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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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