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6 Materiality in Invention Pedagogy

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Introduction

Making practices are central to invention pedagogy, in which abstract ideas are transformed into tangible forms and functional prototypes. Materiality transforms the process and requires the students and teachers to be ready to alter their plans and adapt to surprises as they are learning to work with the materials, technologies, and schedules at hand. In this chapter, we discuss invention pedagogy from the point of view of materiality. We consider how active and dynamic matter alters practices and how this perspective enriches our understanding of the aims of inventive learning. Theoretically, this chapter builds on the traditions of Nordic research on craft education and the concept of relational materialism. Further, our thinking is positioned with the insights from the Finnish educational system and the school subject *crafts*.

We perceive the process of making as an entanglement of maker and matter, where the human participants think with the matter and learn from it (Ingold, 2013). Materials are not considered merely as resources; instead, material transformations and related bodily movements emerge from dialogical negotiations between maker and matter (Aktaş & Mäkelä, 2019). With cultivating their craft practice, the maker develops their knowledge of materials and techniques, as well as people and culture reciprocally (Lahti & Fernström, 2021). Materiality embeds processes of learning and knowing into the tangible world (Mehto et al., 2020). Making provides an opportunity to reflect on one's position in the world and to sensitize to the dependencies and responsibilities with the environment (Groth, 2020).

Within invention pedagogy, we have illustrated how prototyping practice acts as an aid for thinking, as a social mediator, and provides inspiring constraints through materiality (Yrjönsuuri et al., 2019). Further, we have analyzed how materiality constrains and enables collaboration, for example by hindering opportunities for participation or providing tangible access to common ideas (Mehto et al., 2020). Focus on the epistemic roles of materiality emphasized the importance of thinking with materials in making (Mehto et al., 2020). During these studies, our perspective has gradually shifted from how students use materials to perceiving relationalities of materiality. Such a perspective aims to enrich the prevailing human-centered perspective by shedding light on the edges of the intentional learning process and the obscure, wide-reaching connections of matter.

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To help us understand how matter affects situations, we turn to theories that flatten the ontological hierarchies between humans and non-humans (e.g., Bennett, 2010). Perceiving humans as parts of the world unravels dichotomies, such as mind/body or nature/culture, highlighting the interdependency of humans and environments (Latour, 2005). Therefore, we emphasize the indeterminacy prompted by materiality in making. Further, the perspective of sociomaterial entanglements is steered toward seeking more-than-human collaborations that are crucial for living on a damaged planet (Haraway, 2016; Tsing, 2015). Thus, we highlight making as sensitizing to materiality to seek collaborations with the material world. The call for re-evaluating the position and responsibilities of humans also includes knowledge practices and pedagogies (Braidotti, 2019), setting demands for futures of education (Common Worlds Research Collective, 2020). In this chapter, we discuss the potential that making could have for cultivating learning with the world. Our approach is practical, as we consider how ontological ideas of relational materialism could relate to everyday life in school.

In addition to these onto-epistemological stances, our thinking is based on the practices of Finnish education, in which material making is present especially in the school subject crafts. Materials play an essential role in the tasks, objectives, content, and learning environments of crafts (Pöllänen, 2020; Porko-Hudd et al., 2018), and they can be used for their expressive qualities, as resources that are tested and analyzed for creating design solutions, or as constraints that enable or hinder technological activities (Finnish National Agency of Education [FNAE], 2016). Materiality requires appropriate learning environments for crafting, where versatile equipment, machines, and tools enable adopting a responsible attitude toward working (FNAE, 2016; Jaatinen & Lindfors, 2019). Further, Nordic research on craft and sloyd (a school subject equivalent to crafts) education emphasizes materiality. Working with materials develops students' material knowledge that contributes to advancement in their designing (Härkki et al., 2016); therefore, students should be encouraged to work with materials to experience both their potential and limitations (Illum & Johansson, 2012). Communication and meaning-making in crafts take place through several connected levels of interaction: between humans; between humans, tools, materials, and the surrounding space; and between mind and body (Kangas et al., 2013a). Teaching and instruction in crafts rely on the multimodality of interaction (Ekström, 2012; Koskinen et al., 2015), providing students with multifaceted opportunities to generate and communicate their ideas and knowledge (Kangas et al., 2013b). Materiality of crafts can also promote awareness of sustainability as well as critical and ecological stances toward consumption (Väänänen et al., 2018).

To bridge the practical and theoretical takes on materiality, we discuss the theoretical approaches with an invention project in which students aged 14–15 designed and built smart products in small teams. The aim of the design task was to orient students toward the problems in their everyday lives and the artifacts involved. Initial ideas were first materialized as mock-ups and then as functioning prototypes. Two researchers were present in the classroom throughout the process, making field notes, videorecording the teams' design activities, and conducting short interviews with the teachers and the students. This chapter focuses on two example vignettes that are written based on video recordings and complemented by our field notes and student interviews. The vignettes consider the making of two inventions: a smart piggy bank, which counts the money inserted and announces when a target sum is reached, and a smart shirt with LED lights that turn on in the dark.

In this chapter, we first discuss material agency, that is, how matter contributes to creating the unpredictable nature of the invention project, and second, how materiality allows acting amidst this complexity by embedding the creative process into local materialities. The approach is inspired by the methodology of thinking with theory (Jackson & Mazzei, 2012). Next, we illustrate the concept of assemblage with a vignette about a striped fabric. Then, we discuss potentials for acting with uncertainty with a vignette about an abrasive belt grinder. We conclude with implications for research and practice.

Material Agency

Matter matters: it affects situations. However, claiming that matter is agentic can be problematic, especially in the education field, where agency has traditionally been a human ability with connotations of intentionality and power. Therefore, discussing the agency of matter requires a different perspective. In this chapter, we reframe the concept of agency, not as an attribute of someone or something, but as emerging in encounters (Latour, 2005). Instead of focusing on what someone or something does, the interest turns to relations—how entities transform each other. Thus, flattening the ontological hierarchy between humans and non-humans shifts the focus from individual actors toward loose, messy gatherings. We follow the example of thinkers such as Mol (2002) and Tsing (2015) and choose the term *assemblage* to illustrate this open, fluid, dynamic, entangled nature of reality. Next, we describe how the theoretical concept of assemblage changes our thinking about the example vignette about a striped fabric that participated in the materialization of the idea about a smart shirt (Jackson & Mazzei, 2012).

> Team Smart Shirt collaboratively designed a shirt for each team member. They chose fabrics for each team member from a large plastic box filled with leftover fabrics from other projects. Alice (pseudonym) spotted a black-and-white striped fabric. It was thin, almost see-through. Alice was delighted. She stated that she did not currently have a striped shirt in her wardrobe.
>
> Pinning the plastic sewing pattern onto the striped fabric turned out to be difficult. The fabric curled, crumpled, and slid away. Other team members were already sewing. Alice was distressed and said, "This will take the whole session, but okay. It's because my fabric is like this; it, like, moves and…well, sucks. More rigid [fabric] would be easier". The teacher came to help. She set the fabric on the table and, with slow and careful movements, smoothed out the wrinkles with her palm, emphasizing that the most important thing to have with this fabric was patience. When Alice finally began sewing, she noticed that the stripes of two pieces did not meet unless she paid special attention when aligning the pieces. Careful alignment made the hem straight,

also. She told her team members that starting the project made her anxious, but now she liked crafts and sewing. When the shirt was sewn, Alice wore it and danced around a bit.

Sewing the shirts took most of the design sessions; therefore, the team decided to pare down smart functionalities and focus on making the LED lights light up with the push of a button instead of using sensors that reacted to the environment. However, in Alice's case, the e-textile equipment, LED lights, microcontroller, thick conductive thread, and battery pack were too heavy and clunky for her lightweight fabric. The teacher confirmed that her shirt would not be able to carry such heavy components; even the needle required for the conductive thread would make holes big enough to result in the fabric's unraveling. The team decided to attach the smart functionalities to a separate, sturdier piece of fabric, which could be attached and detached from the shirt.

In the vignette, matter was intentionally given space to affect (Braidotti, 2019). The making process was not predefined but instead adapted to the properties of the materials. The striped fabric was not intended to be included in this particular project, but it was part of the rich material resources of the classroom that allowed multiple opportunities for learning to emerge (Keune & Peppler, 2019). So, the properties of the striped fabric transformed the course and rhythm of the invention process. For example, the problems sparked by the thinness of the fabric required slow, careful work, i.e., time. This affected what else the team could do during their limited time, and thus restricted other features of the initial planned invention. The thinness of the fabric caused trouble only when combined with the limited resource of time, relatively thick pins, plastic patterns, and the student's lack of experience with sewing such fabric. This transformation emerged through encounters. The invention process could not be reduced merely to the rational reasoning of the students, but instead, the process emerged from the more-than-human assemblage.

In addition to transforming the invention process, the striped fabric itself was constantly changing and transformed during encounters (Latour, 2005). Its stripes were a fashionable element that would complement Alice's wardrobe at one moment, and at the next, a structural element complicating the sewing process by making the pattern alignment visible. The thin softness of the fabric, which made the finished garment light and flowing, was at first alluring, making it stand out amidst other fabrics in the box. However, during sewing, those attractive qualities became problematic. These examples illustrate how turning one's gaze from singular stable properties to fluid assemblages allows for acknowledging the agency of matter.

The striped fabric was not only part of an assemblage but an assemblage itself. It consisted of matters and their properties, such as color, texture, and physical structure. These assemblages within assemblages relate to each other in the classroom and beyond. When reflecting on the relations among assemblages, a useful comparison is with the metaphor of rhizomes (Deleuze & Guattari, 1987). Unlike roots, rhizomes are not hierarchical and have no center, beginning, or ending. The striped fabric also has these wide-reaching "rhizomes". Research centralizing materiality could follow the entanglements of the fabric manufacturing or, further, the chemicals used for dying the fabric and how they affect the environment. This kind of research would link local and global scales and provide an understanding of the politics of specific material practices (Gallagher, 2019). Thus, turning one's gaze to agentic matter explicitly emphasizes how the invention process is rooted beyond the classroom.

Amidst these endless connections, students, teachers, and researchers make decisions on which "rhizomes" to focus on. These decisions are also affected by non-human participants (Bennett, 2010), such as curriculum, sociomaterial practices, or material resources. For example, the stripes of the fabric prompted a conversation about consumer culture and fashion when students were selecting fabrics. These aspects were not deliberately addressed later; however, they remained present in the matter and artifacts (Latour, 2005). Not all choices to address certain connections were verbal; connections were also met with actions. For example, the teacher had organized the classroom in a way that allowed storage and re-use of leftover materials, such as the striped fabric. This practice considered the topic of waste and the problematic relationship with maker education and the use of matter. Similarly, the focus on proficient sewing brought up issues relating to quality, usability, and the life cycle of artifacts. These issues were not solved or rationalized but handled in a tangible manner.

Perhaps the most practical consequence of acknowledging more-than-human agency is the expansion of responsibility. When considering matter as more than a mere resource for inventing, we must acknowledge how pedagogical choices or making activities affect humans and more-than-humans not directly present (Bodén et al., 2019). However, constantly changing and endlessly expanding assemblages make it impossible to determine outcomes. Therefore, responsibility requires staying with the trouble and responding with action or by giving space and listening (Haraway, 2016). Next, we discuss how making practices might enable learning that cannot rely on definite conclusions.

Acting with Uncertainty

Attuning to rhizomatic relationships, open-ended questions, and thus the relational and unpredictable nature of the invention project might feel overwhelming. Educators, students, makers, and researchers must act amidst uncertainty when hierarchical categorization falls short. Braidotti (2019) has emphasized that embracing uncertainty does not mean falling into relativism, but instead requires acknowledging the embodied and embedded nature of knowing. To learn with the world, instead of mastering it from the above, Tsing (2015) advocates for cultivating "arts of noticing", becoming attentive to the vibrant more-than-human details (Bennett, 2010), that are sometimes deemed as a passive backdrop. The attentiveness should aim not only to understand and explain the world but also to generate something new, being conscious of the material consequences of knowledge practices (Haraway, 2016). Next, we reflect on the encounter of an abrasive belt grinder and two students, from the perspective of acting with uncertainty.

Team Magic Bunny ideated a smart piggy bank, shaped like a magician's top hat. When they started to search with the teacher for materials, they came across a drawer filled with metal clippings from another project. The teacher showed them a metal sheet and asked if that could work; metal would be lighter and easier to handle than wood that they had initially planned on using. The students agreed and decided to adjust other parts of the piggy bank to the size of the metal sheet so that they would not have to cut it.

The teacher instructed the students to make a cylinder by spot welding the edges of the metal sheet together. After welding, the edges of the cylinder were still sharp and had to be smoothed. The teacher recommended using an abrasive belt grinder, which was located in a separate small room with transparent walls. Two students, Haley and Lily (pseudonyms) were tasked with using the machine. As the teacher demonstrated how to use it, a loud noise filled the room and sparks flew. Haley and Lily jumped back and screamed, nervously said they would not do that. The teacher gave Haley and Lily protective gloves and safety goggles and reassured them, "Those are just sparks. They won't hurt you".

In the hallway, Haley put on the gloves and goggles. Lily laughed and took out her smartphone; Haley posed for some pictures. They giggled and danced around, but when Haley stepped into the room with the belt grinder, her movements slowed. The teacher took a step back and let Haley do the work by herself. Her gaze was focused on the edge of the metal while she carefully rotated the cylinder. Lily recorded the whole process with her smartphone. Afterward, Lily and Haley ran to excitedly tell their classmates what they did.

The materiality of making requires attention to detail. While working with the powerful and cacophonous belt grinder, it was necessary to slow down to notice the movement of sparks and metal. Hayley's embodied activities adapted to the rhythm of the matter and tools (Aktaş & Mäkelä, 2019; Groth, 2020). Further, the making process required deliberation of functionality of the artifact in everyday life. Considering the cultural aspects of the piggy bank was not enough, but the students also had to focus on materiality, such as the sharpness of the edges of the metal sheet. However ambitious or imaginative the initial idea was, the students had to grapple with the mundane details during making (Haraway, 2016) (Figure 6.1).

Making rooted the abstract and somewhat universal idea into local materialities. It was no longer a common piggy bank: it was a piggy bank made with materials available in the classroom using the combined skills of the students and teacher within the time constraints of the school day. The metal sheet, excess material from an earlier project, transformed not only the structure of the artifact but also which craft practices were learned during the project. Inventing was explicitly situational in that aim was not to discover general facts; focus was on finding solutions that would work in the specific time and place. Materiality made visible the embeddedness of inventing (Braidotti, 2019), providing an opportunity to experience learning as a balancing act. When adapting design aspirations to local constraints, students were balancing creativity with practicality.

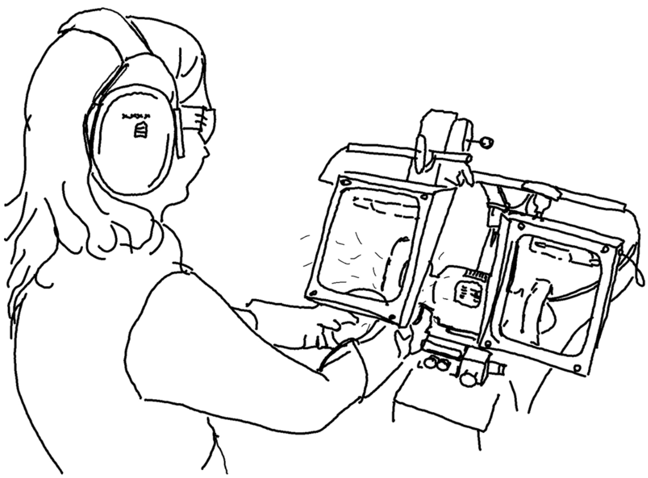

Figure 6.1 Haley using the abrasive belt grinder.

While constraining action, the unscripted material making also allowed students to focus on more than just predefined learning tasks—there was plenty of space for non-task-related play and material experimentation. In the vignette, the invention process was simultaneously a learning task and play. These two seemingly contradictory making practices were able to co-exist (Mol, 2002). On one hand, making scaffolded complexity with situated activities, and on the other hand, allowed co-existence of multiple practices. Even though the students were obliged to act within the institutional setting of the school and from the position of students, they were also able to transform the process according to their own interests.

Conclusions

We have illustrated with examples how matter can be agentic and how it can aid action amidst uncertainty. Open-ended tasks and unscripted making sessions provide space for matter to affect. Matter transforms a process through relations; therefore, its effects are not prefixed. Also, matter itself changes throughout processes depending on what and whom it encounters. These connections of matter reach beyond the boundaries of the classroom; societal, ethical, and ecological questions are present, whether addressed deliberately or not. While matter creates unpredictability and forms endless rhizomatic connections, it can also aid in acting amidst the uncertainty. Materiality insists on careful deliberation and attentiveness to details. Adapting the process to material constraints makes the embedded nature of inventing tangible, highlighting learning as a balancing act.

Considering the perspective of agentic matter can deepen the understanding of complex practices. First, sensitizing oneself to matter may help shed light on practices or technologies whose roles are taken for granted, thus revealing actors hiding in mundanity (Bodén et al., 2019). Attentiveness to material details can therefore reveal situations and places that call for a response (Haraway, 2016). This responsibility reaches beyond humans to all those we share the planet with (Tsing, 2015).

Methodologically, the more-than-human perspective requires the readiness to follow even the most surprising trains of thought, the ability to shift one's focus to relations instead of singular actors, and the use of firmly situated perspectives instead of universal claims (Bodén et al., 2019). Finding ways to attune to the more-than-human requires embracing all fields of knowledge (Tsing, 2015). Educational research could offer a functional platform for bringing together humanism and sciences since we already have plenty of experience in coping with a broad and somewhat incoherent discipline that is nevertheless based on practice.

Second, acknowledging agentic matter can widen our understanding of what kind of learning matters. Philosophers such as Braidotti (2019) and educational researchers, such as Common Worlds Research Collective (2020) have argued that education and pedagogies should learn to place students and teachers in, and have them be parts of the world, not outside observers. However, what this more-than-human learning could be in practices of formal education is still an under-researched area. In this chapter, we illustrated how material-making practices enable and require learning beyond traditional academic skills, such as situated and embodied knowledge, attentiveness to mundane details, and generative action. As these skills are crucial for cultivating "the arts of noticing" (Tsing, 2015), the potential of craft practices should be further explored in various educational settings.

In practice, taking the more-than-human perspective turns one's attention to the fluidity of matter. In other words, when planning an invention project, it is not fruitful to attempt to fully predetermine the effects of materials. Providing rich material resources and an adaptable learning environment can enhance opportunities for learning on students' own terms (Keune & Peppler, 2019). These opportunities depend not only on the properties of the material, but also on the uncertain relations; for example, on the skills (or lack thereof) of the user, time resources, and/or available tools. Therefore, cultivating students' craft skills can also aid the process of ideating and making. However, learning with matter requires time and opportunities to adjust to the tempo of work, emphasizing the importance of allocating enough time for making.

Matter carries with it connections to political, environmental, and societal issues. Even non-verbal practices can address wide-reaching connections. Therefore, to grapple with such complicated issues ethically, careful attention needs to be paid to the design task, material resources, and classroom practices. Involving matter into pedagogical practices introduces global connections into the classroom thus providing natural opportunities for addressing wide-reaching issues. Considering questions of responsibility through making shifts the focus from rationalizing an external abstract phenomenon to mundane details at hand. Therefore, making promotes sensitizing to matter and affirmatively generating something new. Instead of aiming at mastering the world, this kind of situated knowledge emphasizes living with it.

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