure of the case study report (Robert K Yin, 2017, pp. 93-95).

Further, Yin (p.94) recommends that a case study protocol includes four sections, A, B, Cand D. These sections should give an overview and clarification about the sources of the empirical data, and the relationship between evidence and theory, including the internal logic. Yin suggests that in section A an overview of the case study is presented, including objectives, issues and key literature. In Section B are the data collection procedures should be described, such as sources of data, key participants and stakeholders, selection of participants and logistics. In section C are the level two protocol questions should be listed. The level two relates to Yin's model of five levels of protocol question orientations (Yin, 2017, p. 100).

Yin (p.100) explains that questions in the protocol have different orientations in order to give a holistic picture of the study. Listing these different questions should allow a researcher to plan and clarify research agenda. To do that the related sources of evidence should be listed together with these questions. In level one questions are verbalized to be posed to specific participants such as in interviews and questionnaires. In level two, questions are posed to researcher self in order to guide the inquiry in the field. They represent the line of inquiry in the specific case study. Level two questions are important because they are posed to. At level three is the explanation of the strategy for identifying patterns of findings from multiple cases. Level four include the questions for the case study, based on the current literature and facts. The Level five includes normative questions such as policy recommendations beyond the specific study.

Case Study Protocol for the article: How designers learn: objects of representation as means of knowledge transfer

Protocol topics	Content description	-Date, outline
Section A. Overview of the case study		
Mission and goals of the researcher	There is a need to study how do human, procedural and media factors influence the process of information exchange among the participants, learning and consequently design conception. This is an important issue because meetings where ideas are created, and important decisions are made can be influenced by the media used on these meetings. Media can present the information in such a way so that certain issues are perceived with importance and feasibility of certain ideas are increased. In this way media amplifies certain conversations and diminishes the others. Moreover, as media become an everyday professional tool for designers, the design education has to take this media usage as the part of the learning and pedagogical strategy.	
Stakeholders	Student participants and workshop organizer - researcher are the key stakeholders in this research. However, this research is meant to feed into the PhD project sponsored by the faculty of Technology, Art and Design by Oslo Metropolitan University and the Department for Product Design. The PhD project is a part of OsloMet's 2024 strategy, which is concerned with technology, welfare and organizational topics. Similarly, the department for product design is	Nenad Pavel, Student participants, Gunnar.H. Gundersen-head of the department

	concerned with use of media in design process, especially with the use of emerging technologies.	
Case Study questions and propositions	The premise for this study was that the medium could lead towards different discussions among participants and different experience of designing. The research strives to understand underlying principles behind this phenomenon and give a framework that can allow for better organization and steering of these meetings.	Research Question: "How can designers facilitate the choice and transfer of knowledge for problem solving in a teamwork context?"
Theoretical framework	Because learning by the means of objects was the key topic, Papert's constructionism (Papert, 1980) and the concept of the objects of representation (Stary & Stary, 2013) was chosen as a theoretical perspective to study the phenomenon. Workshop based research (Ørngreen & Levinsen, 2017) should allow for a controlled but unrestricted manifestation of the phenomenon of learning by using objects of representation. The general methodology of case study (Robert K Yin, 2017) is used to structure the phenomenon through the units of analysis.	
Role of the protocol for the inquiry	The protocol gives a framework for workshop procedure and interview of the participants. Further, it secures equal treatment of the two groups of participants.	

Section B. Data collection procedures

Preparation for the field work	Literature review including theoretical background for the study and workshop research methodologies	09-10.2016

	Personal recruitment of student participants through the class representative.	09-10.2016
	Reserving a room and acquiring materials from the department workshop	19.10.2016
Data collection plan	*Workshop procedure* 1. Preparation 12.00-12.10. Welcome participants and present the minutes of workshop. 12.10-12.25. Introduce the task and encourage questions. 2. Workshop 12.25-12.45 Information exchange- how can task be described from the designers' point of view? Who are stakeholders? Who owns a problem of the 'problematic child'? What are the ethical issues around the case? 12.45-13.00 Break 13.00=13.15 *only for the pinboard group) Introducing the pinboard method. 13.00- 13.45 Designing- development of potential solutions, pin-pointing interests of the stakeholders and possible interventions 13.45- 14.00 Break 3. Presentation 14.00-14.10. Let students present their concepts without guidance or constraints 4. Interview 14.10-14.20 Allow for free discussion and reflection on the experience students had-take notes 14.20-14.45 Group interview-focus on the process and experience of learning and designing- take notes	09-10.2016

	5. Learning through reflection 14.45-15.00 What is learned? How concept mapping can be used in future projects? How can representations be used in the projects that students are involved in	
Data material	Pictures of students using objects of representation – 60 chronological pictures	25.10.2016
	Sound recordings of participant discussions – 70 minutes	
	Notes from the participant observation	
	Notes from the group interview	
Data analysis	Personal notes transcript	11.10.2016
	Audio transcript of the workshop	11.2016
	Coding the topics in NVivo	11-12.2016
	Confirming the validity of the case study report with participants	24.01.2017
Section C. Protocol questions		25.10.2016
	Instruction: How did students understand the task? What was not understood?	To obtain by interviews
	Learning: How did the students learn from each other? What do they think they learned from each other? What was the process in detail-what were the steps of the process?	To obtain by interviews, sound recordings and picture series
	Design process: How did they plan their design process? How did the ideas emerge?	To obtain by interviews, picture series and participant observations
	Medium pin-board/whiteboard: How did they used the board, in what ways? How do they think they used it? How did it help them, or interfered designing their concepts?	To obtain by pictures, interviews, sound recordings, participant observations

	What are the biggest challenges with the board?	
	Impressions: What do participants criticize? How would they prefer to do their workshop? What was the biggest challenge in conducting the assigned tasks? How satisfied are they with own learning and achievements of the workshop? How satisfied are they with the solutions they generated?	To obtain through interviews

Section D. Outline of the case study report through the topics

Key Topics	-Addressing the issues in communication in design teams from previous research -Chronology of the workshop – material and experiential outcomes -Conceptual development of objects of representation -Explanation on how material artefacts influence learning and designing in this case - Implications of finding on pedagogics and workshop design
Description	This case study explores the designing and learning as a phenomenon that emerges among participants in meetings and discussions. Instead of identifying this phenomenon as a result of communication, the study focuses on the medium used to share knowledge among participants. According to previous studies issues in design projects emerge as design learners are far more concerned with the development of their concepts, rather than sharing what they know so that the concept can be formed from that. Moreover, as

design problems are becoming more complex and problem aspects turn unpredictable, designers' main responsibilities are shifting towards the facilitation of analytical processes. Case study the phenomenon of knowledge exchange and design conception emerging from it by the means of media.
The research is situated in a three- hour workshop with design students who are already experienced with this kind of creative processes. Data is obtained through interviews, participant observations, pictures and sound recordings. The case study relies on constructionism, and the concept of the objects of representation to explain the influence on content and focus of the designing process. Finally, the implications are discussed through the prism of interdisciplinary collaboration and application in design projects. The recommendations for management of the design meetings is given in the form of vectors for rich learning.

Case study protocol for the article: Multistable technologies and pedagogy for resilience: A postphenomenological case study of learning by 3D printing.

Protocol topics	Content description	Date, outline
Section A. Overview of the case study		
Mission and goals of the researcher	There is a need to study how the novel, uncharted socio-technological assemblages establish learning and designing practices and how do participants accommodate to this new environment. The goal of this case study is to reveal how do humans and machines come together to build these new practices. The aim is to explain this phenomenon through the underlying principles of human technology co-evolution and mediation.	
Stakeholders	This research is meant to feed into the PhD project sponsored by the faculty of Technology, Art and Design by Oslo Metropolitan University and the Department for Product Design. The PhD project is a part of OsloMet's 2024 strategy, which is concerned with technology, welfare and organizational topics. Similarly, the department for product design is concerned with use of media in design process, especially with the use of emerging technologies such as 3D printing. Finally, and most importantly, this project is part of the funding provided by the Norwegian board for internationalization and quality development in higher education. The study is funded through the UTFORSK project which is focused on	- Norwegian and Brazilian students, - Researchers: Nenad Pavel, Fausto Orsi Medola, - SORRI rehabilitation center: Claudia Rodrigues, Juliana Antoniucci - Project leader: Gunnar H. Gundersen, - Project manager: Frode Eika Sandnes

	Norwegian economic cooperation and strengthening quality education with Brazil, China, Russia, India, South Africa and Japan.	
Case Study questions and propositions	The proposition of the study is that the participants will be able to establish new practices and human technology relations that will be sustainable to certain extent. The aim of the study is to discover how does this happen and how sustainable are these practices.	Research question: How can human-technology mediation facilitate resilient learning?
Theoretical framework	The case study (Robert K Yin, 2017) tracks human – technology mediations (Verbeek, 2015) as units of analysis to draw conclusions about the principles of the new learning practices. The units of analysis rely on postphenomenological concepts introduced by different postphenomenological philosophers and researchers (Ihde, 1990; Kiran, 2012; Rosenberger, 2014a)	
Role of the protocol for the inquiry	The protocol is generated to secure the evenness and quality of data throughout the numerous meetings and discussions. The protocols are designed so that the participants can have equal say throughout the data collection and give a feedback on the results of the study report.	

Section B. Data collection procedures

Field work contact persons	Fausto Orsi Medola	
Preparation for the field work	The preparation included series of iterations with the contact person as well as the practical and theoretical preparations	
	Literature review	11.2016-01.2020
	Sending an application for research in own practice to the Norwegian Center for Research data NSD through an internet page. See in Appendix 3.	26.01.2017

	Confirmation Response from Norwegian Center for Research data NSD	17.03.2017
	Setting up the course description in cooperation with Fausto Orsi Medola: **INCLUSIVE DESIGN - INTENSIVE COURSE PROGRAM** **TEAM: Fausto Orsi Medola (UNESP), Nenad Pavel (HiOA), Ana Claudia Rodrigues (SORRI), Juliana Antoniucci (SORRI).** **DATES: April 23 – May 17.** **LOCATION: Room 78, FAAC/UNESP, Bauru.** **OBJECTIVES:** At the end of the course, the students must be able to comprehend the relations between Design, Disability, Functionality and Accessibility. The practical knowledge and skills will be acquired by means of the analysis of the difficulties that people with physical, cognitive and sensorial impairment experience during the interaction with several products and environments in daily routine, in order to develop design solution proposals in the context of inclusive design. Still, it is expected that the students understand the relations between the concepts and applications in Inclusive Design, Universal Design and principles of feasible design proposals in Assistive Technologies. **CONTENT** - Inclusive Design: Concept and Applications - Disabilities: characteristics and demand of Physical, Sensorial and Cognitive Disabilities. - Global challenges for an inclusive society - Design for the ageing society - Rehabilitation Technology	01-04.2018

- Universal Design
- Rapid prototyping of Assistive Technologies
- Accessibility
- User-centered design for subjects with disabilities
- Empathy empowering the inclusive design process

METHODOLOGY

The course comprises theoretical classes, practical activities and seminars with discussions on the main topics covered by the course. Final projects will be developed by groups of students and presented by the group at the end of the course.

CRITERIA

Students' grade will be based on their participation in the course's classes and activities, as well as the seminars and the projects developed in groups.

EXAMINATION

- oral presentation through demonstration of prototypes

BIBLIOGRAPHY

BRYDEN, D. CAD and Rapid Prototyping for Product Design (Portfolio Skills). Laurence King Publishing, 2014, 176p.

COLEMAN, R.; CLARKSON, J.; CASSIM, J. Design for Inclusivity: a Practical Guide to Accessible, Innovative and User-Centered Design. CRC Press. 2016, 268p.

COLEMAN, R. et al. What is inclusive design? Disponível em: http://www.inclusivedesigntoolkit.com/betterdesign2/whatis/whatis.html

NORMAN, D. A. The design of everyday things. London: Mit-Press, 1999. 257p. NORWEGIAN

	DESIGN COUNCIL. Innovating with People: The Business of Inclusive Design., 2010, 96 p. COMMISSION FOR ARCHITECTURE AND THE BUILT ENVIRONMENT. The principles of Inclusive Design. 2006. 20p. Available at: https://www.designcouncil.org.uk/resources/guide/principles-inclusive-design	
	Sending an Application for funding by the UTFORSK project to the project manager Frode Eika Sandnes	15.01.2018
	Confirmation by Frode Eika Sandnes	18.01.2018
	Ordering tickets to and residence at Bauru, Brazil	31.01-01.02.2018
	Setting up the course program in cooperation with Fausto Orsi Medola: **INCLUSIVE DESIGN PROGRAM** Week Date Topic / Content Observations April 24 Introduction: Inclusive Design: Concepts and Applications; Fausto/Nenad April 25 Disability and Rehabilitation (SORRI); SORRI April 26 Empathy: empowering the inclusive design process; Ergonomics Lab team May 02 VIsit to SORRI; SORRI May 03 Project Development: User's assessment (SORRI) - Manter esta data SORRI May 04 Project Development: Concept Development **(initial design brief);** Fausto/Nenad May 07 Rapid Prototyping Nenad May 08 Project Development: Concept Development; Fausto/Nenad May 09 Presentation 01 – Design Proposals- **(revised design brief);** Fausto/Nenad/SORRI	02-04.2018

May 10 Project Development – Prototyping;
Fausto/Nenad
May 14 Project Development – Prototyping;
Fausto/Nenad
May 15 Project Development – Prototyping;
Fausto/Nenad
May 16 Project Development – Prototype Testing;
Fausto/Nenad/SORRI
May 17 **- Final Presentation**
-Course feedback and evaluation
- **Group Report** delivery A4, pdf, max.1GB;
Fausto/Nenad/SORRI

DELIVERY THROUGHOUT THE PROJECT:
Design brief (no more than one A4 sheet) which describes:
- Intention of the project
- Research question
- Scope of the project (which activities are planned to be done)

After revision previous points should be revised and these points should be added:
- Key insights from the field (SORRI)
- key product aspects and their specifications

Final presentation should include:
- Final prototype that demonstrates functioning principle of the product
- Mockups developed throughout the project to show the process
- Screen presentation - 15 minutes presentation, 10 minutes discussion

Group Report should include developed points from the design brief and very short description of the

	process activities. Document should not have more than 15 pages and should be delivered in the form of pdf format, A4. You can create the document in the software of your choice. Tips: Use more photos, renderings and sketches, keep descriptions minimal and factual (what did you want to achieve? what have you done to achieve it? what happened?). Proposal for the structure of the report: - Intention of the project - Research question - Design process activities and their outcomes (testing included) - Key insights from the field (SORRI) - Key product aspects and their specifications	
Data collection plan	Data including ca. 170 pictures, sound recordings personal notes and student reports and reflection notes are collected through numerous discussions with students and therapists and prototypes testing throughout the period of the four weeks of the assistive technologies course.	23.04-17.05.2018
	Personal notes collected from visiting SORRI and first ***meeting with patients***. Personal notes from discussion about user needs and potential solutions with students	02-03.05.2018
	Personal notes and pictures collected from the ***initial meetings with student groups*** discussing the design concepts and the progression of the first mockups at UNESP	03-08.05.2018
	Sound recordings and personal notes from the ***student presentation of concepts*** about their concept development at UNESP. Recordings include questions posed to students about their project and process.	04.05.2018

	Personal notes and pictures collected from scheduled ***meetings with student groups***, discussing 3D printed prototypes with the student groups and functionality of prototypes at UNESP	10-15.05.2018
	Personal notes and pictures collected from ***prototype testing with patients and therapists*** at SORRI	16.05.2018
	Sound recordings, personal notes and power point slides from the final presentation with students at UNESP. Recordings include questions posed to students about their project and process.	17.05.2018
	Student ***project report*** and ***student reflection notes*** on the course. Documents collected electronically	17-19.05.2018
Data analysis	Personal notes transcript	05-06.2018
	Presentation audio transcript	05.06.2018
	Coding the topics in NVivo	
	Confirming the validity of the case study report with participants via email	20.11.2018

Section C. Protocol questions

	Project planning: What do students ask about the project and their tasks? What were the topics emerging in their questions? How did they plan their projects? What are the similarities and differences?	- Initial meeting with student groups - Presentation of concepts - Reflection notes
	Mockups and 3D printing: How did students planned to 3D print by using mockups? How did they approach 3D printing? Which software did they use, how did they use it? What is their experience of 3D printing? In which contexts do they address 3D printers and 3D printing? What were the biggest challenges with 3D printers? What is observable? What they experience as the most frustrating? Do the initial and 3D printed prototypes	- Initial meeting with student groups - Presentation of concepts - Meetings with student groups - Project report -Reflection notes

	differ from mockups? How do they differ? What are the possible explanations for this?	
	Process and collaboration in groups: What was the creation and collaboration process in detail? What were the steps of the process? How do they create ideas? How do people, media and other circumstances form these ideas? How did they select ideas to be prototyped? Which factors influence this?	- Initial meeting with student groups - Presentation of concepts - Project report - Reflection notes
	Cooperation with the patients and SORRI staff: How do patients react to prototypes? What are the consequences for patients after being introduced to these prototypes? What are the biggest issues with prototypes? Is there any pattern with these issues? How do therapist influence conversation and prototypes? How insightful they are about patients and the testing situation?	- Meeting with patients - Prototype testing with patients and therapists - Final student presentation - Project report - Reflection notes
	Course and learning experience: What do students criticize about the course arrangement? What kind of arrangement they think would be better? What do students perceive as the most important learning in the course? How satisfied are students with own learning and achievements throughout the course? How satisfied are they with the 3D printed prototypes they generated? What did the students experience as the biggest challenge in the course?	- Initial meeting with student groups - Meetings with student groups - Final student presentation - Project report - Reflection notes

Section D. Outline of the case study report through the topics

Key Topics	- Introduction to the phenomenon of the research: disruptive learning environment and technological mediation. - Introduction to the units of analysis, consequently postphenomenological concepts

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

	account learners' relations with their social and technological environment.

Appendix 3- Application for ethical handling of data

Copies of the documents starting from the next page are arranged as fallowing: Application to Norwegian Center for Research (NSD), Approval bill from NSD, Request for participation in the study.

MELDESKJEMA

Meldeskjema (versjon 1.6) for forsknings- og studentprosjekt som medfører meldeplikt eller konsesjonsplikt
(jf. personopplysningsloven og helseregisterloven med forskrifter).

1. Intro

Samles det inn direkte personidentifiserende opplysninger?	Ja ○ Nei ●	En person vil være direkte identifiserbar via navn, personnummer, eller andre personentydige kjennetegn. Les mer om hva personopplysninger er. NB! Selv om opplysningene skal anonymiseres i oppgave/rapport, må det krysses av dersom det skal innhentes/registreres personidentifiserende opplysninger i forbindelse med prosjektet. Les mer om hva behandling av personopplysninger innebærer.
Hvis ja, hvilke?	□ Navn □ 11-sifret fødselsnummer □ Adresse □ E-post □ Telefonnummer □ Annet	
Annet, spesifiser hvilke		
Samles det inn bakgrunnsopplysninger som kan identifisere enkeltpersoner (indirekte personidentifiserende opplysninger)?	Ja ○ Nei ●	En person vil være indirekte identifiserbar dersom det er mulig å identifisere vedkommende gjennom bakgrunnsopplysninger som for eksempel bostedskommune eller arbeidsplass/skole kombinert med opplysninger som alder, kjønn, yrke, diagnose, etc. NB! For at stemme skal regnes som personidentifiserende, må denne bli registrert i kombinasjon med andre opplysninger, slik at personer kan gjenkjennes.
Hvis ja, hvilke		
Skal det registreres personopplysninger (direkte/indirekte/via IP-/epost adresse, etc) ved hjelp av nettbaserte spørreskjema?	Ja ○ Nei ●	Les mer om nettbaserte spørreskjema.
Blir det registrert personopplysninger på digitale bilde- eller videoopptak?	Ja ● Nei ○	Bilde/videoopptak av ansikter vil regnes som personidentifiserende.
Søkes det vurdering fra REK om hvorvidt prosjektet er omfattet av helseforskningsloven?	Ja ○ Nei ●	NB! Dersom REK (Regional Komité for medisinsk og helsefaglig forskningsetikk) har vurdert prosjektet som helseforskning, er det ikke nødvendig å sende inn meldeskjema til personvernombudet (NB! Gjelder ikke prosjekter som skal benytte data fra pseudonyme helseregistre). Les mer. Dersom tilbakemelding fra REK ikke foreligger, anbefaler vi at du avventer videre utfylling til svar fra REK foreligger.

2. Prosjekttittel

Prosjekttittel	Design and Technology Competence in Additive Manufacturing (Design media as tool for learning design process)	Oppgi prosjektets tittel. NB! Dette kan ikke være «Masteroppgave» eller liknende, navnet må beskrive prosjektets innhold.

3. Behandlingsansvarlig institusjon

Institusjon	Høgskolen i Oslo og Akershus	Velg den institusjonen du er tilknyttet. Alle nivå må oppgis. Ved studentprosjekt er det studentens tilknytning som er avgjørende. Dersom institusjonen ikke finnes på listen, har den ikke avtale med NSD som personvernombud. Vennligst ta kontakt med institusjonen. Les mer om behandlingsansvarlig institusjon.
Avdeling/Fakultet	Fakultet for teknologi, kunst og design	
Institutt	Institutt for produktdesign	

4. Daglig ansvarlig (forsker, veileder, stipendiat)

Fornavn	Nenad	Før opp navnet på den som har det daglige ansvaret for prosjektet. Veileder er vanligvis daglig ansvarlig ved studentprosjekt. Les mer om daglig ansvarlig. Daglig ansvarlig og student må i utgangspunktet være tilknyttet samme institusjon. Dersom studenten har ekstern veileder, kan biveileder eller fagansvarlig ved studiestedet stå som daglig ansvarlig. Arbeidssted må være tilknyttet behandlingsansvarlig institusjon, f.eks. underavdeling, institutt etc. NB! Det er viktig at du oppgir en e-postadresse som brukes aktivt. Vennligst gi oss beskjed dersom den endres.
Etternavn	Pavel	
Stilling	stipendiat	
Telefon	[redacted]	
Mobil		
E-post	[redacted]	
Alternativ e-post	[redacted]	

Arbeidssted	Institutt for produktdesign	
Adresse (arb.)	Kunnskapsveien 55	
Postnr./sted (arb.sted)	2007 Kjeller	
5. Student (master, bachelor)		
Studentprosjekt	Ja ○ Nei ●	Dersom det er flere studenter som samarbeider om et prosjekt, skal det velges en kontaktperson som føres opp her. Øvrige studenter kan føres opp under pkt 10.
6. Formålet med prosjektet		
Formål	A study of acquiring design competence through use of additive manufacturing technologies in the context of design studio at department of product design HiOA. The design studio is becoming a place to go when generating products, systems, or services. However, designers are not only developing products but design media as well. As the design problems are getting more complex, the design research process needs material media to mediate this knowledge. How can the practice of additive manufacturing contribute to acquiring design competence?	Redegjør kort for prosjektets formål, problemstilling, forskningsspørsmål e.l.
7. Hvilke personer skal det innhentes personopplysninger om (utvalg)?		
Kryss av for utvalg	□ Barnehagebarn □ Skoleelever □ Pasienter □ Brukere/klienter/kunder □ Ansatte □ Barnevernsbarn □ Lærere □ Helsepersonell □ Asylsøkere ■ Andre	Les mer om forskjellige forskningstematikker og utvalg.
Beskriv utvalg/deltakere	studenter KUL2016/17, institutt for produktdesign, Høgskolen i Oslo og Akershus	Med utvalg menes dem som deltar i undersøkelsen eller dem det innhentes opplysninger om.
Rekruttering/trekking	Studenter er tilbudt deltagelse i forskningsprosjektet muntlig og gjennom avtale.	Beskriv hvordan utvalget trekkes eller rekrutteres og oppgi hvem som foretar den. Et utvalg kan rekrutteres gjennom f.eks. en bedrift, skole, idrettsmiljø eller eget nettverk, eller trekkes fra registre som f.eks. Folkeregisteret, SSB-registre, pasientregistre.
Førstegangskontakt	kontakt med utvalget blir oprettet av forkser selv	Beskriv hvordan førsstegangskontakten opprettes og oppgi hvem som foretar den. Les mer om førstegagskontakt og forskjellige utvalg på våre temasider.
Alder på utvalget	□ Barn (0-15 år) □ Ungdom (16-17 år) ■ Voksne (over 18 år)	Les om forskning som involverer barn på våre nettsider.
Omtrentlig antall personer som inngår i utvalget	opp til 45 personer	
Samles det inn sensitive personopplysninger?	Ja ○ Nei ●	Les mer om sensitive opplysninger.
Hvis ja, hvilke?	□ Rasemessig eller etnisk bakgrunn, eller politisk, filosofisk eller religiøs oppfatning □ At en person har vært mistenkt, siktet, tiltalt eller dømt for en straffbar handling □ Helseforhold □ Seksuelle forhold □ Medlemskap i fagforeninger	
Inkluderes det myndige personer med redusert eller manglende samtykkekompetanse?	Ja ○ Nei ●	Les mer om pasienter, brukere og personer med redusert eller manglende samtykkekompetanse.
Samles det inn personopplysninger om personer som selv ikke deltar (tredjepersoner)?	Ja ○ Nei ●	Med opplysninger om tredjeperson menes opplysninger som kan identifisere personer (direkte eller indirekte) som ikke inngår i utvalget. Eksempler på tredjeperson er kollega, elev, klient, familiemedlem, som identifiseres i datamaterialet. Les mer.
8. Metode for innsamling av personopplysninger		

Kryss av for hvilke datainnsamlingsmetoder og datakilder som vil benyttes	□ Papirbasert spørreskjema □ Elektronisk spørreskjema ■ Personlig intervju ■ Gruppeintervju ■ Observasjon ■ Deltakende observasjon □ Blogg/sosiale medier/internett □ Psykologiske/pedagogiske tester □ Medisinske undersøkelser/tester □ Journaldata (medisinske journaler)	Personopplysninger kan innhentes direkte fra den registrerte f.eks. gjennom spørreskjema,intervju, tester, og/eller ulike journaler (f.eks. elevmapper, NAV, PPT, sykehus) og/eller registre (f.eks.Statistisk sentralbyrå, sentrale helseregistre). NB! Dersom personopplysninger innhentes fra forskjellige personer (utvalg) og med forskjellige metoder, må dette spesifiseres i kommentar-boksen. Husk også å legge ved relevante vedlegg til alle utvalgs-gruppene og metodene som skal benyttes. Les mer om registerstudier. Dersom du skal anvende registerdata, må variabelliste lastes opp under pkt. 15 Les mer om forskningsmetoder.
	□ Registerdata	
	□ Annen innsamlingsmetode	
Tilleggsopplysninger	Lydopptak med godkjent utstyr for innsamling av intervjudata (kryptert) Ikke med bruk av mobiltelefon.	
9. Informasjon og samtykke		
Oppgi hvordan utvalget/deltakerne informeres	■ Skriftlig ■ Muntlig □ Informeres ikke	Dersom utvalget ikke skal informeres om behandlingen av personopplysninger må det begrunnes. Les mer.Vennligst send inn mal for skriftlig eller muntlig informasjon til deltakerne sammen med meldeskjema. Last ned en veiledende mal her. Les om krav til informasjon og samtykke. NB! Vedlegg lastes opp til sist i meldeskjemaet, se punkt 15 Vedlegg.
Samtykker utvalget til deltakelse?	● Ja ○ Nei ○ Flere utvalg, ikke samtykke fra alle	For at et samtykke til deltakelse i forskning skal være gyldig, må det være frivillig, uttrykkelig og informert. Samtykke kan gis skriftlig, muntlig eller gjennom en aktiv handling. For eksempel vil et besvart spørreskjema være å regne som et aktivt samtykke. Dersom det ikke skal innhentes samtykke, må det begrunnes. Les mer.
10. Informasjonssikkerhet		
Hvordan registreres og oppbevares personopplysningene?	□ På server i virksomhetens nettverk □ Fysisk isolert PC tilhørende virksomheten (dvs. ingen tilknytning til andre datamaskiner eller nettverk, interne eller eksterne) □ Datamaskin i nettverkssystem tilknyttet Internett tilhørende virksomheten □ Privat datamaskin □ Videoopptak/fotografi ■ Lydopptak □ Notater/papir □ Mobile lagringsenheter (bærbar datamaskin, minnepenn, minnekort, cd, ekstern harddisk, mobiltelefon) ■ Annen registreringsmetode	Merk av for hvilke hjelpemidler som benyttes for registrering og analyse av opplysninger. Sett flere kryss dersom opplysningene registreres på flere måter. Med «virksomhet» menes her behandlingsansvarlig institusjon. NB! Som hovedregel bør data som inneholder personopplysninger lagres på behandlingsansvarlig sin forskningsserver. Lagring på andre medier - som privat pc, mobiltelefon, minnepinne, server på annet arbeidssted - er mindre sikkert, og må derfor begrunnes. Slik lagring må avklares med behandlingsansvarlig institusjon, og personopplysningene bør krypteres.
Annen registreringsmetode beskriv	Fotografier av omgivelser, ikke deltagere	
Hvordan er datamaterialet beskyttet mot at uvedkommende får innsyn?	Krypterte filer lagret på forskeren datamaskin. Maskinen er passordbeskyttet i henhold til Høgskolens krav.	Er f.eks. datamaskintilgangen beskyttet med brukernavn og passord, står datamaskinen i et låsbart rom, og hvordan sikres bærbare enheter, utskrifter og opptak?
Samles opplysningene inn/behandles av en databehandler (ekstern aktør)?	Ja ○ Nei ●	Dersom det benyttes eksterne til helt eller delvis å behandle personopplysninger, f.eks. Questback, transkriberingsassistent eller tolk, er dette å betrakte som en databehandler. Slike oppdrag må kontraktsreguleres.
Hvis ja, hvilken		

Overføres personopplysninger ved hjelp av e-post/Internett?	Ja ○ Nei ●	F.eks. ved overføring av data til samarbeidspartner, databehandler mm.
Hvis ja, beskriv?		Dersom personopplysninger skal sendes via internett, bør de krypteres tilstrekkelig. Vi anbefaler ikke lagring av personopplysninger på nettskytjenester. Bruk av nettskytjenester må avklares med behandlingsansvarlig institusjon. Dersom nettskytjeneste benyttes, skal det inngås skriftlig databehandleravtale med leverandøren av tjenesten. Les mer.
Skal andre personer enn daglig ansvarlig/student ha tilgang til datamaterialet med personopplysninger?	Ja ○ Nei ●	
Hvis ja, hvem (oppgi navn og arbeidssted)?		
Utleveres/deles personopplysninger med andre institusjoner eller land?	● Nei ○ Andre institusjoner ○ Institusjoner i andre land	F.eks. ved nasjonale samarbeidsprosjekter der personopplysninger utveksles eller ved internasjonale samarbeidsprosjekter der personopplysninger utveksles.
11. Vurdering/godkjenning fra andre instanser		
Søkes det om dispensasjon fra taushetsplikten for å få tilgang til data?	Ja ○ Nei ●	For å få tilgang til taushetsbelagte opplysninger fra f.eks. NAV, PPT, sykehus, må det søkes om dispensasjon fra taushetsplikten. Dispensasjon søkes vanligvis fra aktuelt departement.
Hvis ja, hvilke		
Søkes det godkjenning fra andre instanser?	Ja ○ Nei ●	I noen forskningsprosjekter kan det være nødvendig å søke flere tillatelser. Søkes det f.eks. om tilgang til data fra en registereier? Søkes det om tillatelse til forskning i en virksomhet eller en skole? Les mer om andre godkjenninger.
Hvis ja, hvilken		
12. Periode for behandling av personopplysninger		
Prosjektstart Planlagt dato for prosjektslutt	27.02.2017 15.04.2021	Prosjektstart Vennligst oppgi tidspunktet for når kontakt med utvalget skal gjøres/datainnsamlingen starter. Prosjektslutt: Vennligst oppgi tidspunktet for når datamaterialet enten skalanonymiseres/slettes, eller arkiveres i påvente av oppfølgingsstudier eller annet.
Skal personopplysninger publiseres (direkte eller indirekte)?	□ Ja, direkte (navn e.l.) □ Ja, indirekte (identifiserende bakgrunnsopplysninger) ■ Nei, publiseres anonymt	Les mer om direkte og indirekte personidentifiserende opplysninger. NB! Dersom personopplysninger skal publiseres, må det vanligvis innhentes eksplisitt samtykke til dette fra den enkelte, og deltakere bør gis anledning til å lese gjennom og godkjenne sitater.
Hva skal skje med datamaterialet ved prosjektslutt?	■ Datamaterialet anonymiseres □ Datamaterialet oppbevares med personidentifikasjon	NB! Her menes datamaterialet, ikke publikasjon. Selv om data publiseres med personidentifikasjon skal som regel øvrig data anonymiseres.Med anonymisering menes at datamaterialet bearbeides slik at det ikke lenger er mulig å føre opplysningene tilbake til enkeltpersoner. Les mer om anonymisering av data.
13. Finansiering		
Hvordan finansieres prosjektet?	prosjektet finansieres av PhD midler	Fylles ut ved eventuell ekstern finansiering (oppdragsforskning, annet).
14. Tilleggsopplysninger		
Tilleggsopplysninger	Dette er forskning i egen profesjonsarbeid.	Dersom prosjektet er del av et prosjekt (eller skal ha data fra et prosjekt) som allerede har tilrådning fra personvernombudet og/eller konsesjon fra Datatilsynet, beskriv dette her og oppgi navn på prosjektleder, prosjekttittel og/eller prosjektnummer.
15. Vedlegg		
Vedlegg	Antall vedlegg: 2. ● intervju_Nenad PAvel.docx ● Nenad_Pavel_foresp1rsel av detagelse.doc	

Nenad Pavel
Institutt for produktdesign Høgskolen i Oslo og Akershus
Kunnskapsveien 55
2007 KJELLER

Vår dato: 17.03.2017 Vår ref: 52572 / 3 / AMS Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 27.01.2017. Meldingen gjelder prosjektet:

52572	*Design and Technology Competence in Additive Manufacturing (Design media as tool for learning design process)*
Behandlingsansvarlig	*Høgskolen i Oslo og Akershus, ved institusjonens øverste leder*
Daglig ansvarlig	*Nenad Pavel*

Personvernombudet har vurdert prosjektet og finner at behandlingen av personopplysninger er meldepliktig i henhold til personopplysningsloven § 31. Behandlingen tilfredsstiller kravene i personopplysningsloven.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 15.04.2021, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Kjersti Haugstvedt

Anne-Mette Somby

Kontaktperson: Anne-Mette Somby tlf: 55 58 24 10
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

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NSD – Norwegian Centre for Research Data NO-5007 Bergen, NORWAY Faks: +47-55 58 96 50 www.nsd.no

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 52572

Utvalget informeres skriftlig og muntlig om prosjektet og samtykker til deltakelse. Informasjonsskrivet er godt utformet.

Personvernombudet legger til grunn at forsker følger Høgskolen i Oslo og Akershus sine rutiner for datasikkerhet.

Forventet prosjektslutt er 15.04.2021. Ifølge prosjektmeldingen skal innsamlede opplysninger da anonymiseres.

Anonymisering innebærer å bearbeide datamaterialet slik at ingen enkeltpersoner kan gjenkjennes. Det gjøres ved å:
- slette direkte personopplysninger (som navn/koblingsnøkkel)
- slette/omskrive indirekte personopplysninger (identifiserende sammenstilling av bakgrunnsopplysninger som f.eks. bosted/arbeidssted, alder og kjønn)
- slette digitale lydopptak

Request for participation in the research project

Design media as learning tool

Background and purpose

The purpose of the project is to study how design practitioners (design students) adjust the use of material media (especially additive manufacturing) in their design process. How they learn about design problems through customization and what the main challenges in the process of adjusting to this technology are. The project is part of my PhD degree, practice-based research in the design teacher's profession. The PhD degree is affiliated with the Department of Product Design, Oslo and Akershus University College of Applied Sciences. The project does not involve cooperation with external actors.

The criteria for selection of design practitioners are that they do not have extensive previous experience with the use of additive manufacturing technology or the prototype-based design process. (Most interns only have experience with material-based design processes)

What does participation in the study consist of?

The participation consists of participatory observations, images of product prototypes, use of student reports, own reflections, notes, drawings, and images of surroundings in which the design process takes place (workshop and design studio). Besides, the discussions in groups around the models will be sound recorded.

What happens with the collected data?

All personal information will be treated confidentially. The collected data is stored as encrypted files on the researcher's computer. The machine is password protected according to the university college requirements. Audio recordings will be collected with approved equipment. Data is handled by the researcher himself. Participants will not be recognizable in the published study. The study shall not contain the participant's personal information or pictures. The study may contain images of virtual or physical prototypes and drawings.

Recognition may occur in cases where the student exhibits the drawing, prototype or pictures of the prototype publicly.

Data collection will start 27.02 and end on 15.04.2019. The project ends on 15.04.2021. After that, all data is anonymized and stored on an internal, protected HiOA server.

Voluntary participation

It is optional to participate in the study and you can at any time withdraw your consent without giving any reason. If you withdraw, all information about you will be anonymized.

If you wish to attend or have questions about the study, please contact Nenad Pavel, (telephone number or e mail adress).

The study has been reported to the Personnel Ombud for Forskning, NSD - Norwegian Center for Research Data AS.

Consent for participation in the study

I have received information about the study and I am willing to participate

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(Signed by project participant, date)

Article 1 - Supporting collaborative ideation through free hand sketching of 3D shapes in 2D using color

The first article "Supporting Collaborative Ideation Through Freehand Sketching of 3D-Shapes in 2D Using Colour" (Sandnes et al., 2017) examines the issue of the usability of CAD systems. The article shows how a simple change in a software code by introducing color mapping instead of gradient can allow for more intuitive use of sketching in 3D. This article contributes to the discussion about how computer graphic technologies can be used in participatory settings and possibly facilitate collaboration in groups throughout engineering and design projects. There is a need to discuss expanded utilization of these technologies; hence, the topics of the Conference on Cooperative Design, Visualization and Engineering are focusing on computer science aspects of these technologies and especially applying these technologies in new human–technology contexts.

Article 2- How designers learn: objects of representation as means of knowledge transfer

This proceeding is published in *Engineering and Product Design Education Conference 2017*, which has a focus on the issues of design and engineering education. The contribution "How Designers Learn, Objects of Representations as Means of Knowledge Transfer" (Pavel, 2017) challenges current practices in service design teaching by reintroducing artefacts in the conceptual phase of the design process. The article therefore contributes to an ongoing discussion in Engineering and Product Design Education conference about innovation of teaching practices but also design and engineering methods.

Article 3- Norway-UK comparative analysis of sustainability in design education

The contribution "Norway-UK Comparative Analysis of Sustainability in Design Education" (Pavel & Zitkus, 2018) was published as proceeding at *Engineering and Product Design Education Conference* 2018. The contributions has introduced new ideas and concepts in discussion about design curricula in sustainable education. The article also had regional significance as this international conference has its core in northern Europe. The article therefore joined the ongoing discussion on the themes of the conference related to teaching, assessment, and preparing students for a sustainable future.

Article 4 - Postphenomenological perspective on free learning with maker technologies: An action research study of 3D-printing

The article "Postphenomenological Perspective on Free Learning with Maker Technologies – An Action Research Study of 3D-Printing' (Pavel, in review) has been submitted to the Journal of *Technology, Pedagogy and Education* and is currently in reviewing process. The article is a direct answer to an ongoing discussion on the feasibility of makerspace education. In the article "Making Sense of Making: Critical Issues in the Integration of Maker Education into Schools," Godhe et al. (2019) criticized the overly optimistic attempts to introduce makerspace postulates of pedagogy to schools. They have called for an alternative approach to pedagogy that can integrate makerspace approaches outside of the narrow making setting and adjust it to the formal educational demands. The article addresses these issues by altering design studio education and introducing a relationalist approach to teaching and learning and a postphenomenological view on the learner–maker technology relationship.

Article 5 - Multistable technologies and pedagogy for resilience: A postphenomenological case study of learning by 3D printing

The last article cited in this paper, “Multistable Technologies and Pedagogy for Resilience: A Postphenomenological Case Study of Learning by 3D-Printing” (Pavel et al., 2020) was published in *Design and Technology Education: An International Journal,* 2020. This article contributes to the ongoing discussion in this journal about design teaching methodologies that include technological environments. The article especially addressed the journal’s goal of introducing new theoretical concepts to address challenges of modern design education.

Article 1

Sandnes F.E., Lianguzov Y., Rodrigues O.V., Lieng H., Medola F.O., Pavel N. (2017) Supporting Collaborative Ideation Through Freehand Sketching of 3D-Shapes in 2D Using Colour. In: Luo Y. (eds) Cooperative Design, Visualization, and Engineering. CDVE 2017. Lecture Notes in Computer Science, vol 10451. Springer, Cham. DOI: **https://doi.org/10.1007/978-3-319-66805-5_16**

[Article not attached due to copyright]

Article 2

Pavel, Nenad (2017). How designers learn: objects of representation as means of knowledge transfer. Berg, Arild; Bohemia, Erik; Buck, Lyndon; Gulden, Tore; Kovacevic, Ahmed; Pavel, Nenad (Red.). DS 88: Proceedings of E&PDE17 - 19th International Conference on Engineering and Product Design Education, Building Community: Design Education for a Sustainable Future, Oslo, Norway, 7 & 8 September 2017, s. 304-309. E&PDE. The Design Society. Web page: **HOW DESIGNERS LEARN – OBJECTS OF REPRESENTATION AS MEANS OF KNOWLEDGE TRANSFER**

THE 19TH INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
7 & 8 SEPTEMBER 2017, OSLO AND AKERSHUS UNIVERSITY COLLEGE OF APPLIED SCIENCES, NORWAY

HOW DESIGNERS LEARN – OBJECTS OF REPRESENTATION AS MEANS OF KNOWLEDGE TRANSFER

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ABSTRACT
This article focuses on design practitioner's facilitation of knowledge transfer at the boundaries of communities of practice. As design problems are becoming more complex and problem aspects turn unpredictable, designers' main responsibilities are shifting towards the facilitation of analytical processes. This paper strives to study the means of this facilitation through pedagogical constructivism. A case study about interfaces for knowledge transfer for the purpose of problem solving is presented; it obtains data through interviews and workshop observations. The case study analyses show how objects of the problem representation can influence the nature and amount of knowledge transfer, and how it can influence the solution generation process. Finally, the implications are discussed through the prism of interdisciplinary collaboration and application in design projects.

Keywords: knowledge transfer, boundaries of practice, rich learning environments

1 INTRODUCTION - KNOWLEDGE FACTOR IN PROBLEM SOLVING

Knowledge is recognized as an important factor for innovative problem solving; organizations are now focusing on both knowledge transfer and creation, resulting in a growing body of literature [1]. Knowledge transfer is "the process through which one unit (e.g., group, department, or division) is affected by the experience and knowledge of another" [2]. There is also an understanding that knowledge is difficult to transfer because it is embedded in the production of practice, embodies individual experiences [2], and has tacit properties [3]. Designers are often described as specialists in the process, rather than specific knowledge areas [4], which makes them dependent on gathering knowledge about design aspects from specialist project stakeholders or from external sources [5, 6].
As design thinking is being applied to new fields and disciplines, the design problems are becoming more complex [7]. In addition, accelerating changes in technology, culture, and markets make design problems comprehensive and design aspects unpredictable and random [8]. This moves design practice to the context of multidisciplinary teams, where complex problems are solved through activities of extensive knowledge transfer and development [9]. Since designers require knowledge transfer to conduct the design process, there is a need to research their role in that context. There is also a need to study how design competence can be used to extract and choose relevant knowledge for problem solving in these teams. Considering these aspects, the research question is: how can designers facilitate the choice and transfer of knowledge for problem solving in a teamwork context?

1.1 Combining Knowledge in a design team and on the boundaries of practice

The recurrence of knowledge transfer in design work happens internally through mental models and problem framing, but also externally through sketches, materials, physical models. These processes do not happen separately, but are entangled, while recognition occurs with practical action [6]. One challenge that designers have in practice is that opportunities for knowledge transfer are not thoroughly explored. This is partly because knowledge transfer often occurs through opportunistic and non-structured activities as well as different sources can be subjective and incomplete.

Cross addresses this problem in his study of collaboration in a design team where designers overlooked important information from the user evaluation report by being too eager to frame the problem [10]. Further in the study he notices the challenges that designers have with extracting, gathering and sharing relevant information. He states that the design team had informal style in information management in comparison to time management as well as relying heavily on the personal, tacit knowledge that was relevant to the problem [10]. According to this case there seems to be a gap in the way designers gather information in the research process and how they put it to use. Moreover, this gap can be further widened by the involvement of other stakeholders in the design-thinking process, which would lead to further misunderstandings. Cross explains how the misunderstanding further increased when designers started developing a solution concept because of the very abstraction of the ideas and use of metaphors to describe practical solutions [10]. The situation described by Cross illuminates how designers might benefit from the facilitation of knowledge transfer, which could be put directly to use. The aim of the research is accordingly to study the suitable learning environment for knowledge-transfer situation from the constructivist standpoint in which the knowledge transfer is seen as product of individualized learning environment.

2 RESEARCH METHODS

The theoretical perspective for this study relies on constructionism, advised by Seymour Papert to explain individually constructing knowledge by creating meaningful objects [11]. Construction that takes place "in the head" often fittingly happens when it is reinforced by construction "in the world." Papert describes "in the world" as when "a" [11]. It attaches a special importance to the role of constructions in the world as a support for those in the head, thereby becoming less of a pure mental concept. This theoretical framing which is useful to study designers' facilitation of knowledge transfer can be described by Papert's two principles: "First, relate what is new and to be learned to something you already know. Second, take what is new and make it your own: Make something new with it, play with it, build with it. So for example, to learn a new word, we first look for a familiar "root" and then practice by using the word in a sentence of our own construction" [11].

The case study discussed in this paper presents a workshop of two groups of four design students, including both genders equally. One group used communication based on the mathetic principles described above, while the second discussed the problem in front of the whiteboard. This case study serves to exemplify and examine the characteristics of the knowledge-transfer process in a group setting in a learning situation [12], and it is suitable for examining an event and the process that occurred through it. In addition, the case study allows the examination of not only events, but also artifacts such as participant models (Figure 1) [13] and the relevant personal experiences of the participants. Data for the case study have been gathered through a participatory observation approach, and using sound recordings. The participant groups discussed their experiences in group post-workshop interviews of each group. The workshops were chosen for the case study because the intention was to test a method for increasing a designer's ability to learn about an existing situation, which may allow for an easier framing of a design problem. The workshop is conducted outside of the course activities and is presented to the participants as a service design exercise with the goal to enhance their service design skills. Service design is a cross-disciplinary practice combining design, logistics and management, which produces systems and processes aimed at providing a holistic service to a user [14]. Service design focuses on discovering the problem area for a user or an organization by mapping stakeholder relationships and networks. To do this, service designers often use complex charts, or giga-maps which describe visible and hidden power structures [15].

3 KNOWLEDGE TRANSFER THROUGH OBJECTS OF REPRESENTATION

The two groups of master students in design were given a workshop task to use their own experience and knowledge to generate a stakeholder map around a problem defined by an imaginary client, in this case a municipality that wants to provide a service for a "problematic child". The term "problematic child" is chosen in order to reflect on client's approach to the situation, and engage interpretative design brief capabilities of participants, that might stimulate knowledge transfer. Participants were instructed to initially map the institutions around the "problematic child," then the stakeholders in these institutions, and finally the relationships in the stakeholder network. Participants then proceeded separately with the workshop. The first group of students were given objects (markers) to represent stakeholders in their service design project and different thread materials to represent relationships between the stakeholders (see Figure 1). Participants metaphorically translated the material properties of the threads into a description of the relationships between the stakeholders. For example, copper wire was described as being stiff, highly conductive, shiny, and cold; the participants wrote these properties down so that everybody could share that understanding. The second group of students were not instructed about the communication tools, but ended up using whiteboard drawings to communicate their understanding of the design problem.

Both groups discussed the task, then switched focus shortly after to which institutions had the most influence on the child. Both groups tried to incorporate what they knew or assumed in a circular, ripple model to explain the central position of the child and the degree of influence and importance institutions have on it (Figure 1). The center represented the child, the first ring portrayed the family, and the last ring contained institutions such as police, childcare centers, and medical or psychological help services.

The next step was to describe representatives of these institutions such as “teacher,” “father,” the “best friend,” and “nurse.” Participants were now encouraged to use the threads and their properties to describe relationship between these stakeholders as accurately as possible. Additional rules were introduced to describe reciprocity, dependency, and the character of these relationships. The pin heights, where and how they were tied, and the thread material enabled designers to describe a story with complex relationships. For example, if the thread is loose, the relationship is not fully developed, and if it is tight, that means conflict. Similarly, if the thread is tied from top of one pin to the bottom of another, that represents the position of power in this relationship network.

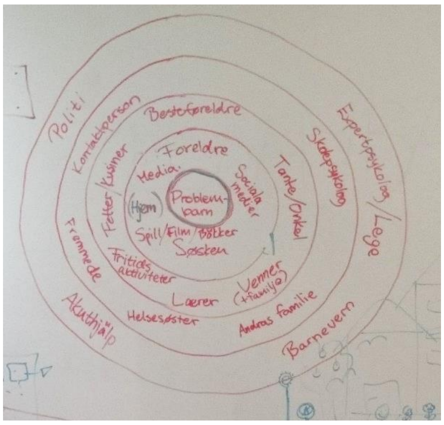

Figure 1. “pin and thread method”; Figure 2. “whiteboard drawing discussion”

The difference in the process started as the groups progressed from mapping the institutions towards mapping the stakeholders. The “pin and thread” group was using pins to map every single possible stakeholder in the network, with pins chosen according to color. The “whiteboard” group was much more focused on the narrative within “institutions,” naming stakeholders only when it was necessary to support the story. Even though participants were explicitly asked to map relationships in the stakeholder network, the whiteboard group did not do it; and when asked to explain relationships they did so orally as a part of a narrative. In contrast, the pin and thread group spent more time discussing and mapping each relationship while choosing the threads to describe it. Furthermore, stakeholder activities became a matter of discussion and part of the mapping process for both groups. The whiteboard group had more focus on moving institutions within their ripple model, while the “pin and thread” group soon abandoned the following ripple model and focused on clustering stakeholders in groups according to activities related to the problematic child.

When asked to generate solutions, the whiteboard group focused on framing their problem description around the ripple model, asking “How can we keep the problematic child within the inner circle so that it doesn’t slip towards the edges of its environment?” They provided three concept solutions, which did not involve stakeholders within the mapped network but rather provided a service outside it. The first solution focused on training parents to deal with the problem; the second solution was a service that would help the parents and the child through home visitations; and the third solution focused on building a network of parents of problematic children, to be used for learning and developing individual strategies.

When asked to describe their concepts, participants in the pin and thread group explained: “We anticipate that the problematic child and its parents might need additional support from other stakeholders in the network. We discussed how we can allow a stakeholder network to support the child.” Their first concept included a website on which friends of the problematic child can learn about the problem and obtain ideas on how they could be more supportive; and the second concept revolved around influencing the problematic child positively. They tried to design their concepts around activities in which older siblings can be figures of influence and provide support for the child.

Additionally, participants in the pin and thread group commented on this method of mapping the stakeholder’s network in the interview. They had noticed the amount of detail they managed to trap using this method: “We were surprised by how many stakeholders are involved in this network.” They described their insights on using this tool as: “It is fantastic how much overview one gets from others through this method. It enables you to decide what to do next in the process very effectively. Unfortunately, it would be difficult to share with somebody who did not participate in the workshop.” One of the participants noticed that: “Working with materials makes sense. This just would not work for example on a touchscreen. It’s just so much easier to remember when you are moving pins while discussing the problem.” Another participant replied: “Yes, it almost feels like we know them (stakeholders)”. The whiteboard group participants explained that the task was too abstract and that therefore they wanted to spend more time on finding principle solutions then learning about the problem. One of the participants explained: “ There needs to be a broader systemic solution for these kind of problems”. The pin and thread group discussed stakeholders using representation objects, and their solution revolved around methods of supporting stakeholders. The whiteboard group, however, focused on keeping the child at the center of the ripple model and their solutions involved stakeholders that were not originally mapped.

4 FINDINGS – VECTORS FOR RICH LEARNING

The pin and thread method used by participants in the first group applies Papert’s principles of learning [11], with the assumption that this method can create a richer learning environment for designers in the context of knowledge exchange. Expectedly, the study provides indications that the group using objects of representation had voluminous exchange of knowledge, however the effects of this knowledge exchange comprise also narrowed focus and more practical and detailed approach to problem solving. This seems to have happened because objects of representation steer participants’ focus on different information. The constructivist pedagogical approach explains this through the dependency of objects and learning: “The more objects are available in a concrete form and way, and the more focused communication occurs, the more effectively and efficiently learning can be supported in knowledge managed environments.” [16]. In this case study, both groups’ solutions seem to be an outcome of the focus that objects of representation create. Accordingly, rich learning environment developers are required to find the suitable format for representing knowledge, the semantic distance to domain knowledge, and the creative act of meaning generation [11].

There are three vectors for rich learning [18]. The first vector focuses on the relationship between content and participants, with a goal of enabling participants the ability to handle objects with minimal semantic distance to the problem formulation. In the study, the problem was defined around relationships, and accordingly, the threads that represent relationships were more defined and relatable than stakeholders represented by improvised object like markers. The results might be different if participants could generate representations of stakeholders like Lego-figures or similar items. The whiteboard group on the other hand created their own graphic model spending less time on building semantic closeness to it. This prevented semantic closeness to the problem formulation but enabled openness to many personal interpretations and therefore solutions outside of their model.

The second vector of learning addresses the allocation of tasks to participants, with a goal of binding them more tightly to the environment to support effective articulation and sharing of knowledge. In the case study, pin and board group participants used time to build common understanding of the metaphorical meaning of the thread materials and defining many stakeholders in the network; this is an important step for binding participants in the environment. The whiteboard group on the other hand, by not having means of representation was unsuccessful in attempt to define aspects of the problem such as relationships and stakeholders, and has eventually failed to include specific stakeholders in their model. This led to unstructured learning process where the aspects of the problem emerged randomly. Finally, the third vector addresses the actual activities to be set and the processes to be performed for learning or problem solving. The whiteboard group discussed their solution in the context of the generated ripple model, while the pin and thread group moved pins and organized threads by height, tension and material metaphor. The verbal and motoric activity generates a framework for what can be explained throughout the workshop boundaries. The type of activity, the engagement of senses and cognitive abilities, and load can shift the focus of learning. As the result of using whiteboard the second group actually used their body language to describe concepts and was much more engaged verbally.

5 IMPLICATIONS FOR DESIGN ENVIRONMENT

The findings illustrate how the involvement of Papert's learning principle in teamwork can create focused knowledge transfer. In this case study, it seems that the more objects of representation were used, the more detailed knowledge was transferred, but also the more narrowly the problem definitions and solutions were formulated. Using objects of representation in the way illustrated in this study, participants seemed to narrow down and focus on already-defined problem framing. However, if the goal is to have a broader discussion and explore possibilities in the wider sense, the vectors for rich learning should be adjusted differently. The conclusion is therefore that objects of representation allow effective knowledge transfer but at the same time can prevent complementary knowledge transfer and generation that enables wider exploration of opportunities in problem solving settings. The focus of the study was on how the participants can explore, and therefore choose complementary knowledge that can lead to novel solutions rather than whether they can just learn from each other. In that sense this case study research design has failed to provide expected answers. Still, the vectors for rich learning can be beneficial in design pedagogics and practice, and can also expose the influence that a facilitator might have in the design process.
Different phases of design process demand different kinds of activities [4]. In the beginning of the process, when the wide range of design aspects are considered the vectors for rich learning can be used to randomize the emergence of knowledge. In the case study the randomness is caused by the lack of instruction to the participants. The randomness of ideas and exposed knowledge can be also attempted by either casual semantic closeness of the objects of representation, random allocation of tasks to the participants and randomly generated activities to answer these tasks. In the later stages of design process, as the problem definition emerges and design aspects become more prominent, such as relations and stakeholders in the study, the vectors for rich learning could be more specifically designed and deployed by the facilitator of the knowledge transferring process. The further research is needed with adjusted research design to study this proposition.

According to constructivist pedagogics effective learning can only occur in situations which are suited for individual knowledge-transfer. On one hand, learner capabilities determine the individual method and extent of grasping information. On the other hand, the design of the environment has to address learner capabilities directly or indirectly, since learners have to interact with elements of that environment [19]. To comment on this in the light of the case presented by Cross in section 1.1, the designers do not only need a formalized role within the team for knowledge transfer, but also the skill for its facilitation. This skill should fit design practitioners' regime of competence, which is collecting knowledge in teams through visual means, rather than only generating evidence to use in the design practice. Moreover, this skill may be found in ability to manipulate creative teams' focus, through the utilization of a constructivist approach to learning by using vectors of the objects of representation. The formulation of the tasks around the objects of representation, their order and character can be used to shift the focus of learning.

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Article 3

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NORWAY-UK COMPARATIVE ANALYSIS OF SUSTAINABILITY IN DESIGN EDUCATION

ABSTRACT
Education for sustainability seeks to educate students in a manner that promotes sustainable development, acknowledging upcoming societal, economic, and technological changes and equipping learners to adapt to these developments. This preliminary exploratory study investigates British and Norwegian government strategies and visions that address these changes and compares them to curricula for design education. This study uses a hermeneutical approach to textual interpretation based on emerging topics from the strategies, and analyzes the curricula in light of sustainable education and transformative theory. The findings show the similarities between the two countries; both favor technical skills, whereas issues of an aging society and practicing critical reflection are rarely addressed. Therefore, this paper calls for discussion on the formulation of design education curricula and the skills it prioritizes.

Keywords: Sustainable design education, design education curriculum, transformative learning

1 INTRODUCTION

There is ongoing discussion in post-secondary education about creating curricula for adopting technology in schools and preparing students for future uncertainties caused by automation and a global workforce [1]. The critics of current practice argue that theory and practice should be brought closer together, combining academic and vocational studies and making them more accessible [1], that situated or contextualized participatory learning and cross-disciplinarily approaches should increase [2], and that continual learning throughout one's professional life is vital [3]. To meet the needs of the changing society, it has been suggested that these three concepts of should be integrated into post/secondary curricula: *education for sustainability* [4], *resilient learner* [5], and *transformative learning* [6]. Education for sustainability addresses the kind of knowledge that will be needed to enable *sustainable development*, as well as how is this knowledge thought so that learners can cope with disruptions and uncertainties. *Resilient learner* refers to an individual who is capable of adapting his or her expertise by adopting new skills, knowledge, and perspective [5]. *Transformative learning* replaces transmissive learning, such as learning by listening. Transformative learning occurs through consciously directed processes of self-examination of one's unconscious set of beliefs, values, and attitudes, and critical reflection on their underlying premises [6]. The three concepts highlight needs beyond the scope of traditional teaching methods.
Design education, which is transdisciplinary and taught through the studio practice of trial and error, could be a leader in sustainable education, as it fosters the ability to adapt and think creatively and requires the learner to confront problems and uncertainties. However, in general, the vision, mission, and objectives in design higher education do not address the needs of the changing society from a sustainable perspective. This article discusses certain challenges in design education in the United Kingdom and Norway, considering its compatibility with the changes of our societies. The comparison between Norway and the UK will highlight planned changes in design education, allowing for reflection on their mission, objectives, and implementation. The overall objective is to determine how design skills can address the challenges of education for sustainability, and which changes in curricula can be made to enhance this.

2 METHOD

The goal of this exploratory study is to present sustainability topics and initiate discussion of education for sustainability in design education. It compares Norway and the United Kingdom by outlining issues that education for sustainability should address, which in turn will shape two case studies on curriculum formation for sustainable design education[7]. As this is an initial exploratory study, we choose countries that will allow us to examine variety of the sustainable policy topics. We choose two countries that are focusing on sustainability [8], and are from one region, but differ in size and economy. This is in order to find the variation in the government focus of sustainability issues. The school curricula were chosen randomly—using the 2018 *Guardian* University guide to design courses [9]—because the concept of education for sustainability is considered an educational format with content that can benefit any type of education. Thus, we have chosen general product design education, though education in the UK can be specially tailored for design for sustainability. Norway on the other hand has three master product design programs, which are included in this study. The prerequisite, however, was that curricula are product design or product design engineering educations.

2.1 Theoretical Perspectives

Education for sustainability focuses on learners' autonomy, critical reflection, and ability to shift perspective and overcome constraints in order to develop resilience. Mezirow [6] explains that humans make meaning of information through "sets of immediate specific expectations, beliefs, feelings, attitudes, and judgments," which he terms "habits of mind." Individuals change their habits of mind when confronted with "disorienting dilemmas," and do so through rational discourse and critical reflection. From the perspective of education for sustainability, transformative theory is critical to how the knowledge or sustainable development is thought. It is therefore of interest to study how and where these metacognitive approaches to learning occur in the design curriculum.

2.2 Curricula and government strategies analysis

The curricula of three higher design education programs in Norway and the UK were used to examine how learning outcomes are defined. In parallel, four political strategies for future challenges were studied in order to determine the governments' perspective on sustainability. The hermeneutical approach to textual analyses [10] was chosen as the goal is to study policies and their possible influence on curriculum development. The hermeneutical approach [11] recommends iterative phases of analysis in which the researchers reexamine their prior understanding of the topic and of the text. The emerged topics were compared to one another within the perspective of education for sustainability, which is the theoretical concept and the starting point of this research.

2.3 Coding Procedures

First, the government strategies and visions were coded using Nvivo software to discover emerging topics and approaches to sustainable development. Second, these topics were used as a starting point for curriculum investigation by coding themes associated with these topics. Finally, the verbs used in the curriculum to describe learning outcomes, which indicate how the selected design curriculums envision the type of knowledge students should gain through their programs, were coded indirectly. This approach reflects the pedagogical concept of sustainable education. The coding process was first conducted by automated word search, and later manually examined to ensure that every topic was included or correctly assigned.

3 FUTURE CHALLENGES IDENTIFIED BY GOVERNMENT STRATEGIES AND VISIONS

The two main ideas behind education for sustainability are the type of knowledge and how it is obtained, enabling it for students in the foreseen contexts of the future. Thus, documents related to government strategy and design education were analyzed and categorized according to sustainable education issues such as adaptive expertise. The intention is to connect the formulation and structure of design education strategies to the socio-political context of sustainability. Therefore, this section analyzes the future challenges highlighted by the UK and Norwegian governments as well as organizations such as Innovate UK, the National Endowment for Science-Technology and the Arts (Nesta), the Organisation for Economic Cooperation and Development (OECD), and Innovation Norway.

Four recent documents that address future societal challenges and contribute to or are part of Norwegian or British government strategy were selected: "Industrial Strategy: Building a Britain Fit for the Future," a British government document published in December 2017 [12]; "The Future of Skills," a foresight exercise of the skills necessary for the British workforce in 2030 [13]; "Digital Government Review of Norway" (OECD, 2017) [14], which provides recommendations on upgrading the Norwegian government digital services to the digital level of the nation (European Commission, 2017); and "The Dream Commitment," a document based on "reports on the needed transformation of the Norwegian economy"[15]. All documents are available to the public online.

3.1 Future challenges for sustainability by the UK

The UK's "Industrial Strategy" [12] aims to fund the private sector and R&D to put the "United Kingdom at the forefront of the industries of the future." Working with Innovate UK, the government identified four major areas of investment, which are "**artificial intelligence and data-driven** economy, **clean growth**, the **future of mobility** and our **aging society**." (emphasis added). According to the document, these are "major global trends that are significant not just for our economy, markets and people, but for societies cross the world." "The Future of Skills" [13], a forecast report conducted by Nesta, identified key technology trends and contrasted them with global challenges. The report considers the rise of the internet of things, 3D printing, and biotechnology the top three technologic trends. Meanwhile, it highlights significant global changes:

1. **Growing global middle class** that will prompt a significant increase in global consumption.
2. **Aging population**, to whom job automation will be more a solution than a threat, as the workforce will shrink in developed countries; the elderly are the largest consumers of healthcare, thus healthcare innovation will expand; the needs of the elderly will also prompt changes in the housing sector as it accommodates this population.
3. **Climate changes** will lead to other sources of energy, introducing low carbon economy.
4. **Urbanization** will require cities to review urban design to accommodate the needs of the aging population as well as waste and recycling policies; smart cities will call for "digital infrastructure technology."
5. **Increasing inequality** will increase demand of social and healthcare services.

3.2 Future challenges by Norway

The Norwegian government also identified several of the above technological trends and challenges. The Digital Government Review [14] finds the **digital data driven society** and the **need for inclusion across age groups, migrants, refugees, and other sectors** to be areas of investment. It highlights the "need to use digital technologies to modernise, simplify and improve public sector processes and external outputs. To make the lives of citizens and businesses easier and enhance their productivity, Innovation Norway [15] recognizes the following six areas of investment:

1. **Ocean space**: investment in new technology that captures the ocean's biological raw material and contributes to clean energy production, among other benefits.
2. **Clean energy**: new technology to cover **future transportation needs** on land and at sea, with the goal of a complete transition to renewable energy.
3. **Bio-economy**: The use of renewable bio-based products to reduce the impact of three significant global challenges—resource scarcity, climate change, and population growth and urbanization.
4. **Health and welfare**: "[An] **aging population** and new, large patient groups provide growth in public health tasks. The comprehensive needs make a potentially powerful driver for innovation in health industry."
5. **Smart societies**: Making Norwegian industry part of the "global solution" for future urban and technology changes.
6. **Creative businesses and tourism**: The development of art, culture, nature, and leisure activities. It includes industries such as film, music, design, literature, architecture, and computer games.

In both the UK and Norway, challenges and investment opportunities can be clearly linked to design. These include:

1. **Green alternatives** (referred to as low-carbon, renewable, or clean growth)
2. **Automation** (automated vehicles, automated jobs, smart cities)
3. **Inclusion** (aging population and ethnic minorities)
4. **Healthcare and welfare**
5. **Increased consumption** (clean growth, alternative materials, resource scarcity, and bio-economy).

These five terms are the type of knowledge needed for sustainable development which might appear in the curricula of design schools in the UK and Norway.

4 CURRICULA ANALYSIS

It is argued that design skills are essential for the global future economy [13]. This section evaluates six curricula from design schools in the UK and Norway. The three Norwegian design schools are included in the study as well as three British design schools randomly selected from the 2018 *Guardian* university guide [9]. All six design curricula are publically available online. They are contrasted with the five common future challenges identified by both countries. The section aims to start discussion about whether the training offered by design schools aligns with the challenges soon to be faced by society, including technology trends, environmental disruptions, and population growth [13]. The findings from the curriculum textual analysis are presented in the form of topic frequency percentages.

4.1 Curricula for sustainable development

Figure 1 reveals how the frequent topics in the design curricula correspond to challenges identified in the government strategies and visions. It shows the coding categories correspond to many of the skills necessary to understand and address the five future challenges. Our findings show that technical skills are present in the UK design curricula more frequently than in Norwegian curricula. On the other hand, ethical perspectives, which include reflection about consumption and the role of design in waste production, are more common in Norway. Environmental awareness and inclusivity issues appear in roughly equal measure in the UK and Norway curricula. However, both sets of curricula neglect reflection on welfare and healthcare future challenges.

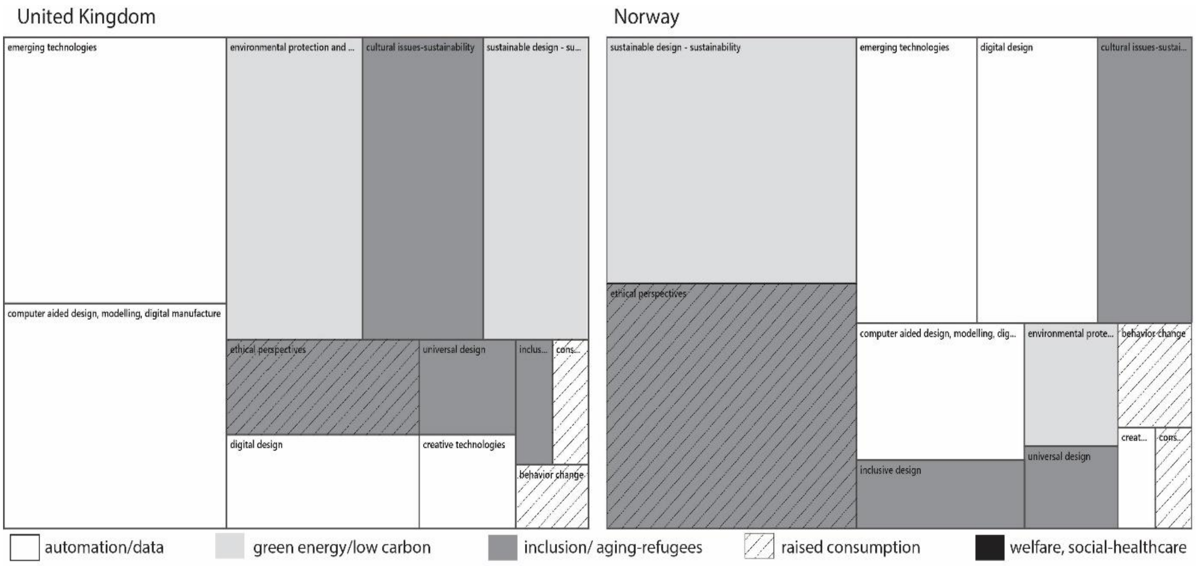

Figure 1. Frequent sustainability topics in the curricula of the selected design schools

4.2 Curricula for sustainable education

Figure 2 shows the frequency of verbs used to describe intended learning outcomes in the Norwegian and British design curricula. The verbs are sorted by the types of knowledge they promote. When describing knowledge or skills, British and Norwegian design curricula samples often use phrases that contain verbs such as “obtain,” “acquire,” and “have,” suggesting an essentialist approach to the curriculum. Procedural knowledge is quite pronounced in both sets of curricula. The British curricula use more verbs that emphasize the meta-cognitive abilities of learners, while the Norwegian curricula are richer in verbs that emphasize declarative knowledge.

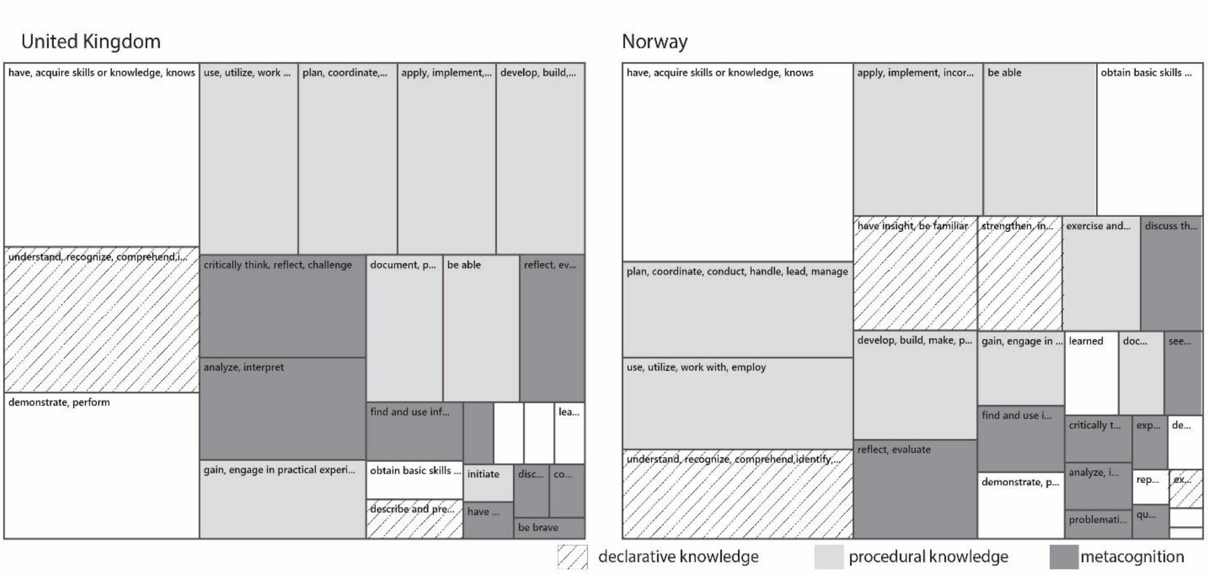

Figure 2. Frequently used verbs to describe intended learning outcomes in the curriculums of the selected design schools

5 DISCUSSION

Transformative theory advises that individuals change their “habits of mind” by learning through “experience, critical reflection, rational discourse and action” [16]. This suggests that meta-cognitive abilities and procedural knowledge are crucial elements in a curriculum devised to educate resilient learners. Declarative knowledge, though necessary for effortless processing of new information, does not necessarily enable significant shifts in the learner’s perspective. This study shows that technical skills and procedural knowledge are predominant in the selected UK curricula, and represent a significant percentage of the Norwegian curricula. This is remarkable, as technology awareness and digital design will be essential in order to meet the future challenges highlighted by the governments. For instance, interactive interfaces, like apps and other digital resources, are tools that can inform users about consumption and green alternatives and can leverage environmental sustainability, welfare, and healthcare services. However, while technology can be used to address future challenges, it appears inclusive/universal design is rarely included in these curricula. The need to address the concerns of an aging society is noted in each of the analyzed documents and affects the welfare and healthcare systems of both countries. If this population is not taken into account, the production of new technology is likely to be underutilized by a large percentage of the population. Thus, future designers should be trained to consider how older adults perceive and use technology; they are the potential users of new interfaces in automated vehicles, smart cities’ services, and healthcare products.

Although technology skills predominate in these curricula, they do not seem to be giving expected outcomes. We emphasize the need for a balanced curriculum where technical skills and ethical, sustainable, and inclusive perspectives should be pursued equally. However, the current curricula do not seem sufficient to encompass the current demand for technical skills, according to the British Design Council’s skills report [17]. This report highlights the skills gaps between supply and demand, stating, “*Recruitment of design skills is challenging*”; due to the level of specialization the job requires, employees with design skills often have post-graduate degrees [17]. Among the design sectors that evidence skills shortages, the Design Digital group had the highest percentage of “hard to fill” vacancies in 2015, at 53%. More than 80% of employers were concerned that design workers lacked “*technical, practical or job specific*” skills.

5.1 Limitations

The data does not indicate the frequency of words that relate to education for sustainability in comparison to other relevant topics of the design curricula. This is because the purpose of this article is to study current and future approaches to education for sustainability, rather than the scope of implementation. Furthermore, in Norway the government dictates curricula have the same structure, which includes descriptions of knowledge, skills, learning outcomes, and general competence for each

course. In the UK there is no such regulation, allowing for different curricula forms; learning outcomes are listed for the entire program rather than divided by subject. This makes comparison difficult.
Another limitation is the criteria we used to select the British curricula, which was a random selection. However, as the curricula are compared to employee demand according to the outcomes of the design skills report, they could have been selected using the employability rate of design schools. Nevertheless, further research will be conducted using a mixed methods approach. Finally, the data does not represent empirical evidence of the impact of education for sustainability on design education, but rather the frequency of topics used by curriculum designers when describing design course.

6 CONCLUSION

Matching the necessary knowledge and design skills to address future challenges in promoting education for sustainability is not an easy task. However, this preliminary exploratory study identifies three topics for discussion: 1) although technical skills in design education could be a way to address future challenges, there may be a disparity between what employers expect from designers and what skills they have after the education; thus, how can we develop education for sustainability?; 2) the need for critical reflection rather than essentialist thought when designing curricula, so that future designers will be able to develop and relearn skills in new contexts; 3) the need to address the aging of society is not reflected in the design curricula, which indicates a gap in the necessary knowledge for sustainable learning.

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Article 4

Postphenomenological perspective on free learning with maker technologies: An action research study of 3D-printing.

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Postphenomenological perspective on free learning with maker technologies – an action research study of 3D-printing

ABSTRACT

This research critically assesses 3D-printing as an educational technology in free learning. The study shows how free learning can be defined in terms of postphenomenology and relationalist ontology. Through an action research approach, maker technologies' feasibility in formal and informal learning processes is put to the test. Circles of action research and qualitative direct content analysis are deployed to reconcile free and accessible learning. Consequently, the research process steers away from constructivist pedagogics and toward a postphenomenological view of learner-technology mediation. This promotes new terminology for explaining free learning, such as field of perception, multistability, and transparency. This new theoretical framework will strengthen sustainable educational practices and pedagogical instruction in maker technologies.

KEYWORDS: free learning, 3D-printing, mediation, multistability, resilience

Word count: 6971

Introduction: Maker technologies as educational technologies

The application of additive manufacturing, colloquially called 3D-printing, has been promising to disrupt production processes, distribution of goods, and consumption. Still, this technology has not been fully utilized in industry (Marak, Tiwari, & Tiwari, 2019, pp. 87-89). In learning, however, 3D-printing has been used for both formal and informal education. There already exists a substantial body of research on using 3D-printing as an educational technology (Ford & Minshall, 2019, pp. 135,136). The use of maker technologies in education is viewed as beneficial for divergent and convergent thinking such as 'defining problems' and 'designing solutions' as core engineering practices (Quinn & Bell, 2013, pp. 37-42). Accordingly, this kind of thinking is of importance for learners' 'individual agency' and can foster learners' autonomy (p. 45). This can differ from the traditional curriculum approaches in which topics and activities are planned in advance in order to ensure the quality of intended learning outcomes. A theoretical paper recently published in the *Technology Pedagogy and Education Journal* scrutinizes maker technologies, commenting on the issues arising from the attempts to emulate makerspace learning approaches in formal education. The paper proposes both reconfiguration of maker technologies and calls for new ideas for 'alternative conceptual pedagogical frameworks that move beyond the narrow concerns of maker education' which can fit formal education in a more effective way (Godhe, Lilja, & Selwyn, 2019, p. 12). Of the many thoughtfully and rightfully raised issues in the paper, I would like to outline and elaborate on two.

The first issue is curriculum, content, scope, and quality of knowledge. Maker movements rest on the free endeavor of its participants in which they can play in a social setting and freely explore what interests them (Martin, 2015, p. 35). Learning through maker technologies should therefore facilitate learners' autonomy by being freed from curriculum and instruction. It should be process-oriented, participatory with unpredictable outcomes and should transfer learning responsibility to learners. Than how do learners choose what to learn? This question is important as future learners have to scrutinize, systematize, and make sense of the saturated information they encounter daily. They also need to have an adequate overview of the learning content to focus their inquiry and decide what actually can be learned in the given time of a course. Also, in terms of quality, if the knowledge gained through maker technologies has to be applicable, how can learners utilize it and verify its impact through practice?

The second challenge is instructional. The maker technology-based learning model poses constructionism, which implies learning by making, failing, and experimenting versus instructionism, which implies successful outcomes and avoidance of error (Bevan, 2017, p. 76). If learning is not content- but process-led, what is the role of pedagogy in learning through maker technologies? This is an important question because of the emergence of two opposing trends. On the one hand, there is standardization in education, especially of intended learning outcomes and explicit standards as a way of insuring quality and content in globalized and mass-enrolment higher education (EuropeanCommission, 2019, p. 5). On the other hand, informal learning approaches and learning at work are gaining considerable interest as options for future students.

Maker technologies and their developing pedagogical frameworks can be applied to educate autonomous critical thinkers, who can adjust to new situations, shift perspectives, and take initiative for their own learning. However, the goal of maker education should be to provide learning experiences for everyone, not just those who have a special interest in making or accessibility to maker tools and communities. Accessibility of this autonomous way of learning is a resource that I see as critical in pedagogical practice.

The sections of this include a description of the action research methodology used in this study, a brief summary of theoretical perspectives on learning with maker technologies, justifications for researching 3D-printing technology in the design studio in higher education, and a description of the three cycles of action research, followed by a discussion section.

Method - Action research

The aim of this research project was to study the phenomenon of learning through the use of 3D-printing and to develop a pedagogical approach to accommodate this phenomenon in formal higher education. This process of the cultivation of pedagogical approaches applying maker technologies in a formal learning setting was intended to give a perspective on learning processes, pedagogical issues, and implications for educational guidelines.

Action research is an effective framework for enacting and studying change and facilitating learning by using maker technologies. It cultivates learning and teaching practices in terms of creating new pedagogical approaches, relating these practices to relevant literature and elevating practitioners' professional accountability (McNiff, 2014, p. 16). The methodology of action research is described as narrative writing in the first person in which cycles of action and reflection inform each other leading to transformation (McNiff, 2014, pp. 73,74). In this study, three cycles of action research were implemented through three repeated and modified six-week courses with a different group of 45 freshmen students for each cycle. As the students were freshmen, this meant that very few were familiar with digital modelling and 3D-printing. The first course was introduced at the end of the first year in the product design study in 2017, followed by the second and third in 2018. The study was authorized by the 'NATIONAL' Council for Research Data as a research in one's own practice and according to its ethical standards. These standards include participant consent, anonymization, and secure data handling.

I engaged two experienced and qualified colleagues to be critical friends and assess grades for students. One was present during daily activities and the other provided feedback on learning outcomes. The Head of Studies was involved providing opinion on behalf of the department. This arrangement allowed me to observe the research setting as a pedagogical situation and avoid grading projects myself, which would be unethical. Being first-person action research, this study questions role of student participation and pedagogical instruction in design studio.

Constructivism and postphenomenology

The design studio as a learning setting is characterized by learning through cycles of critical reflection as described by Schön (2015, p. 58). The literature concerning maker technologies and learning settings, outlines constructionism as a learning theory that explains learning as internalization of the processes of making as defined by Papert (Vossoughi & Bevan, 2014, p. 2).

Postphenomenology, instead, does not address learning, at least not as a psychological or pedagogical process. Rather, it addresses the phenomenon of mediation between humans and machines. This concept, derived from the philosophy of technology and has been used by Idhe as technologically-arbitrated phenomenology (Ihde, 2003, pp. 15-18). Mediation in the postphenomenological sense means that technologies are not only used by humans, but that the interaction is reciprocal (Rosenberger & Verbeek, 2015, pp. 13-15). Namely, technologies transform human perceptions by amplifying or reducing certain aspects of the experience and translate human actions by inviting or inhibiting humans to do certain things. Thus, through this research, I explored these transformations as a way to explain learning as an outcome of human-technological mediations. This approach offers a new insight into learning by 3D-printing because it explores how human-technology relation affects reality. This is distinct from constructionism, which sees technology as used by learners in order to construct and internalize knowledge, or as a reflective practice in which learners act upon technology and the world so as to critically reflect on their own activity. Through the cycles of action research, I changed my pedagogical approach when challenged by many emerging issues. My initial understanding of learning in the design studio was on reflective practice but evolved to include the learning traits of 3D-printing technology. Thus, postphenomenology revealed itself as a viable framework for this approach.

Research setting – 3D-printers in design studio

Technology of 3D-printing refers to the fabrication of three-dimensional objects of nearly any shape or geometry. The mass production character of the process is enabled as a digital model built in a computer software can be converted into material layers (Lancu, Lancu, & Stăncioiu, 2010, p. 73). Today, 3D-printers are commercially accessible desktop equipment, which allows continual contact between learners and the technology. It is therefore of interest to research the individual and social experiences of using 3D-printers to describe human machine mediations and relate that to the environment in which it occurs.

The design studio pedagogical setting provides the environment in which the experience of 3D-printing can be related to answering the above stated research questions. There are a number of reasons for this: the design studio is formal education; divergent and convergent phases in learning are common practice; the design studio is situational and includes maker technologies, media, and materials; and it can be characterized by peer learning and can involve external stakeholders such as users and clients. This particular setting was beneficial because a new 3D-print lab had recently been opened, and the department’s management was motivated to learn more about its utilization, making the phenomenon a matter of pedagogical practice.

Research design – Qualitative direct content analysis

The research was designed around the usage of 3D-printers and pedagogical instruction. To research this, I gathered course evaluations, design reports, produced artefacts, sound recordings, and reflection notes from participant observations. I or my colleagues collected the data throughout the course. The data indicated how learners experienced the design challenge and their feeling about the course after time had passed.

The research process relied on direct content analysis, which applies theory to determine classification topics in advance (Hsieh & Shannon, 2005, p. 1281). Direct content analysis allows for exploration of existing learning's theoretical concepts. However, the issues emerging in pedagogical practice are not fully represented in the theory-based classifications. This has led to classifications evolving from the terminology around reflective practice and theory of sense of coherence toward postphenomenology. This meant that, in this study, the coded data had to be reinterpreted and exchanged for what I saw originally as background material.

In postphenomenological reasoning, the use of technology has intentionality (Ihde, 2003, pp. 11-13). When technologies are used, they establish relationships between humans and their environment. Subsequently, my students did not just do 3D-printing per se; instead, they 3D-printed artefacts for a certain purpose. The current series of technologies mediate among the learner, the artefact, and the artefacts' purpose in the real world—modeling, layer slicing software, and, finally, the 3D-printer. In doing so, these technologies help to shape the subjective experiences and objective reality of learners. Three sets of classifications emerge from postphenomenological concepts which describe the mediations between learners and 3D-printers.

The first classification encompasses how learners adopt the technology. This means the extent to which learners manage to operate it and produce the intended immediate results with it. The more they use the technology, the less it obstructs them in their intention, and the more it becomes *transparent* to them or, on the other hand, remains *opaque* to them (Rosenberger & Verbeek, 2015, pp. 14-15).

The second classification encompasses how learners adapt technology into their practice. This means the extent to which the technology is meaningfully used for learners' causes. The more they establish practices around the technology to fit their needs, the more it becomes *sedimented* in their routines or, conversely, remains *multistable* or open for a variety of usages (Rosenberger & Verbeek, 2015, pp. 25-29).

The third classification encompasses how learners apply the technology to affect their environment. This means the extent to which learners comprehend reconfigurations in the human-technology mediations they cause through their activity and produced artefacts. The more they take the responsibility for mediations, the more they recognize their agency, changing their *field of awareness* (Rosenberger & Verbeek, 2015, pp. 25-29) and tapping into the *potentiality* of the used technology. In the opposite case, the more they rely on the existing *field of awareness*, the more they use it in its *actuality*. (Kiran, 2015, pp. 132-135)

These classifications are contextualized by two attributes. The first attribute relates to students coping with the given pedagogical instructions. The second attribute relates to students developing their own directives through the process (see Table 1). The citations used in the descriptions of the findings section are therefore representative citations from the classification categories in the revision cycles from this data. The data were collected and processed in NVivo software in 'NATIONAL' language, and the citations and conclusions were translated for the purposes of this article.

Results

Research Cycle 1- Challenges in constructivist pedagogy

In the department of 'NAME', the course manager and the head of studies develop course plans and intended learning outcomes to fit the curriculum. However, the activities of a learner and a course manager are often marked by established design studio practice, which was well described by D. A. Schön (1985):

> Given an architectural program or brief and the description of a site, the student must first set a design problem and then go on to solve it. Setting the problem means framing the problematic situation presented by site and program in such a way as to create a springboard for a design inquiry. The student must impose her preferences onto the situation in the form of choices whose consequences and implications she must subsequently work-out all of the field of constrains (1985, p. 6).

Thus, for the purposes of this study, I presented students with an existing one-part handheld product as a *site*, and instructed them to produce a *design brief* as a *design program* where they were to analyze this product and critically assess it. From the analyses, they were to *frame the problematic situation*, impose *their preferences*, and test them through a series of physical prototypes, *working out* the *constraints* in material, processes, and functionality. Students were expected to implement and demonstrate new *imposed preferences* with each iterated prototype by testing and reflecting on them.

The focus of the course was students' development as design professionals and their personal approach to the design process. The pedagogical method relied on individual tutoring, reflective journaling, prototype presentations, and collegial critique.

The students were encouraged to manage their own design process and acquire the skills needed for it. I had previously introduced 3D-printing through lectures and live or video demonstrations as optional techniques. My intention was to observe how they could utilize 3D-printing in a free learning process and make their design decisions.

The overwhelming majority of the 28 students were reluctant to make prototypes. It took two tutoring sessions and two weeks wherein the students discussed their ideas among themselves, often over rough sketches. Once they started building prototypes, they used techniques learned from the previous courses. Only four of the students 3D-printed their prototypes.

Revision 1

When coding the first attribute, the most commonly noted topic was the learners' struggle with the pedagogical instruction, which they characterized as incomplete, unspecific, confusing, and contradictory. This topic was further mentioned in respect to other classifications. Learners struggled to formulate what they wanted to achieve, as represented in the third classification, and had difficulties with the processes of accomplishing it as presented in the second one, as well as the means of doing it in respect to the first one. One learner said: 'It took me half of the course to understand what the task was really about.' Another directly addressed the inability to comprehend the expected outcomes of the assignment: 'It was very difficult to understand what is expected in this course, what are the course requirements and what should be the effect of our designs.' This was also pervasive in participant observations, where learners asked for clearer instructions and insisted on practical guidance: "What is the right way to do this (assignment)?' This topic was also noted among the students who got top grades but still wondered for what reasons their work was perceived as good by teachers.

When coding the second attribute, that signifies autonomous directives, the first classification was very pronounced. The main topic in this classification was learners' descriptions of making processes, such as glazing, gluing, or woodwork. However, in this case, material outcomes were not measured by set criteria but by colleagues and tutors' critiques.

The third emerging classification was much less pronounced but varied. Learners discussed and described their thoughts about certain design concepts such as ergonomics, tension in material, and even gender-neutral form semantics in the context of their user preferences. These topics emerged through the learners' own critical analysis of the site and interests.

In all four projects of the course, 3D-printing was used by the learners. In two of these projects, I found some evidence for adoption and adaptation where leaners had discussed their design processes through a series of 3D-prints.

At the end of the course, the critical friends assessed that the major issue with the student projects was lack of meaningful problem formulations, or that the problem formulations were not addressed properly through the prototypes. The critical friends noticed that there was a 'big split in the quality of the projects', and that those who did exceptionally well showed a lot of independence in their work. The critique from the management was that 3D-printers were not used and that the department did not gain new insights about the 3D-printing lab from this course.

The central idea of constructivist pedagogy is to allow learners to decide what and how they want to learn, and support them in their own inquiry (Montessori, 2013, p. 348). However, the tension between the quality of autonomous learning and lack of effectiveness in direction (Sterling, 2010, p. 515) seems to favor learners who are already autonomous. This collides with my values of accessibility to free learning, inclusion, and respect for learners' integrity. Schön described the relationship of learner and tutor through the model of master practitioner and apprentice in a design studio (1985, pp. 6,54,90). I could identify with this model with uneasiness, as I was not teaching students a transparent design practice. Instead, practice was delivered spontaneously, distilled from personal experience, and tailored to the individual learner. This highlighted the issue of power and threatened the prospect of educating critical learners.

The issues I have investigated do not seem to be unique according to the literature. A recent qualitative study of architecture students in a design studio (Hokstad, Rødne, Braaten, Wellinger, & Shetelig, 2016, pp. 322-328) addressed difficulties which this educational approach presents to learners. This qualitative study portrays the individual voices of learners and their struggle when coping with the ambiguity of the design learning process. Schön himself described design learning as a paradox in which students are instructed to learn by simultaneously determining what designing is and how to do it (Donald A Schön, 1987, p. 83). Thus, according to this idea, my instructions were not only misinterpreted, they were unattainable. This is because learners did not have enough practice to do the task and not enough understanding of design to organize their individual practices. This I did not find reassuring; rather, it led me to doubt this pedagogical approach.

My own research, the input from my colleagues, and the literature review showed that the actual challenges the students experienced were analyzing the existing sites, turning analysis into a problem framework, and adequately addressing this framework with their prototypes. The random and unplanned use of technologies made the learning ineffective as learners struggled to materialize their ideas. This indicated that the transition in the autonomous learning processes and use of maker technologies had to be pedagogically sustained.

Research cycle 2 – Teaching by instructional design

To support these transitions, we taught students digital modelling in workshops and online tutorials before the course started. The course itself consisted of two shorter assignments, an individual one and a group one. The aim of the assignments was to practically demonstrate and pedagogically support the learners' ability to connect design methods, prototypes, and the problematic situations. Students received a design brief which included a detailed description on how to redesign a generic product to become a personal product for their colleague. This required them to conduct an interview with their colleagues, discuss form semantics through using mood boards and sematic differential analyses, and finally iterate ideas through a series of 3D-prints.

The second assignment was designed for groups of six students, and it was introduced as an action research process. Action research methodology was used to break up the framed design problem into observation, action, and reflection to be presented in a design brief. This design brief was missing text, but had either images of existing products, mechanical parts generated by 3D-printing, or constructions unique to 3D-printing technology. Students were instructed to formulate their own tasks around these manufacturing principles, complete the design brief, and keep modifying it throughout the design process, turning it into an instrument for reflection in their action research. The goal of the assignment was for students to learn how to conduct action research in their own practice and test their assumptions practically through 3D-printing.

Throughout the first assignment, I explained the process, teaching how to conduct and analyze interviews, use semantic differential analyses, and use various techniques when designing objects. Throughout the second assignment, I commented on their action plans in meetings and in the joint design brief, posted online.

Revision 2

Direct content analysis exhibited the first attribute in this cycle, as well. However, this time, the learners described the instruction as overwhelming, too detailed, and difficult to follow, especially when relating to the first assignment: "The instructions were very detailed, and if you don't follow up fast, you easily start lagging behind." This applied particularly to the second assignment and the second classification, in the context of adapting technologies to their practice. The detailed instruction was also incomprehensible for some learners as their own questions were unanswered by the methodology prescribed by the given methods. The codes in second classifications pointed toward difficulties in adaptation of the methods, such as the mood boards, semantic differential analysis, and 3D-printing in the first assignment. Here, the topics revolved around the appropriate use of mood boards and semantic differential analysis.

The other stated topic emerged regarding the second attribute, first classification, as students described their group work experience in the second assignment. The students who were not yet competent in digital modelling took other tasks in the group, further diminishing their opportunities to become familiar with 3D-printing. In the second classification, the emergent topic was how the lack of participation in activities using 3D-printing was demotivating. Students for whom 3D-printing technology was not transparent enough seemed to fail to sediment the technology in their practice.

When coding, the second attribute of the adoption classification presented itself with different themes concerning 3D-printing. One very pronounced topic was the learners' struggle to predict the proportions of the 3D-printed artefacts as they had a "different feel of it on the screen." The topic which emerged in the adaption classification was planning when to use 3D-printing as it could be time-consuming depending on the size and details of the artefact. Students discussed how to optimize their designing process to accommodate this issue also by printing overnight. This, as well as the mechanical properties of the 3D-printed parts, was a central issue when learners were deciding whether to use other making processes such as laser cutters for parts of their artefacts. These topics indicated that 3D-printing was becoming more transparent to learners, and that new practices were emerging and turning into sedimented routines through their own autonomous instructions.

Critical friends noticed that the students produced more and better detailed prototypes. They also noted that more of the students could explain how their prototypes addressed their problem formulations. In this course, the student grades were grouped in the middle and upper range of the grading scale. Also, 3D-printing became the living practice in this course, and the head of studies initiated moving the course to the very beginning of the first year. The rationale for this was that students need to be exposed to this way of conducting the design process before they get extensive training in the workshop's tools.

In the second cycle, the instruction was defined by curriculum that included topics such as form semantics, product construction, user interviews, and action research as method. In that sense, learning was defined by the instructional design in formal education and could not be described as learning freed from curriculum and instructions. The personalized approach to design process and skill acquisition was abandoned. Students were comprehensively instructed in a variety of skills, as well as introduced to the topics they would investigate. In the third assignment, learners were provided with a starting point they had to problematize, media they had to utilize, and a method for their inquiry.

In this cycle, my role as a pedagogue seemed less personal, relying on theory and method rather than on my experience as a design practitioner. I found my work more in the line with what Kalantzis and Cope (2005, p. 9) defined as that of an instructional designer. Instructional design should engage learners in their learning by providing the adequate experiences of learning for the intended learning goal. According to some researchers (Halverson & Sheridan, 2014, p. 500; Martin, 2015, p. 37), it is challenging to emulate a makerspace learning setting in formal education because of the risk of tool-centrism and curriculum-centrism, both problematic for a maker mind-set and an open approach to learning.

Thus, it appeared that the perceived improvement in results seemed to rely on comprehensive instruction, which diminished the need for learners to engage in problem framing as well as hiding the incompetence in 3D-printing of the students in groups. This approach seemed to benefit design results more than learning outcomes, as it did not sufficiently expose learners to critical reflection. However, my colleagues shared a different viewpoint, underlining that it is positive for students’ motivation to experience proficient implementation of their ideas so early in the studies.

Research cycle 3 – Relation-driven learning

The third iteration of the course was scheduled at the very beginning of the 2018–2019 school year. This meant that my colleagues and I had to implement training in digital modeling as part of the course. The course therefore consisted of three assignments. The first included training in digital modeling, and the second and third were repeated from the previous course with modifications. First, action research was introduced as a method at the very beginning of the course for all three assignments. Secondly, the course was organized so that the media used in the assignments were predetermined, but their specific use was not. In the first assignment, students were given sketches of a unfinished abstract artefact and asked to finish them as a digital model and a 3D-print. The second individual assignment, redesigning a product for a colleague was repeated. However, this time, students were instructed to propose their own methodology and implement it in the cycles of action research. The third assignment was modified in two ways. First, the groups consisted of three students who were instructed to participate equally in the production of prototypes and the production of a brief. Second, students were not given any content instruction other than to write a design brief before they used the 3D-printer. The design brief was to document their action research plan which they fully controlled. To help them accomplish the first assignment, we gave feedback and provided video tutorials to students on how to create digital models. For the second and third assignments, we offered assistance on design briefs for coherence and the practical aspects of the project.

Example of learner-technology mediation

Most of the data sets included personal reflections or discussions, where learners evaluated different aspects of the design challenge through a series of design proposals. In the data sets, the classifications were shifted interchangeably. The classifications also appeared on two levels in the context of the usage of the 3D-printing technology, but also on the emerging technology the learners designed.

Learners explained their chosen task through the changed field of awareness and technologies' potentiality: 'We wanted to use 3D-printing to make fasteners because we can make them complex, test, modify, and reproduce them quickly.' They assessed multistability of the new invented fastening technology: 'Clips could allow modifying the storage; it could be modular.' They discussed the new modular clipping technology and its potentiality: 'We want to design a system for storing clothing but we haven't landed on that yet.' Further, they discussed how this could be done by 3D-printers, sedimenting 3D-printing into their own practice: 'We will 3D-print clipping modules that hold the plywood structure.' Finally, they turned this into comprehensible instruction: 'The most important thing in the first round is to make sure the modules hold the structure and they are easy to mount and demount for one person.' They further discussed how transparent this new modular shelf technology could be: 'We will not have time to test this on users. We cannot claim it is easy to adjust the shelves.' Finally, they created a more comprehensible and manageable task: 'Let's make a modular bookshelf that you don't adjust too often, but can fit in any interior. We can then demonstrate different shelf configurations' (see Figure 1). Their design and learning topic were defined by the allowances and prohibitions of the fastening technology as was the new practice that emerged from the mediation between learners and 3D-printers.

Figure 1. Modular shelf system made by a group of six freshmen students in two weeks.

Revision 3

The first attribute and third classification were still present but less pronounced. Even though some students had pointed out that the instruction was overly detailed, and others said it was confusing, the more common opinion was that it was complex, demanding, and difficult. The word 'challenging' was used in multiple instances. They noted a ‘steep learning curve’ when they had evaluated adaption of 3D-printing technology: ‘It was challenging but insightful. We found out that many of the things we wanted to make had to be adjusted or discarded in the process.’ They also expressed a need for a more holistic understanding of the process they were involved in: ‘I wish I had had a better overview of what we were doing beforehand.’

The classifications in the context of the autonomous learning attribute were much more pronounced in this course. In the adoption classification, the delayed haptic feedback was repeated in seven of the projects. Learners described this as having to adjust and reprint their artefacts in order to get the right proportions. Further, modifying and reproducing digital files on 3D-printers with different mechanical material properties was a topic that emerged.

In the adaption classification, learners were struggling to decide what 3D-printing as a medium is best suited for, in order to take advantage of it in their projects. Similar to the previous research cycle, the printing time dictated work routines in the 3D-printing lab, including printing overnight. In the application classification, learners discussed the ability to share digital files over internet sites for personal reproduction. The other commonly noted topic in this classification was complex geometries, such as enclosed hinge systems and Voronoi structures. Finally, some of the students talked about how they had researched on the internet to learn more about the application of 3D-printers.

My colleagues evaluated the results of the projects in terms of accomplishment and quality, similarly to the previous course. However, the grades declined slightly toward the middle of the scale.

Discussion

The research started by formulating questions from the perspective of formal education but ended by discussing affordances of 3D-printers and their relationship with learners. Rather than asking how and what students learn by 3D-printing, one should ask what kind of learner 3D-printing allows to emerge. Likewise, rather than looking at what should be the curriculum and instructions with maker technologies, one should ask how the relationship between humans and 3D-printers works, and what topics and activities emerge from that relationship.

Augmentation and limitations of learners' capabilities

Mediation between learners and 3D-printers is characterized by what 3D-printers can afford and what they prohibit learners from doing. In this study, there were recurring and overlapping topics throughout the classifications about 3D-printers that describe these affordances: multi-purposefulness through multistability, form and construction complexity, sharing of the ideas through files and the internet, rapid modification, and replicability of the artefacts. The prohibitions, on the other hand, were the temporal delay of the haptic feedback, which results in confusions with geometric proportions while designing, and establishing time management routines for printing. Workshop tools, such as a woodturning machine or jigsaw, do afford stable, sedimented procedures. To build complex forms and structures, learners need to perform series of procedures. It takes a significant amount time for a learner to become sufficiently competent to do this. Conversely, the 3D-printer is multistable and can produce complex results using the same manufacturing procedure. This demands that only one technology becomes transparent to learners. Learners can then rapidly advance to a level where they can cope with complex design topics, which they can apply and test.

Similarly, 3D-printing augmented my teaching abilities. My intention to implement free learning was augmented by multistabilities of 3D-printers.

Implications for pedagogy – Relational ontology in maker technology pedagogics

Learning by 3D-printing in a postphenomenological sense is seen through relational and inter-relational ontology. Learning is an outcome of mediation, or a relationship between 3D-printers and learners (Rosenberger & Verbeek, 2015, pp. 19-21). Learning is inter-relational and transformative, meaning that the use of technology permanently changes humans and their capabilities (Ihde, 2003, pp. 11-15). Knowledge can be described as the transformation and augmentation of human capabilities and agencies, whereas skill can be seen as the extent to which learners' environment is transparent and susceptible to their intentionality. Thus, autonomy can be described as the leaners' resilience to an environment's multistability while maintaining personal integrity and responsibility.

The process of learning and knowledge itself therefore emerges from the affordances and mediations of learners' environment and situational context. In the study example, where learners were exploring 3D-printed fastener technology, they were forming their field of awareness in their environment. This environment comprised 3D-printers and fellow students in the first year of design study, and it resulted in the construction of a modular shelf. This indicated that free learning, as a concept, is therefore not inherently free. Learners' discussions and activities are bound by the way in which the learners' field of awareness and intentionality are shaped by affordances of the technology.

Nor is free learning entirely instruction free if it is to be effectively accessible to different learners, which is the goal of formal education. Learners' intentionality directly depends on their sense of technological transparency. While technology is opaque to a learner, instruction is meant to support her intentionality so she perceives the process as worthy of engaging in. Once the technology becomes transparent, instruction is meant to support her resilience and integrity. In the last research cycle, I formulated instructions bound by the field of awareness. In the first assignment, I removed the multistability and potentiality of the technology by providing a sketch. In the second assignment, I removed potentiality and assigned intention by asking learners to design a product for their colleague. Only when the instructions were context bound did learners perceive them as challenging rather than confusing or overwhelming.

Free learning does not have to be institution free either. As a practical result of this research, 3D-printers became the first medium learners encountered when coming to our department. Further, we changed the intended learning outcomes for the course to accommodate the issue of multistable technologies and learners' autonomy and responsibility.

The process of the study was limited by existing practices of a particular department and setting with design students. Further research is needed to study more transdisciplinary mediations of 3D-printers. This study does not disregard authentic pedagogy or curriculum and instruction-led education; rather, it points out distinctive challenges that these can pose. It does not promote relationalist ontology as a general approach, but instead presents it as beneficial in the context of free learning.

Conclusion

Free learning and relationalist ontology bring into focus the materiality of learning in the learning spaces and action research. By focusing on relationships rather than learning content or a learner, it becomes observable how challenging it is to delineate knowledge outside of its socio-technological environment and make it accessible, meaningful, relatable, and applicable for learners. The European qualification framework demands explicit and precise description of the knowledge and skills, as well as the ability of the learner to apply this knowledge and skills autonomously and with responsibility. These descriptions are then graded on 10 levels of progression from primary education to doctoral studies (EuropeanCommission, 2019, pp. 18,19). If free learning is to be described through intended learning outcomes, learners' autonomy and responsibility might be more accurately defined in relational terms, that is, by the role a learner takes and the learning environments she occupies, rather than her skills and knowledge. Moreover, the instruction is used to support responsible adaptation, adaption, and application of technologies. As a variety of multistable technologies with high potentialities, such as artificial intelligence and mixed reality, continue to enter work life and classrooms, learners' resilience to multistability will become of increasing importance. As learners become augmented by technology, they will progress faster through intended learning outcomes, but will also need strengthened integrity and responsibility. It is therefore essential to position free learning in the context of universities' role of educating learners to develop both integrity and resilience (Levin & Greenwood, 2008, pp. 218-221). In the end, these learners will be the ones who can cope with socio-technological disruptions and who can think critically about the affordances and prohibitions of the technologies in order to implement sustainable development (Sterling, 2001, pp. 56-59).

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Article 5

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25.1

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

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Abstract

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

Keywords

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

Introduction – disruptive workplaces

The emergence of new technologies will bring major changes in the work market, but also opportunities that are yet to be explored. This is reported by Organization for Economic Co-operation and Development (OECD) in "Education 2030" (OECD, 2018). The future workplace environment will be one characterized by the solution of evolving and ill-structured problems, a cross-cultural workforce, unpreceded technological development, and threats to the environment and well-being. The abilities of future students are characterized in this way: "Students will need to apply their knowledge in unknown and evolving circumstances. For this, they will need a broad range of skills, including cognitive and meta-cognitive skills (e.g. critical thinking, creative thinking, learning to learn and self-regulation); social and emotional skills (e.g. empathy, self-efficacy and collaboration); and practical and physical skills (e.g. using new information and communication technology devices)." (OECD, 2018, p. 5)

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

Theoretical perspective – a brief introduction to postphenomenological concepts

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

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

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

Innovation accelerates multistability

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

Method - case study

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

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

Case study research design

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

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

Researcher role

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

Findings

Example 1 – designing dynamic orthosis for a stroke patient

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

Figure 1. Dynamic orthosis assembled and tested with the patient

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

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

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

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

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

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

Example 3 – redesigning a wheelchair armrest for an immobile patient

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

Figure 3. Wheelchair table with mounted fishing rod

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

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

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

Discussion

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

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

Implications for design and pedagogy

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

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

Integrity can be seen as a learner's ability to use the field of awareness to critically assess field compositions in her environment and choose ones with sustainable outcomes. Resilience can be seen as a learner's ability to switch field compositions, pivot, explore technological potentialities, and stabilize and sediment sustainable practices. The focus here is not on the learner's reframing of the problematic situation or applying design methods; rather, it is on the exploration of relations, mediations, and making choices. The other more obvious role of pedagogy is to provide human-technology networks that are unlikely to emerge in business research and development environments, which can facilitate and nurture their integrity and resilience. From that perspective, one cannot teach, for example, inclusive design or assistive technologies outside of the relationships made by patients, therapist, and designers. This relational view on design studio pedagogy also transforms the role of an educator as a "master practitioner" who provides critique (Schön, 1985, pp. 10-17), to that of one who teaches critique.
Sterling (2010) has already provided a theoretical framework for this perspective on pedagogy in his description of resilient learning in relational ontology:

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

Conclusion – an expanded conceptual framework for resilient learning with technologies

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

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

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

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Errata list

explanation	The text follows the APA 6th referencing guidelines, except that the page numbers are referenced whenever the text directly relates to specific pages of the reviewed literature, not only citations. This is in line with the tradition of social science studies.
Page 16	In his observation of design studio, the philosopher D. A. Schön (1985) explained this: Given an architectural program or brief and the description of a site, the student must first set a design problem and then go on to solve it. Setting the problem means framing the problematic situation presented by site and program in such a way as to create a springboard for a design inquiry. The student must impose her preferences onto the situation in the form of choices whose consequences and implications she must subsequently work-out all of the field of constrains. (p.6) corrected to In his observation of design studio, the philosopher D. A. Schön (1985, p. 6) explained this: Given an architectural program or brief and the description of a site, the student must first set a design problem and then go on to solve it. Setting the problem means framing the problematic situation presented by site and program in such a way as to create a springboard for a design inquiry. The student must impose her preferences onto the situation in the form of choices whose consequences and implications she must subsequently work-out all of the field of constrains.
Page 17	Common wisdom today holds that the trend of expertise is to greater and greater specialization and, therefore, success will come more readily to those who choose to specialize early and plan their training accordingly. *Design thinking*, to the contrary, is highly generalist in preparation and execution. In a world of specialists, there is real need for those who can reach across disciplines to communicate and who can bring diverse experts together in coordinated effort. For inventive creativity, the wider the reach of the knowledge base, the more likely the creative inspiration. A designer is a specialist in the process of design, but a generalist in as wide a range of content as possible. (p. 24) corrected to Common wisdom today holds that the trend of expertise is to greater and greater specialization and, therefore, success will come more readily to those who choose to specialize early and plan their training accordingly. *Design thinking*, to the contrary, is highly generalist in preparation and execution. In a world of specialists, there is real need for those who can reach across disciplines to communicate and who can bring diverse experts together in coordinated effort. For inventive creativity, the wider the reach of the knowledge base, the more likely the creative inspiration. A designer is a specialist in the process of design, but a generalist in as wide a range of content as possible. (Owen, 2007, p. 24)

Page 45	Instead, learning is explained as bodily situated and therefore happening in relation to the environment. Merleau-Ponty (Merleau-Ponty, 1996, p. 164) explained that physical and social embodiment shapes meaningful learning. corrected to Instead, learning is explained as bodily situated and therefore happening in relation to the environment. Merleau-Ponty (1996, p. 164) explained that physical and social embodiment shapes meaningful learning.
Page 46	Learning is seen as an essentially creative, reflexive and participative process. Knowing is seen as approximate, relational and often provisional, and learning is continual exploration through practice, whereby the meaning, implications and practicalities of sustainable living are continually explored and negotiated. (p. 523) Corrected to Learning is seen as an essentially creative, reflexive and participative process. Knowing is seen as approximate, relational, and often provisional, and learning is continual exploration through practice, whereby the meaning, implications and practicalities of sustainable living are continually explored and negotiated. (Sterling, 2010, p. 523)
Page 49	Rosenberger, (2014b) etc Corrected to Rosenberger (2014b)
Page 60	In the third article, (Pavel, 2017), the documented research was confined by the context of two groups' experience in a three-hour **workshop**. corrected to In the second article, (Pavel, 2017), the documented research was confined by the context of two groups' experience in a three-hour **workshop**.
Page 70	Media was described by Marshall McLuhan as the amputations and extensions of our bodies and senses (1994). corrected to Media was described by Marshall McLuhan (1994) as the amputations and extensions of our bodies and senses.
Page 91	In these zones, competence takes on new meaning. There is a demand for a reflection, through turning to the surprising phenomena and, at the same time, back on itself to the spontaneous knowing in action that triggered surprise. It is as though the practitioner asked himself, "What is this?" and at the same time, "How have I been thinking about this?" Such reflection must be at some degree conscious. It converts tacit knowing in action to explicit knowledge for action." (p. 25) corrected to

	In these zones, competence takes on new meaning. There is a demand for a reflection, through turning to the surprising phenomena and, at the same time, back on itself to the spontaneous knowing in action that triggered surprise. It is as though the practitioner asked himself, “What is this?” and at the same time, “How have I been thinking about this?” Such reflection must be at some degree conscious. It converts tacit knowing in action to explicit knowledge for action.” (Schön,1985, p. 25)
Page 92	Weimer (2012) asked: “Can learning experiences be designed so that transformative learning happens more regularly? What sequence of activities best transforms dependent learners into independent learners?” (p.439). corrected to Weimer (2012, p. 439) asked: “Can learning experiences be designed so that transformative learning happens more regularly? What sequence of activities best transforms dependent learners into independent learners?”.
Page 106	With distant origins in the apprenticeship of the medieval guilds and more recent origins in the Ècole des Beaux-Arts of the late 19th and early 20th centuries, architectural studios are prototypes of individual and collective learning by doing under the guidance and criticism of master practitioner (1985, p. 6). corrected to With distant origins in the apprenticeship of the medieval guilds and more recent origins in the Ècole des Beaux-Arts of the late 19th and early 20th centuries, architectural studios are prototypes of individual and collective learning by doing under the guidance and criticism of master practitioner (Schön,1985, p. 6).