How Students in Creative Educations Appropriate Technology: A phenomenological analysis.

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Abstract

Building technological literacy is an important topic in education today while at the same time, creativity is seen as a desirable skill for professional practice and education alike as it is considered a catalyst for innovation. In this paper, we present a case study where we aim to understand how students in a creative education appropriate technology. We analyze qualitative data collected from students in a STEAM higher education undergraduate program called Art&Technology: a program where students are introduced to an assortment of technological tools including software, programming, digital fabrication and physical prototyping which they employ in creating a variety of artifacts. We analyze how students learn and interact with these technologies by analyzing the collected data through a phenomenological lens of technology appropriation. We contribute with understandings on how technology is appropriated as it transforms from an object, to a tool until it finally becomes equipment.

CCS Concepts

• **Human-centered computing → Empirical studies in HCI**.

Keywords

creativity, art, design, technology, appropriation, phenomenology

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1 Introduction

The past three decades have radically transformed the nature of creative work as technological tools became the tools for the trade. Creative practitioners such as architects, designers and artists make use of a collection of tools in their daily practices. While many of these tools are often built *for* different creative practices (for example by large tech companies such as Autodesk or Adobe), they are not always built *in collaboration with* creative practitioners. And while some studies exist that trace how creative work happens and how it could be defined, the practice of creatives (meaning how do they work precisely, and how they come to the outputs they do) remains scarcely documented. Even less documented is how creatives work with technology, how they learn how to use the collections of tools that they end up using in their practices, and how they mis-use it - or bend it to create things that were not intended in the technology's initial design. In this paper we set to investigate how students in a creative education learn to appropriate technological tools. We consider as such tools the ones that contribute to the production of creative work, such as software packages, visual and text-based programming languages, Arduinos, Rasbery PIs and sensors, VR and AR. We believe that this is an interesting and important area of investigation for a number of reasons. First, transcending domains such as art and technology, design and computation, or media technology and arts and culture, have been growing in impact and popularity [19, 25–28]. Second, acquiring technological literacy through art and design is a field of growing interest on its own [62, 65]. Numerous studies show that using the arts and design as end goals, or utilizing art and design methods throughout a learning process can be helpful in achieving deep learning [44] across most STEM curricula [8, 66]. As such, learning how to program can be facilitated through music- or graphics-making as outputs, or sculpture can be the output while learning about geometry and mathematics. The integration of art and design in the STEM curricula has been pioneered by the Rhode Island school of Design in what is often referred to as STEAM (science, technology, engineering, art and mathematics) [39].

Within this frame, we conducted a study that focused on how students in a creative education appropriate technology. To do so we collected qualitative data and we analysed them using an existing *phenomenological theory of appropriation* [60]. Our findings provide rich understandings on how students within a creative education appropriate technology by inspecting it as an object, to making place for it to become a tool and finally having it perform as equipment. We consider this as the primary contribution of this work.

This paper is structured as follows: we start by providing a short review of relevant literature on creativity, creative work and technology and appropriation within creative fields. Next, we present the methodological details of our study, our research question, our theoretical anchoring in detail, and our findings. Finally, we place our findings in a broader discussion on learning and thinking *about*, *with* and *beyond* technology and we unpack the relationship between artistic concepts and technology appropriation.

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2 Related work

There are two areas of related work relevant for our study. The first has to do with defining creativity and examining creative work, while the second has to do with technology and learning, and how technology is appropriated in creative work.

2.1 Creativity and creative work

One of the most commonly used definitions of creativity is the 4P framework introduced by Mel Rhodes [58] and discussed extensively in the literature since [7, 43, 50]. The 4P framework describes creativity as a process that involves four elements: the *person* (the one conducting the creative work), the *product* (the outcome of the creative work), the *process* (how the creative work is conducted), and the *press* (the evaluators of the outcome of creative work). Based on this, Vlad Glăveanu, one of the most prominent researchers on creativity today, who looks at the topic from the perspective of cultural psychology, proposed rewriting the 4P framework into the 5A framework [22]. The 4P framework focuses on the individual and has been criticized for being a-contextual, so the 5A framework is grounded in literature from sociocultural and ecological psychology. In this view, the person in Rhodes's framework becomes the *actor* (and the focus is on the creators' attributes within a societal context - as opposed to the creator seen as independent), the process is rewritten as the *action*, the product becomes the *artifact* (referring to the cultural context of artifact production and evaluation), and the press is divided into *audiences* and *affordances* (referring to the interdependence between creators and a social and material world) [7, 12, 22]. In this case, creativity cannot be evaluated in a vacuum but needs an audience that assesses the results of the creative outputs, also against the affordances (material, temporal) the authors or actors have at their disposal.

But what is creative work? Hsueh et al. [29] argued that while a large portion of HCI research deals with designing technologies that support creative work, what exactly is creative work remains vaguely defined. To address this, they analyzed different definitions of creativity from fields such as psychology, social sciences, anthropology, and philosophy. Based on this, they categorize four epistemic positions on creative work: (a) creative work as a problem-solving activity; (b) creative work as cognitive emergence; (c) creative work as embodied action, and (d) creative work as a tool-mediated expert activity. In the first case, as a problem-solving activity, research on creative work focuses on developing heuristics for navigating solution spaces. In the second case, research on creative work focuses on how new creative ideas might emerge, while in the third case, the focus is on understanding how to do creative work by engaging with embodied knowledge and the dynamic material world. Finally, in the fourth position, research focuses on understanding how creative work is mediated by tools [29].

Another way to look at creativity is by considering entire fields: some fields are positioned as being creative, while others are not. For example, the fine and applied arts as well as different forms of design are positioned as creative fields, while engineering or the natural sciences are not. In this view, some fields can be considered according to the constraints they have to work within (i.e. architects will usually have to work with clients and abide by functional constraints and laws about how and what can be built, while visual artists might create works without a client in mind, and without specific functional or legal requirements). While thinking about constraints in different creative fields, Elliott [48, 49] proposes a visualization where he positions different types of art and design activities, taking the definitions of speculative design and design fiction from [18] as starting points. Here, art, and design sit on a gradient from having fewer constraints to being more constrained. Urban, service design, or strategic design for example deal with more constraints than science fiction or sculpture.

Yet another way to look at creativity is to consider how creative fields will work towards creative outputs. One distinction being drawn between *compositional creativity* and *improvisational creativity* [14]. Compositional creativity is how industrial designers or architects might work: starting with a set of requirements, they will then develop a concept, and once the concept is complete - it remains fixed, and is implemented as close as possible. Improvisational creativity on the other hand originates in the performing arts and in non-western artistic traditions. When working with improvisational creativity, the concept is not fixed, but rather acts as a framing within which the artwork is performed. Improvisational music, contact improvisation or Argentinian tango are instances of this case. Examples of systems that make use of technology to perform with people in various artistic settings, and discuss the nature of creativity as improvisation in this sense include [14] who unpacks the ways in which musical instruments (physical or electronic) influence his own practice as an improvisational composer, and [13, 34, 35] who use various types of robots in performance art.

Therefore, creativity is a complex concept understood and theorized across different disciplines, and we understand it here as an interplay between an *actor* - the one(s) performing the creative *action* towards creating an *artifact* which is presented to an *audience* that evaluates the work according to a set of *affordances.* These affordances include the materials and tools available to produce the artifact. Entire fields can be considered as creative fields, and categorized based on the constraints they have to produce various outputs. For example, the arts, design and architecture are included in this category. These creative fields might work in different ways to achieve their outputs: some, such as industrial design, graphic design, or architecture work in a compositional way, thus using compositional creativity, while other creative fields, such as the performing arts, may work with improvisational creativity.

2.2 Technology and appropriation within creative fields

Over the last decades, digital technologies became part of creative work (*action*) for producing a variety of *artifacts*, from 2D and 3D graphics to animation and music production. Typically, such digital tools have an interface that users interact with (e.g. Photoshop, Illustrator, Maya or AutoCAD). Furthermore, visual programming languages have also become popular among different communities of practice of creative work: MaxMSP [51] for music inspired the development of Grasshopper for 3D design [1], and Touch Designer [67] for interactive installations. These combine the visual interfaces of software tools with the flexibility of coding one's own functionalities. Moreover, they tend to be popular among creatives as they afford building specific functionalities visually by connecting nodes (which represent functions). Recently, increasingly popular became text-based programming tools specifically made for creatives, mostly because they do not need compiling and in this way the distance between coding and the results of the code is shortened. Examples include SonicPi [2] for music production and Processing [21] for visual arts. Finally, various libraries tailored for creative work exist now, among the most famous being p5.js for JavaScript [46] and Open Frameworks for C++ [42], and new tools are constantly being created as Frich et al.'s [20] review of research on creativity support tools (technological tools meant for creative practitioners) shows. Thus, there are numerous digital or computational tools available for creative practitioners. But how are these tools appropriated over time by creatives?

Numerous studies have been conducted within HCI dealing with the interplay between creative work and technology. Some of them focused on idea and concept generation, particularly for the early stages of a creative process. Williford et al. [68] conducted a study where participants were asked to create concept sketches with and without exposure to a technology probe that generated ambiguous stimuli, and found that the use of the probe at the beginning of the ideation process resulted in less fixation and more unusual sketches. In [30] Hsing Chi Hwang & Stevenson Won investigated how participants collaborated with a chatbot in creative idea generation tasks and found that when interacting with a chatbot that is perceived as a machine-mediated bot, participants consistently produced more ideas. Furthermore, Choi et al. [11] presented a tool called CreativeConnect which allows users to generate new graphic design ideas by recombining existing designs, and similarly Kim et al. [37] presented a novel tool (Mixplorer) aimed at supporting novice designers by recombining existing designs to produce new ones. Through a study the authors demonstrated that Mixplorer provided significantly better support for creativity and novelty. Shen et al. In [32] an AI-driven tool to facilitate ideation in fashion design called FashionQ was used, and through a user study with professionals the study demonstrated that the tool supported both convergent and divergent thinking. Meanwhile., in [63] the authors present Neural Canvas, a tool to be used for scenic design and, through a user study, they found that the tool facilitates scenic design prototyping and allows users to explore new ideas that they would not have conceived otherwise. A similar example is described in He et al. [23] who introduce Cinemassist, a tool to support cinematic composition design, while Zhang et al. [70] present a tool called StoryDrawer, an AI-mediated drawing system to support childrens' collaborative storytelling. A user study with 64 children suggested that StoryDrawer helped participants to elaborate ideas and in this way contributed to their creative outcomes.

Trying to understand how professional artists use and develop software code, [40] conducted interviews with artists, and suggest that artists should participate in the design of technologies meant for them. In [20] the authors find that from the plethora of tools developed to support creativity reported in HCI research, many of them are not maintained due to lack of resources. In relation to learning, we turned to the research domains of learning technology [52], blended learning [5], and technology-enhanced learning [38]. Here, there are multiple studies that provide strategies on how educators can more effectively introduce technology in classrooms (for example, [10, 52, 61], but most of them are typically focusing more on the lecturers and less on the learners, and they try to supplement existing teaching activities [38], instead of rethinking them.

Therefore, there is a need for studies that extend the related work by focusing on two underrepresented aspects. The first is the need to go beyond studying specific tools, and study how creatives make use of multiple digital technologies concurrently. The second highlights the need to conduct studies over long periods of time in order to understand how creatives appropriate technology.

3 Our Study

In the following subsections, we first discuss our research approach and we present in detail the case we chose to focus on. Then we present methodological details on how and why we collected qualitative data, we thoroughly discuss our theoretical anchoring, and we explain how we used the theory to analyse the collected data.

3.1 Research Approach

Our research interests lie in answering this research question: ***How students in creative educations appropriate technology?*** We focused on students, as they provide a great opportunity to extend related work by understanding how multiple technologies are being appropriated by creatives over a long period of time. For this, we conducted a *case study*. The reason for opting for this research method, was its suitability in relation to our research interests and the fact that it would allow us to gain deeper understandings on how technology is being appropriated by students in real-world settings. From the different available case study designs [59], we opted for that of *social construction of reality* [59, 64]. In such case study designs, researchers often have an *intrinsic* interest in the case itself (contrary to *instrumental* cases), since the focus is not that of theory building and generalizing per se [59]. Instead, through these types of case studies researchers provide *thick descriptions* of the complexities within the case, and interpretations are offered to the readers. Furthermore, researchers do not necessarily extract conclusions that are generalizable across multiple cases, but the provided interpretations should be treated by the readers as an opportunity to learn. Readers can make their own generalizations based on *personal and vicarious experiences* ("naturalistic generalization") [59, 64].

The real world case we chose to focus on is an undergraduate program of Art&Technology from a problem-based learning university. The reasons for choosing this program are multiple. First, Art&Technology is a *representative* creative education, as the students work creatively, produce artworks, work in design studios, and exhibit their artworks in public-facing exhibitions every semester (actor-artifacts-audiences, [22]). We do not evaluate whether the final artworks can be considered as having creative value, our focus is on the fact that the program prepares students to become creative practitioners. Second, students utilize knowledge provided by courses (typically three per semester) into a project developed as part of a design studio and they should always engage with a problem in their work. Thus, Art&Technology is an *applied* education where project work is done in groups (typically two to five students), who are responsible for building the artwork itself, making sure the artwork is anchored in theory, and reflecting on

name	semester	technologies they are comfortable with	age
George	4th	Sketchup, Arduino, Processing, Rhino3D, Python	20
Eric	6th	Sketchup, Unity, C#	30
Daniela	3rd	Illustrator, Photoshop, Adobe Premiere, Maya	20
Alexandra	6th	Processing, Arduino, Unity	22
Maria	4th	Processing, Arduino	31
Max	6th	TouchDesigner, Arduino, Maya	29
Sofia	5th	Processing, Arduino	21
Helen	6th	Processing, Arduino, Raspberry Pi, Unity, C#, Python	24

Table 1: Demographics of the interview participants. All names are fictional.

the outcome/results/process through a group report that is part of their exam. Students have the freedom to define the problem they want to engage with through their project. Their produced artifacts are subjected to *few constraints* since there are no functional requirements, or design briefs to answer to, only the premise that they have to use a variety of technologies, and the medium on each semester their artifact should belong to (i.e. public space art, sculpture, performance/theater play). Third, both the input the Art&Technology students receive (e.g. courses and workshops) as well as their artistic outputs always include *diverse* technological components. Courses cover art history and theory, curatorial practices, design theory and creativity methods, as well as artistic and academic research methods. Technology-focused courses and workshops introduce physical prototyping using Arduinos, graphical programming, video editing, 2D graphical representation, 3D modeling, digital fabrication, as well as VR and programming. In this way, students are introduced to a range of technologies and tools, and these are then used as materials for creating different forms of artistic outputs, ranging from interactive sculptures to public space installations, and collaborative performance/theater plays.

3.2 Data Collection and Participants

Four sources of data were utilized in our study, and only one of the authors was involved in data collection. This researcher was also a lecturer/supervisor in the education and we will refer to them as *involved author*. First, the *involved author* conducted eight, 30-45 minute semi-structured interviews with Art&Technology students at different levels in the education: from third-semester students to recent graduates. The interviews were conducted between June 2021 and October 2023 and demographic details about the participants can be found in Table 1. Recruitment of participants was conducted through posters placed in the common areas of the Art&Technology building, asking students to participate in a study that aims to understand how they appropriate technology in their creative practices. Two cut-off criteria were applied: a) participants had completed a minimum of one year in the education, meaning they had acquired at least some technological skills through their studies and had produced at least two artifacts that had been exhibited as part of public-facing exhibitions, b) participants had no active relationship with the *involved author*, meaning they did not have them at the time of the interview neither as a lecturer, nor as supervisor. All eight participants volunteered, signed a consent form that also explained the purpose of the interview, and were informed that they could end their participation at any moment. None chose to do so. After an introduction where students were informed that we were interested about how they appropriate any kind of technology (even beyond the taught ones) in their creative practices, the interviews revolved around: the technologies that students used in their semester projects, whether and how technology impeded and/or enhanced their creative processes, how they learned to use these technologies as well as how they negotiated as groups on how to utilize technology in their creative process(es).

Second, the project reports students submit as part of their project work, were included in the study, since they offered valuable reflections on various aspects of technology appropriation. In particular, we included the publicly-available reports that the eight participants had submitted, focusing on their Design, Construction and Reflections sections.

Additionally, we drew on the *involved author's* personal experiences of teaching three of the technology courses in the program over the last 5 years. More specifically, the courses that have to do with 2D and 3D representation, digital fabrication, and visual programming for 3D modeling and digital fabrication. Each of these courses run five iterations, and the *involved author's* notes, comments and reflections each year, gathered also during feedback sessions after each course were collected in a digital format. Finally, in each semester, students provided evaluations in two forms: a) they participated in two or three meetings with a semester coordinator (typically a lecturer) where they discussed what was working well and what needed to be adjusted and why in a semester, b) they provided anonymous feedback of each module (courses and project) as scores in questionnaires and open-ended comments. These publicly-available minutes and reports were also included in the analysis.

3.3 Theoretical Anchoring

In order to answer our research question on how students in creative educations appropriate technology we opted for a suitable theory to guide our analysis process and shape the interpretation of the findings. Phenomenology [17, 24] was deemed as suitable for our case because: a) numerous seminal research works in HCI have used it to explain how people use technology and design in general (e.g. [15, 45, 69]), b) it moves away from the Cartesian worldview of technology on one side and users on the other by focusing on the socio-materiality of technology [53], and c) it deals with how people transform their everyday practices by engaging with technology (for more see pp.28-34 [45]). The latter is what we understand as appropriation and thus we utilized an existing *phenomenological*

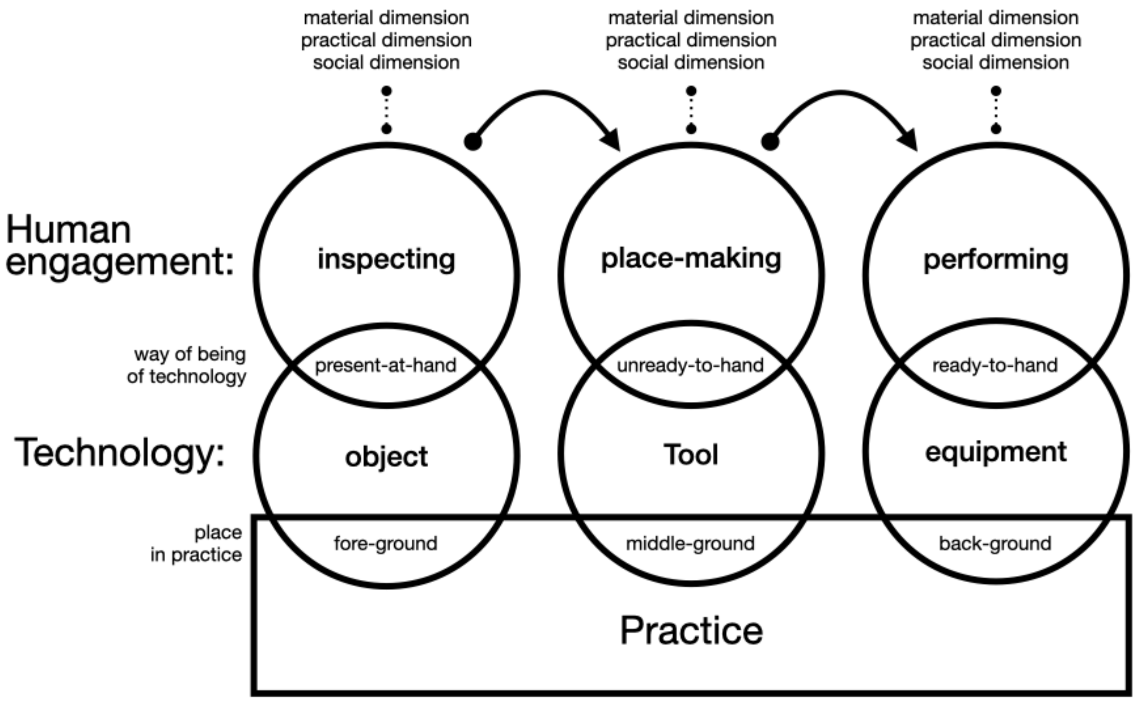

Figure 1: Phenomenological theory of appropriation [60] used in the analysis of collected qualitative data.

theory of appropriation [60] which was applied to the four sources of data as an analytical lens (see Figure 1 for details).

According to Riemer and Johnston's theory [60], people appropriate technology in time, as it moves from an object being *inspected* from the outside, to a time when people, as they start to understand how the technology works and its affordances, make space for it in their existing practices through *place-making*, and finally to it becoming embedded in and part of practice, thus *performing*. Within these activities the *ways of being* of technology are *present-at-hand*, *unready-to-hand* and *ready-to hand*. When placed in the fore-ground technology acts as *object* to be inspected. As people make place for this new technology by learning how to use it, technology becomes a *tool*. Finally, as technology has been absorbed within existing practices, it becomes *equipment*. Thus people will inspect a technology as an object in their initial interactions with it, placing the object in the *fore-ground* of a practice. Then as people learn how make use of the technology (or how it can be useful, and what its affordances are), it becomes a tool among other tools in the *middle-ground* of a practice. Finally, after people understand how and where to employ the technology and after it has been appropriated, technology becomes equipment placed in the *back-ground* of the practice.

As appropriation of technology unfolds over time, each of the three activities has a *material*, *practical* and *social* dimension. As an example, we can look at a painter who wants to integrate Photoshop in their creative practice to illustrate these three dimensions. In the first phase, that of inspecting a technology as an object in the fore-ground, the *material dimension* refers to examining the object's properties against one's existing skills and expectations of what the affordances of the object could be. These expectations are derived from appropriating other technologies in the past. Here, Photoshop is an object of inquiry and the material dimension implies that the painter inspects Photoshop against their existing skills (e.g. using other software tools that have an interface, such as MS Word). The *practical dimension* refers to inspecting the technological object against equipment and existing understandings of the practice that is to be introduced. In this case, the painter might inspect Photoshop brushes against physical brushes. Finally, in the *social dimension*, the technological object would be inspected against existing objects and social norms. The painter would look at Photoshop and consider how other artists use it and how art critics think about the use of technologies for painting (for example, by wondering whether artworks done using Photoshop could or should be still considered painting proper).

In the second phase, as it becomes a tool for practice the *material dimension* refers to acquiring the skill to use the tool, and discovering what the tool affords. In this phase, the painter might spend time experimenting with the different functionalities Photoshop has. The *practical dimension*, implies placing the tool among other tools, and within the logic(s) of the practice. As an example, the painter could consider ways to integrate their physical paintings with Photoshop ones, by projecting an image they drew using Photoshop on a wall, and painting using the projection as a guide. While the *social dimension* refers to making the tool proper in practice, and placing the tool in social identity production. In our example, this would mean that art schools might start to teach Photoshop to painting students, and art studios might start to ask for their employees to use Photoshop as a tool.

In the last phase of technology appropriation, when the technology moved from object to tool and has become equipment, the *material dimension* refers to the equipment withdrawing from attention and becoming a means. The painter would consider Photoshop in the same way they consider their physical brushes and colors. The *practical dimension* refers to the equipment having a place among other equipment and practices; Photoshop is used seamlessly alongside other painting equipment. Finally, in the *social dimension*, the equipment is normal and part of social identity: all painters are expected to be able to use Photoshop.

3.4 Data Analysis Process

In order to answer our research question on how students in creative educations appropriate technology we conducted a deductive analysis [6] on the collected qualitative dataset (all four sources). The pre-defined analysis framework we used emerged from the *phenomenological theory of appropriation* [60]. In more detail, we used the codes of *Human Engagement* (*inspecting*, *place-making*, *performing*), *Technology* (*object*, *tool*, *equipment*) and *Dimension* (*material*, *practical*, *social*) in a five-step analysis process suggested by [6]. To do that, first, the collected data were anonymized and stored in a GDPR-compliant way. Then, the collected data were closely examined by both authors in order to produce initial insights. These initial insights took the form of data excerpts containing information either about *Human Engagement* or *Technology*. During this process, the two authors worked independently. The sum of all those initial insights was then collaboratively and iteratively coded together by the two authors, with the aim to: a) decide where in the appropriation process within a practice the insight belongs to (*fore-ground*, *middle-ground* or *back-ground*) and for which dimension (*material*, *practical*, *social*). From all four data sources, only relevant data - data that fit the applied analysis framework - were included in the analysis. Since the second author was not involved in the Art&Technology education, their role was to also provide critical reflections on why each insight was extracted from the data and to mitigate bias, since it is often difficult for a teacher to distance themselves from data about their own educational materials/practices.

4 Findings

Our findings are structured around the three axes of the phenomenological theory of appropriation [60], and for each one we highlight the material, practical and social dimensions.

4.1 Technology in the fore-ground: objects of inspection

4.1.1 Material Dimension. When students initially *inspect* technology and its ways of being is that of *present-at-hand*, as it sits in the *fore-ground*, in the **material dimension** they will examine it against their existing skills and expectation from other technological objects they have interacted with - such as for example word processors or phone applications. Initially, there is friction when things look and behave unexpectedly. For example, in the case of 3D modelling software, navigating 3D spaces takes time getting used to, as does moving between different views (i.e. perspective, top and front). Sofia explains that: *"when drawing or learning a software tool, to me that is very complex. I feel like the names for the buttons are just words put together that I don't really get, so I'm going to the program and pushing every button to see what it does"*. Similarly, visual programming languages [such as Grasshopper or Touchdesigner] are also challenging as it takes time to understand the structures of the building blocks and what connecting them actually means. Text-based programming languages are often perceived as the most *"alien"*. According to Maria, *"Processing is this whole new language that you don't know [...] If I wanted to learn how to speak Japanese: I don't know the letters, so I would not know where to start and I would say it's similar with Processing"*. Others perceive it as frustrating: *"it can be very frustrating to learn to program when you don't have experience"* (Alexandra), and overwhelming: *"In the beginning it was difficult to start somewhere because there were all these holes and as soon as you filled one hole, you came across a new hole in your knowledge. Then it is explained with words that you also don't understand. And then you go into this rabbit hole of trying to find something that makes sense"* (Maria). Turning to the documentation of a programming language is also challenging due to the technical nature of the language used in these documentations. The syntax in programming is also described as confounding: *"In the beginning, I was asking: why is the name of this function not capitalized? But its capitalized in the middle. Is that important? And its difficult when you have no experience at all – to figure out what is really important"* (Maria) and it takes effort to master all these underlying *"made up rules"* (Sofia).

4.1.2 Practical Dimension. On the **practical dimension**, technological objects are inspected against equipment and understandings of existing practices - in this case, against existing creative practices. For example, when using software tools, their interface is compared with tools from other practices such as other forms of creative work students might be familiar with. From the participants in our study, Maria and Max where the only ones that prior to their studies had done painting, and collage and black-ink etching respectively and so could compare the technological objects introduced to them to their existing knowledge of using these other materials for art-making proper. For Max, the pens used for etching are considered now as equipment that was mastered through trial and error, over time. This approach was also applied while experiencing new technologies: *"I look at learning a new technology in the same way as it is to learn how to use brushes, pencils, ink: drawing and painting tools"*. Furthermore, some of the node-based programming tools were compared to the painting practice and thus perceived as easier to master by some: *[...] Something like Touchdesigner is more intuitive. It's much easier for me because that's how I think when I work. When I paint, it's a visual activity, so I have to see where my process is [...] I have to see what I am doing [..] I can easily just put things together and see how it works in Touchdesigner [in comparison to Processing* (Max). Physicality though had the opposite effect for Helen: *programming usually makes sense even when it does not. But when it becomes physical, like with the Arduino, there is more physics in it, electricity and those things. I have always found harder to understand how a sensor actually works. With code it is easier for me.* The practice of looking for help online for programming tasks, was also challenging in the beginning, as *"I'm not so good at finding the right forum posts for coding"* (Alexandra) and *"even with documentation and examples, they don't do exactly what you want* *them to do, or don't fit exactly into your code"* (Maria). Finally, during the period we conducted the interviews, Chat-GPT and other AI generative tools started to become available more broadly. For most interviewees, text-to-text generators were initially compared first to Google and then to lecturers and teaching assistants. After the initial exploration, Chat-GPT was seen as complementary to the educators: *"In a class setting, you're thinking, three people have asked this question, and we have been going through the same thing three times, but I still don't understand [...] can you explain to me what a float means, and then it [Chat-GPT] explains it very well"* (Sofia).

4.1.3 Social Dimension. In the **social dimension** of this stage, technological objects are inspected against existing projects in the field, such as other artworks or projects done by fellow students, and social norms. Many of our interviewees informed us that while experiencing an art piece or performance that obviously made use of technology, they often wondered how exactly these had been used in creating the artwork. For example, Max talked about visiting modern art museums, looking at pieces that integrate art and technology, wondering how they were created, and wanting to understand the creative processes that lead to such works. For some of the students, reaching this level of mastering technology was one of their main motivation: *"I think people are usually interested in becoming better at the things they are not good at. So someone might say: oh, I'm not that good at coding, but I want to become better, so I want to code this semester"* (George). For others though, lack of motivation to learn and/or other tasks that are part of the social norm of being in a group and delivering an artwork along with a report were getting in the way: *"In all the groups its been one or two people in charge of technology and then all others have supported with the more practical things like reading on theory and stuff like that. For most projects we started out by saying that everybody wants to work on the coding because everyone wants to get better at it. But it turns out that its just one or two people that end up doing it because they know more about it"* (Daniela).

4.2 Technology in the middle-ground: place-making for new tools

4.2.1 Material Dimension. In the **material dimension** of this stage, students start to acquire the skills to use these technological tools, which become *unready-to-hand*. Students had different views on learning curves for software that have an interface (such as Maya [4], Rhino3D [47] or Ableton [3]) in comparison to text based programming, views that were sometimes contradictory. For example, according to Maria *"Maya is frustrating in a different way than Processing: because there are so many features, so many things that you can do. Its difficult to feel like you actually learn how to use it"*, and similar was Alexandra's experience: *"with such software, its easier to do something more complex. It depends on the software though, because some tools are also so complex that the interface is a language in itself"*. Others prefer coding: *"When you're learning programming its quite simple because its a language, you have to understand that that's just how things are [...] I know when I'm programming - if I write this code, it will do this, so I'm not trying to predict what it will do"* (Sofia). Slowly and as the time progressed many students felt that *it is definitely become better, even though I'm still shaky in all of the programs, but I feel like, every time you do something, because it's a lot of trial and error you learn something from the mistakes"* (Sofia). Skills started to built up for the students, and they describe being able to combine different example files as part of their programming practice: *"I have relied pretty heavily on the examples. But there's always some hole, something I don't know how to do and then I find an example and figure out where everything is placed, like the syntax of it all, and then I try to alter some things in that example, and then try to merge some things from different examples"* (Maria). And looking for documentation becames easier: *"Now it's getting easier to read the documentation because you have had a lot of different bits and pieces and after a while you start to understand some of the terminology and then its easier to read. But [...] it still takes a while to get into the terminology so you don't have to look up every other word"* (Maria). Planning ahead and having a structure in place was also a new acquired skill: *[Now] I would not just start, but also work with pseudocode. I actually make a drawing in the beginning to try to understand what I want to do. I feel like I have gotten better at recognizing issues and realize 'oh, here it would be a great idea to use a for loop, or a list', whereas in the beginning, I was just more chaotic"* (Helen). Using AI tools such as Chat-GPT as a programming aid also started playing a concrete role: *"I Just ask the AI: these are all the things that I don't understand about my code"* (Sofia). Estimating though how much time a programming task would take was still a difficult skill to acquire: "*"It is difficult to plan when you have to code: sometimes it flows and you're making progress and then other days, you get nothing done from the checklist – that can be frustrating* (George)", but at least things were starting to be in place: *"And now after these semesters things are starting to settle, to make sense, and I am able to ask questions about what we're doing"* (Maria).

4.2.2 Practical Dimension. The **practical dimension** implies placing the tool among other tools, and within the logic of the practice. As students make place for one tool in their creative practice, they learn also how to make place for other tools, progressing in their technological literacy. In Alexandra's words: *"I got more and more used to thinking in elements, combining them, and not being afraid to use some technology that I have never used before. I learned over time that I can always learn a new thing in a new project – I don't need to have had experience with it before"*. This relates to Daniela's experience: *"Some of the knowledge that you gain from working with some things can help you work with other things – like other software or other hardware. So I think its been building on each other, but it has not been the same thing. I enjoy trying something new to expand my repertoire of what I know how to work with. It's nice to try something new even though you might not be able to make something advanced with it"*. George describes his experience as: *We're constantly trying new technologies and the things we like that give something good to the process, we take on to the next semester project, and for the others – then you've at least tried it and you can use it as a tool if you want.* Confidence started to build up as students experienced with more technological tools: *"I can already see that there is progress because learning Arduino was a little easier as I already knew Processing and now Python is a little bit easier because I know the other two languages [...] I already have the basis of how programming works"* (George). In relation to AI tools, Sofia explained that at the moment she finds generative AI more interesting as an assistant to help with her programming, rather than in her creative work: *"I like my own creative process better than using an AI to choose something. But when it comes to programming, its more helpful because you can do things wrong. With creative work – you can't do anything wrong. So when you don't understand what you're doing and why it's wrong, you waste a lot of time. I would say AI is more useful to me in the programming part "*. However technology is not always enhancing the creative practice: *"Sometimes you just don't know enough to even have an idea in the first place because you don't see it as a possibility. But I think that once I have an idea and try to use something, and I believe that I can, then I can learn to use it. But I do think sometimes I might cut off ideas because I don't really believe that I'll be able to bring them to fruition. So yes, technology does limit sometimes"* (Daniela).

4.2.3 Social Dimension. In the **social dimension**, tools are placed in the social identity production. Most students were motivated by their environment and their peers to continue experimenting with various tools: *"I think the first courses were quite difficult for me, and I gave up, but then I tried again and when everyone else is trying to do better, you automatically also try to become better and try to get on that level"* (Sofia). Similar was Helen's experience: *"I know that I have encountered problems, and I have sat with them for hours, thinking that I will never make this work, and then in the end we got it to work"*. Additionally, in workshops on digital fabrication, for example, students are more likely to remain engaged in class, and put in more effort if the output is a collaborative artwork - where each student contributes with a part in it, especially if it is exhibited publicly. In these cases students take responsibility of their part in the collective work and feel ownership for it.

4.3 Technology in the back-ground: performing with equipment

4.3.1 Material Dimension. Looking at this from the perspective of the **material dimension**, equipment withdraws from attention becoming a means, and can now be considered ready-to-hand. There is no more distinction between art and technology, but instead they are developed together. As George explains: *"Technology is a tool that you can use and that both means that it is very practical, but using it becomes part of the creative process itself, and [it] helps you gain new ideas and develop new things"*. Moreover, there is no more perceived separation between creative work and technology as it becomes the equipment for creative expression: *"There was never really a disconnect between art and technology – they happen together [...] There are a lot of things that I could not do without technology because this is how I developed my artistic processes. [...] Technology offers me the opportunity to tap into that creative potential"* (Eric). Experimentation with equipment became the means to their creative practice: *"I have never experienced in any group work, people shying away from delving into a technology that they are not used to"* (George), but often due to the learning constraints of a semester this experimentation had to stop: *"But then the pressure came and the enjoyment and the excitement went out of it, there was the anxiety of 'am I going to be able to learn everything in the right time?'"* (Maria). Additionally, when technology was in the foreground, working towards an artifact was more chaotic since students did not fully grasp what they could do with technology compared to when it had become equipment: *"In the first semester we were thinking what we wanted to do, no limitations, and [often] older students and teachers were telling us: 'well, maybe this is not realistic for a first-semester project'. [But now] we have learned more about what we are capable of and what technologies are capable of so we understand now that there are limitations"* (George). And, at this stage, the practicalities of programming such as looking for documentation and code examples, have been normalized. For example, in modifying existing code George explained: *"We do less tweaking now, and more things from the bottom up. We learned through the tweaking what these technologies can do, and then once you start to understand how it works, if you build it from the bottom up you have more control"*.

4.3.2 Practical Dimension. In the **practical dimension** of this stage, the equipment has now a place among other equipment and practices. Among the most common comments was reaching the point of being able to combine different equipment: *"It was almost like a revelation for me because I had been working with something for a few years and all of a sudden I could see how I could use it. Like I can combine these things together [...] And sometimes it works, sometimes it does not. [I keep] mixing stuff together until it works"* (Max), and *"We learned not be stuck on a tool, and also being able to combine different ones [...] We have become better at tackling bigger things, and being comfortable doing something new all the time. By bigger things, I mean more ambitious technical projects and technologies that sound more scary"* (Alexandra). And in order to do that, confidence, inspired by the understanding that they can perform with the equipment, is important: *"It's always about the confidence. I think that even if I don't know how to do something yet, I can learn how to do it"* (Helen).

4.3.3 Social Dimension. Finally, in the **social dimension** of this stage, equipment is normalized and part of social identity. At the end of his three years of education, Max now states: *"At the beginning, technology was very limiting because I did not know what was possible [..] But now I can see how it could work – it got demystified"*. Thus, for him, as well as for his peers, technology is seamlessly and intimately integrated in their creative practice. He believes that *"The future of art is having artists working together with engineers and technologists in making increasingly complex artifacts"*, which is why he finds it important to *"have a common ground where I can talk to people who are more advanced technologically, so in the future when working professionally, I can collaborate"*.

5 Discussion

In this section, we discuss our findings and position them in relation to different theories of creativity, and specifically creativity with technology. We structure the discussion in two subsections. In the first subsection we discuss how creatives think about technology in the first stage of technology appropriation, how they end up thinking with technology for creative outputs in a second stage of technology appropriation, and finally to how they might end up thinking beyond technology - thus understanding both what it allows and what it does not. In the second subsection we discuss the interplay between the artistic concept being developed, and its relationship to the technologies used.

5.1 Learning and thinking about, with and beyond technology

When thinking about technology, in the first stage of technology appropriation, different technological objects appear more or less 'alien' in comparison to prior knowledge. Generally for many creatives, programming is approached similarly to learning a foreign language and the learning curve is a steep one, especially to those who have no prior experience with programming languages. As such, programming conventions like capitalization for variables and language structure are at the fore-ground. Comparably, software tools are perceived as more approachable because users already have prior experiences with tools that have interfaces, but also because the interfaces are thought through to a certain extent - meaning they are designed with aspects of usability in mind. Additionally, as software tools for creative work are typically commercial products, the online resources for them are easier to find and understand. This is in contrast to documentation of programming languages which are designed for general use and rarely have creative work in mind, or - when programming languages are designed for creative work they typically have smaller communities. Finally, learning about visual programming is considered as more accessible and intuitive since its input-output graphical nature is sometimes seen as close to creative experimentation such as testing brushes for painting.

Over time, students in creative educations become less intimidated when approaching a new technology, and slowly start thinking with technology even when such a technology seems "scary" (e.g. machine learning). Thinking this way, allows creatives not to settle on a particular technology or tool, but rather keep experimenting, and as they become more proficient, they become more ambitious in their artworks, while they keep building on their technological literacy. Thus they start to learn with technology: "In other words, when students work with computer technology, instead of being controlled by it, they enhance the capabilities of the computer, and the computer enhances their thinking and learning. The results of an intellectual partnership with the computer is that the whole of learning becomes greater than the sum of its parts. Electronics specialists use their tools to solve problems. The tools do not control the specialist" [36]. In this way, technology becomes a *cognitive tool* [36], and we argue that they end up thinking beyond technology. Thinking beyond technology refers to being able to understand what can and cannot be done with technology, where it can be useful, and understanding its inner logic. Once technology becomes equipment, as it seamlessly integrates within creative practices, students in creative educations that often are expected to do what they (or the audiences to whom they present their work) consider new things, will also try to find ways to mis-use technology. Mis-using refers to finding ways to utilize technology for other purposes than intended, not *"as they are meant to"* (for example they might use medical imaging software to extract 3D models which they later 3D print and make it part of an artwork). This corresponds to findings in other work, such as for example [41] who argues that technology appropriation is always a case of mis-use. As more and more technologies are being mis-used by creatives, by having an object becoming a tool and later equipment integrated [55] in their creative practice, this know-how is transferred to how new objects are approached. This aligns with Seymour A. Papert's constructivist learning theories [54] who proposes that knowledge is constructed during the process of making artifacts.

From an educators perspective, it is evident that the framing within which the creative work happens plays an important role on how creatives appropriate technology. Issues such as the physical space where students work in their group projects, the way semesters are structured by having courses feeding into the project work, and that the end product is always artistic, creative or designerly, and displayed in public, strongly motivates them to learn. Furthermore, the freedom of choice about the problem or topic students will focus upon allows self-expression. Having the freedom to decide on the topic and theories one wants to engage with, means that learning happens in the service of self-expression, and learning new technologies is done in the service of being able to create the artifact. This is in line with other research that calls for integrating art-based and design-based research across curricula [9, 25, 33]. Finally, in our case, learning is best achieved when students were working on a participatory work; when they know that everyone's performance will influence the resulting output. Then, they are more likely to help each other, spend more of their time on their part and feel ownership of the end piece. This is inline with [31] who also suggest that this type of extrinsic motivation will encourage learning.

Making place for new tools also allows people to reflect on the experience of learning proper, comparing different tools between them, and reflecting on one's own learning style. In the second stage of technology appropriation, most participants describe that gaining the skills to use one tool, also helps them to approach other tools - and over time this means *learning how to learn* in a self-directed way. Learning styles are different - some describe setting time off time for free experimentation in the beginning of a project, to simply get used to the new technology. Others however, describe simply starting to use technology and seeing what that might bring forward.

5.2 Artistic Concepts and Technology Appropriation

Students in creative educations and creatives in general do not use technology in void. While appropriating the technology during project work, they do so while at the same time developing concept(s) for a creative artifact. All the interview participants stated that they learn from their teachers, laboratory staff, older students, and from previous projects about what is possible to do with different technologies and that they take this knowledge to their concept development phase. Once they have an idea about what their concept is, then most approach learning a new technology on a just-in-time basis: they will learn whatever is needed to realize and build the concept for the artwork at hand.

The relationship between concept and technology is not the same for all students. Our findings suggest that for some, once the concept is defined, it will remain fixed. Technology appropriation will revolve around supporting this concept and if one technology fails to do so then it will be replaced, or new technological tools will be designed in service of the concept. In this way, they work in a way that is more similar to compositional creativity [14].

Other participants utilized concepts that were loose, meaning they would either start experimenting with a variety of technologies and through experimentation they reach a concept or experiences with technologies will act as a point of departure for a new concept. This approach is closer to improvisational creativity [14]. Our experience suggests that making use of fixed or loose concepts is a matter of personal preference on how people like to work and learn.

Finally, making use of technology for creative outputs needs to manage two different types of thinking: creative thinking and computational thinking. As one of our participants explained - when working creatively on a concept one cannot do anything wrong, while when programming many things can go wrong. Computational thinking - or thinking though the logic of computational tools, in general has been shown to be perceived as limiting by some creative professionals [56, 57]. Understanding and finding ways to navigate between these two seems to be the most interesting challenge and opportunity for these future professionals. When it comes to generative AI, our findings suggest that some creatives might not want to just choose something that an AI makes (although these tools are seen as helpful programming assistants), but prefer their own creative outputs - this means that they would reject the idea that creativity can be automated and creative work can be left to machines.

6 Conclusion

In this paper we investigated how students in a creative education appropriate technology with the goal of unpacking the interplay between creative practice and acquiring technological literacy. Though a phenomenological lens we described how technology is inspected as an object in the foreground, in a first stage of appropriation, to how it moves to the middle-ground and finds its place as a tool, and how it fades in the back-ground as it becomes equipment in future practitioner's work. This perspective can be useful for other educators in understanding and explaining how their students appropriate technology as well as for researchers and practitioners of technologies designed for creative practices in providing functionalities better tailored to creative work. We hope that this work contributes to additional understandings on how students of a creative field appropriate technology. Especially if similar work as ours is supplemented with understandings of the technical foundations of appropriation [16]. We acknowledge that one major limitation of our research is that it is bound to a Western European perspective. In future work, we aim to expand our understandings by including more perspectives. As an immediate next step, we plan to conduct a study with alumni of the same program and inquire how the interplay between technology and creative work unfolds once they become professional creative practitioners and leave an environment that is focused on learning.

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