How does Emotion and Matter Matter in Engineering Education?

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Abstract

Practical activities are at the core of learning in both engineering and science education programs. Hence, such activities are included as important practical learning experiences in each of these fields. During such learning experiences students are confronted by many different entities, from simple equipment to advanced instrumentation, all of which requires knowledge of how, when, why and for what they can and should be used. Emotional outcomes accompany learning through practical activities and can range from feelings of success and satisfaction, to disappointment and worries. Such emotions can play a critical role in a student's decision to start or continue their studies in any science, technology, engineering or mathematics (STEM) education field.

This project explores how practical activities intra-act with emotions and thereby shape learning processes. Three methods of data production were employed: video-recorded observations, fieldnotes, and micro-interviews. These data were collected in two different undergraduate civil engineering courses (genetic engineering and nuclear physics), each with their own unique experimental setups for engaging students in practical laboratory activities. In total, 81 students were filmed for 80 hours in one genetic engineering and one nuclear physics course.

By using Barad's theory of agential realism (Barad, 2007) and Ahmed's 'Cultural Politics of Emotion' (Ahmed, 2014) in the analysis, we found that practical lab activities require many different abilities of the students to be able to navigate in laboratories crammed with artefacts – tools, equipment, machines, instruments, etcetera. During any given practical lab activity students must distinguish what artefacts they should use or not. Much of the learning that takes place is bodily and non-verbal, where the teacher's instructions are also bodily and intertwined with the students, materials, and emotions. Findings indicate that when a practical moment is repeated, the emotions are transformed or even fade away. The study demonstrates the importance of instructor awareness of the active role of both human and non-human entities when designing instruction for the unique educational settings students will encounter in science and engineering, also relevant to technology and design education preparation programs.

Keywords: Agential realism, Emotions, Engineering Education, Laboration, Practical activities, Science Education.

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Introduction

The aim of the engineering profession is to be able to exploit material, information and energy to serve human beings (Feisel & Rosa, 2005). To develop such expertise, a variety of knowledge, abilities and skills are needed. Not least, a deep understanding of key concepts such as force, mass, and physical principles are crucial, and therefore natural science content is included in engineering education (EE) (Litzinger et al., 2011). These same principles and associated natural science content are also integral elements of technology and engineering education (TEE) and design and technology education (DTE). In EE, TEE, and DTE courses, theoretical knowledge also needs to be applied through practical activities (Hansson, 2013; Ropohl, 1997; Vincenti, 1990). Moreover, Bernhard (2015) foregrounded that “the role of instrumental technologies in student learning in laboratories has been rarely studied and is generally either neglected or taken for granted” and argued for wider and deeper research about practical activities in engineering education (Bernhard, 2015, p 407).

Practical activities involving the use of equipment, machinery, and instrumentation for developing artefacts and/or conducting laboratory experiments in the EE, TEE, and DTE classroom arouse diverse emotions in students that may affect their learning. Moreover, the initial encounters students have with new materials can generate emotions such as desire, excitement, expectation ... or worry, fear of exposing clumsiness, destroying expensive equipment etcetera. Studies on emotions in engineering education (EEE) is a growing field inspired by other scientific fields such as educational sciences, psychology and sociology (Lönngren, et al. 2024). The present study addresses the impact of minds-on/hands-on activities on students' learning, based on what the non-human material does and what differences in emotions it evokes. Our aim was to explore how experimental laboratory practices, including material, space and time, shape learning processes as a means of shedding light on the importance of emotions that may arise in connection with these activities. More explicitly, our research focuses on the (1) learning produced in student-teacher-material-emotions intra-actions and (2) how the practical doing is entangled with emotions produced while engaged in the laboratory practices of two engineering courses – genetic engineering and nuclear physics. Findings from this research will inform not only science and engineering education, but TE, TEE, DTE and all STEM education programs where practical activities are integral to the learning processes.

Theoretical Framework

Agential realism

Theoretically, this project is grounded in Barad’s onto-epistemology agential realism (Barad, 2007). Agential realism is meant to provide ‘an understanding of the role of the human and nonhuman, material and discursive, and natural and cultural factors in scientific and other social-material practices' (Barad, 2007, p. 26).

In the theory of agential realism, the agency of matter is central and arises through intra-actions with humans, other organisms as well as matter. Barad (2010) suggests that "distinct entities, agencies, events do not precede, but rather emerge from/through their intra-action" (Barad, 2010, p. 267). Such intra-actions produce what Barad (2003) calls a phenomenon. This invitation implies going beyond dichotomies - such as separating the teacher from the taught, the knower from the known, and the object from the subject - and instead directing our attention on intra-actions. According to Barad (2007) agency is a doing or being, something enacted, and not a property or something that someone or something possesses. In agential realism, boundaries between objects are not given once and for all but are constantly contested or confirmed in an iterative way. Barad states "In my agential realist account, matter is a dynamic expression/articulation of the world in its intra-active becoming. All bodies, including but not limited to human bodies, come to matter through the world's iterative intraactivity- its performativity" (Barad, 2007, p. 392). Thus, in agential realism performativity signifies that matter as well as the discursive practices are active participants in "the world's becoming, in its ongoing intra-activity" (Barad, 2007, p. 136). However, Barad does not explicitly discuss agency of emotions even though emotions can be a substantial actor in how discursive practices matter. Given our interest in how emotions intra-act with learning in engineering education, we integrate Ahmed's cultural politics into the theoretical framework (Ahmed, 2014).

Emotional Politics

When students handle nonliving entities in experimental settings emotions are inevitably intertwined with the students´ learning. The role of emotions on a phenomenon can be understood by Ahmed's theory of emotional politics (Ahmed, 2014). In her view, emotions are not just psychological states inherent in an individual but a product of cultural contexts/practices. Cultural practices also encompass material objects. Repetitions evoke and intensify an emotional response, referred to as a 'sticky sign' that grows stronger with more repetitions (Ahmed, 2014, p. 91-92). Hence, just thinking about a specific type of situation or place (like a laboratory) results in an immediate re-living of the emotions once evoked.

Emotions also generate and acquire meaning due to their history and context. An illustrative example is emotions that emerge due to hair. Thick flowing hair can evoke positive emotions and admiration. However, if just one of these hair shafts is found in food at the lunch restaurant, the feeling can change quickly and even evoke an emotion of disgust.

By combining emotional politics with the intra-active nature of knowledge production, we can analyze the role of emotions in practical activities. Both theories highlight that the sticky signs are not determined once and for all – they remain fluid and change is possible.

Literature Review

Technological experimentation has a long history within technology and engineering education, longer even than the natural sciences, and is characterized by the manipulation of one or more parameters believed to affect a particular outcome (Norström, 2015). Hence, both technological experimentation and practical activities are integral parts of technology, engineering, and design education. The relationship between technology/engineering contra natural sciences has been scrutinised thoroughly. Norström (2015) argued that the distinction between technical/engineering experiments and those conducted in the natural sciences is not clear-cut, and depends on the purpose of the investigation and questions asked. Questions that lead to generalizing and drawing conclusions about the investigated problem are closer to the field of natural sciences, while questions about the utilization, for instance to improve functionality and safety, belong to the field of technology/engineering (Norström, 2015, Hansson, 2007). Bernhard (2015) emphasized the importance of learning in laboratories to enhance engineering students' technology competences, such as handling data, controlling and monitoring production processes. Other arguments put forward regarding the importance of laboratory activities for students are a) to link theory to practice and promote students' conceptual understanding (see e.g., Kalthoff et al., 2018); b) to understand scientific methods of inquiry, attain an ability to use these methods as well as learning practical and experimental skills per se (Bybee, 2000; NGSS Lead States, 2013); and c) because it makes the subject fun and interesting (see e.g. Lombardi et al., 2014). Nevertheless, Bernhard stated that the research within engineering education has neglected the involvement of instruments in learning processes: "Consequently, research generally focuses mainly on instructions, concepts, and ideas or the organization of labs" (Bernhard, 2015, p. 407), where he calls for, in contrast to the traditional view, that handling of experimental equipment also needs to be given a cognitive value. Aligned with this argumentation, doing laboratory work, whether in science, technology, or engineering, requires managing unexpected events and interpreting measurement errors (Bybee, 2000). Knowledge about the messiness of experimental work provides insights into the complexity of scientific work and technological methods. Feisel and Rosa (2005) emphasized the handling of failure and requested a special objective, *Learning from failure*, in engineering education.

Some research studies in engineering and science education show the role of instruments, learners' engagement with the material (or the intra-actions) and emotions in learning science and engineering in the context of practical activities. Emotions contribute to the professional identity and feeling of belonging in educational programs. In the systematic review conducted by Lönngren et al., (2024), 213 publications within the field of emotions in engineering education (EEE) were analysed. The result showed that a majority of the articles had other foci for their studies than emotions per se. The researchers concluded that in the future, EEE would be better served by a broader conceptualization of emotions to develop the research field.

Experiencing too many negative emotions runs the risk of feeling alienated and dropping out of education. This is something that is dealt with in the case study conducted by Danielak et. al, (2014), where a high-achieving electrical engineering student, Michael, was followed for three years. For Michael, an important part of his student identity was being able to understand and make sense of what he learned. At times, he did not feel that the engineering education lived up to this expectation, which meant that he did not feel a sense of belonging to the profession. Despite this discrepancy, he chose to complete the programme, and the argument he claimed was that he loved the practice of engineering. Students' feelings of belonging are composed of a conglomerate of emotions, encounters, and performances, and are iteratively negotiated. The context of a demanding task can for instance be a source for anxiety. Bellinger et al., (2015) examine how anxiety can be mastered in high-stakes academic environments. The participants were undergraduate engineering students. The results show that the feelings of discomfort interfere with cognitive control and that a mindful instructional approach can be a way forward to reduce those feelings and improve students' performance.

Shared feelings also create cohesion in groups. Davis and Bellocchi (2020) used a model of emotional energy to study emotions in two ninth and tenth grade science classrooms. They assert that emotions evolve as individuals perceive a communal emotional connection with others. The students assume that they share reality with others throughout the entire activity, which is evident in the fluidity of their interactions. Within this dynamic interplay, shared emotions do not necessarily imply an understanding of others' thoughts, but it suggests that such shared experiences boost our confidence in non-verbal communication situations.

One way to let materials and instruments become visible actors in research about laboratory teaching is to use Barad's theory of agential realism (Barad, 2007). This was done by Gonsalves (2020) who explored how intra-actions with artefacts, such as instruments in laboratory and other contexts, co-create student identity. Gonsalves used narrative data from a previous study (Gonsalves, 2014) where she analysed discussions with female doctoral students about what it means to do good physics and what a good physicist look likes. Previous research (Danielsson, 2009; Gonsalves, 2014; Wajcman, 1995) has shown that technical skills, such as tinkering, have high status in the field of physics and have been associated with masculine values. By using agential realism instead of discourse analysis, Gonsalves was able to demonstrate how matter has agency, and thereby produced new subject positions for women in physics (Gonsalves, 2020).

In an ethnographic study, Lorenz-Meyer (2014) explored the intra-actions between emotions produced in handling advanced instruments in laboratories grounded in Barad's theory (Barad, 2007) and Ahmed's work on affective economies (Ahmed, 2014). Lorenz-Meyer's (2014) research followed postdoctoral researchers in their struggle to calibrate mass spectrometers. The mass spectrometer consisted of 15 lenses all needing to be calibrated in order to obtain reliable measurement of the samples. This was a demanding task for the inexperienced postdocs and especially Jackie, who struggled with the tinkering and expressed feelings of shame when she didn't succeed. Lorenz-Meyer noted how a senior researcher, Renate, took on the calibration with ease and made the adjustments so quickly that she had trouble keeping up. However, the difficulties mastering the instruments were not, to the researchers' knowledge, discussed explicitly in the laboratory. Lorenz-Meyer explored this lab situation in the context of Barad and Ahmed's concepts which intertwined the handling of the instrument with emotions. Succeeding in mastering the use of lab instrumentation requires training, but also reaching a kind of entanglement, a *feeling* for the instrument. Such skills are hard to both verbalize and instruct.

The review of literature indicates a gap in research investigating the important connection between emotions and learning experiences students encounter through practical laboratory activities. In our study we addressed this gap by further exploring, and putting into words, how the encounters with students-teachers-materials-emotions intra-actions are produced and how such encounters affect students' learning.

Method

Empirical Design

Data collection for this study took place in two different laboratory contexts in two undergraduate civil engineering programs, one in a nuclear physics course, and one in a genetic engineering course. We used three complementary methods: observations through video, fieldnotes, and micro-interviews. The video recording focused on three contexts of intra-action: (1) intra-actions between students and the instruments/material/equipment they handled, (2) intra-actions between students and lab assistants, and (3) intra-actions between students and lab-instructions. Micro-interviews were performed during the lab sessions where we asked participants questions about their activities or possible emotions that emerged. The prefix 'micro' refers to a protocol in which interviews are short and occur in the fleeting moments in the laboration.

In the nuclear physics course, five groups from a class comprised of 37 male and 19 female students, worked one day (eight hours) in the lab. These students were supposed to use a gamma-spectrometer to produce a plot with peaks in order to identify an unknown sample of radioactive material. In the genetic engineering course, 25 students with almost equal gender distribution, had a four-day lab, where the purpose was to alter a bacteria genome using many different biochemical methods. In both cases, students were expected to produce a lab report that would be assessed. Data collected consisted of 40 hours of video-recordings and complementary field notes for each of the two laboratories. The students were informed about the study and signed the letter of consent to participate.

Data Analysis

During analysis of the video-recordings, micro-interviews, and field notes, we incorporated our understanding of Barad's theory of agential realism (Barad, 2007) and Ahmed’s politics of emotions (Ahmed, 2014). This means that the primary ontological units are not students, teachers and materials separately and individually, but the phenomena produced in intra-action of entangled student-student-lab-assistants-instruments-emotions communication.

Diffractive analysis applies agential realism in practice by actively acknowledging and engaging with the dynamic and changing aspects of theories and concepts (Barad, 2007). This method breaks away from dualisms and static perspectives by using diffraction as a metaphor to illustrate complex patterns and mutual relationships between, for instance, humans and nonhumans, or between ideas. In diffractive analysis, the researcher reads various perspectives or materials, such as theoretical concepts, texts, and parts of empirical data through each other (Barad, 2003). An important fundament within this theory is that the researcher is part of the phenomena under study, not just an objective observer.

When we filmed, we paid particular attention to entanglements between students, materials, and intra-actions involving emotions. A situation could range from a few seconds to several minutes. By using diffractive analysis, *reading* the situations from the genetic engineering and nuclear physic laboratories *through* each other, new aspects of the material emerged, revealing both similarities and differences. These variations made the phenomenon in focus come to the fore in certain ways. In this iterative process, several agential cuts were enacted, and their interrelationships were analyzed, ultimately shaping the aspects of the phenomenon. If we had been interested in other entanglements, other cuts would have been enacted and other aspects would have been produced.

Results

The phenomenon studied was different kinds of subject knowledge learning within the context of engineering education laboratories. We focused on two aspects of the phenomenon of learning under the headings: Crowded spaces crammed with artifacts and Human bodies-materials-emotions-learning intra-actions. The first aspect draws on the students’ demands to be able to instantly act in situations with an overwhelming number of items (artifacts) to handle. The second aspect highlights how engineering knowledge is produced in the entanglement between students' bodies, emotions and materials. We present the findings from the two experimental setups through a number of agential cuts, made from video recordings, notes, and micro interviews.

Crowded Spaces Crammed with Artifacts

Agential Cut #1

The laboratory for the genetic engineering course is crowded with students working in pairs at a long bench meant for two groups. Various types of materials and equipment are spread across the bench, on the shelves above, and on the floor – some of which the students need to use and handle. Due to the dense material arrangement, students spend a significant amount of time moving around, searching for the equipment they need. They frequently communicate between the groups and stand close together, queuing to fetch samples or use apparatuses such as centrifuges. Students use as many as 80 different artifacts during the lab session. They have a detailed lab manual that they meticulously follow. Occasionally, the teachers supplement or adjust the instructions by writing new ones on a whiteboard.

There are many different activities during these lab days. One common recurring task is pipetting various samples into different sets of test tubes. Sometimes, students need to make calculations to determine the volumes to be pipetted and the different test tubes must be labelled with markers to keep track of the samples. Simple mistakes can have significant consequences on the results. For example, several students mistakenly use the wrong disposable tips for the automated pipettes because they are unaware of the volume variations. This results in incorrect concentrations of the reaction mixtures, rendering them ineffective.

Agential Cut #2

The laboratory equipment in the nuclear physics lab is arranged on tables with two chairs at each unit. As the students enter the room, they pair up in front of the equipment. Throughout the entire lab session, most students stay at their assigned stations and do not interact with other classmates. However, during one instance observed, six students gathered around a lab unit to discuss what was happening there.

On the bench, there is a computer, an oscilloscope, and a rack with knobs, buttons, and sockets. One part of the rack contains an amplifier, while another part contains high voltage components. There is also a stand where radioactive material can be placed along with a detector that can be plugged into the oscilloscope or rack. Thick lead plates are arranged around the detector and stand. Various types of cables are also available. Only a few instructions are provided for the nuclear lab. The teacher gives every student pair some short introductions and announces that they are free to tinker with everything, except for the high voltage, which should not exceed a given level. In the room, there is a blue cabinet with a warning text indicating the presence of radioactive material to be used in the experiment. The radioactive material can cause personal injury with prolonged exposure, and students may need assistance from the teacher to locate the appropriate material in the cabinet.

Comparison of Settings

The first genetic engineering lab setting is more crowded with artifacts, whereas in the second nuclear physics lab setting the environment appears to be more sparingly equipped, for instance there are some shelves that are almost empty. Furthermore, in the second setting the apparatuses are themselves crowded with buttons and combinations of buttons and knobs to use. The complexity of student tasks is comparable in both settings. And in each of these settings, students need a strategy to discern and decipher the functionality of the instruments and all the materials themselves, without extensive instructions. Students must sort through their impressions to decide how much of the materials and how many of the instruments they will attempt to understand and at what level.

Human Bodies-Material-Emotions-Learning Intra-actions

Agential Cut #3

There are two electrophoresis apparatuses in the genetic engineering lab, used to separate and visualise the bacteria DNA-fragments. The students queue up to apply their DNA-samples. Teacher assistant Doris stands by one electrophoresis apparatus and supports the students when needed. The apparatus contains a prepared gel with small wells, where the students need to insert their automated pipette tips containing samples of just a few microliters volume. They need to press their samples down to sink them into the wells. The student must handle the pipette with skill, so as not to disrupt the sample. The transparent gel is immersed in a liquid bath, making it difficult to see the wells, unless viewed from above at the correct angle. Doris instructs the students how to lean against the apparatus to provide support and minimize the risk of shaking and ruining the sample. The heads of the students and Doris touch each other as they try to achieve the correct angle to clearly see the wells. The students' faces are focused during this moment and do not express any specific emotions, but some of them exhale loudly when the sample has been applied. Several agents are entangled in this situation: the student's body positioned correctly, and the automatic pipette containing a tiny DNA sample. Questions posed by students to Doris are answered with words, but also physically by Doris in moving her head close to the student to see what the student sees.

Agential Cut #4

A device initially entangled with emotions is the centrifuge, that students are instructed on how to balance. An imbalanced centrifuge can potentially damage expensive equipment and cause harm. The proper balancing of the centrifuge is a recurring concern. The students express anxiety about not having done it correctly. They also listen attentively for sounds of malfunction, as the teachers have advised them to switch the centrifuge off should they hear something that sounds wrong. By the end of the week the students' anxiety diminishes, and they swiftly handle the centrifuge without further discussion. At this point the students have mastered using the instrument, and the centrifuge is no longer intra-acting with students' emotions. At the end of the week, a male student and teaching assistant Curt discuss the rpm of the lab's centrifuges. Curt says that the centrifuge they have in his research lab can spin at more than 200,000 rpm. "Then it's important that it's balanced," he says, and shows with his voice and body that knowing how to do this is something that is cool. When analyzing the video, the student is seen listening attentively, and then goes back to his lab mate and immediately retells the conversation. "Oh s---", the lab mate replied clearly impressed.

Agential Cut #5

Initially, during the nuclear physics lab, the students try to understand and learn the instrumentation. They patiently tinker and try out different options by turning various knobs and connecting cables and checking out the result on the computer screen. Even though the students worked calmly and systematically, the interview that followed revealed unexpressed feelings. Rahid described that he got frustrated as time passed without gaining meaningful knowledge: "[The worst part of the activity was the] first two hours when we don't know what to do. What is the meaning of this! So, those two hours were so difficult." However, when they gain knowledge and successfully produce the desired outcomes of peaks on the computer screen, other feelings come into play: "Best feeling [during the practical activity] when I finally find out that this is actually easy."

Various materials, including lead and alpha radiation, shape rules and regulations that must be followed in the physics experimental hall. For example, eating and drinking are prohibited due to the handling of potentially harmful substances. These rules, dictated by the authorities, take part in regulating students' emotions. While Maja walks with the samples to the bench, she shows with sound and body language that she is carrying something dangerous. This behaviour indicated fear, but during the later interview it becomes clear that she uses her feelings as a tool to remind herself and keep her attention to the potential dangers:

> "I find it very alarming because I don't think about them being radioactive. I would easily just grab that [radioactive substance] if no one had told me it's dangerous."
> Her lab partner, Valle, responds:
> "Which is locked in a cabinet!" pointing out that the locker should indicate the danger. To which Malva responds:
> "I know, but I still don't find it scary."
> Valle says: "Yes, you don´t really see it."
> Interviewer says: "Is it scary because it doesn't feel scary?"
> Malva says: "Yes" and laughs, looking at Valle who puts his hand to his forehead.

Agential cuts 3, 4, and 5 show examples of how handling different instruments is an intertwined learning process that includes bodily knowledge and emotions. The situations contain many moments that must be mastered, including different types of emotions. The centrifuge creates anxiety, a feeling that gradually fades as the students become more confident. In the nuclear physics lab, on the other hand, Malva shows how she generates the feeling of fear to alert herself to the risky lab situation of handling radioactive material.

Discussion

Through our research we explored how student-teacher-material-emotions intra-actions can be understood. We also present context-specific perspectives that emerged regarding practical skills and how learning processes can be shaped by the intra-actions.

The laboratories in our study are crammed with artifacts. By reading the results from the two settings diffractively through each other we find commonalities and differences. In both settings students must distinguish what artifacts they should use or not, and what level of understanding is required to do so. However, the difficulty in choosing relevant actions operates on different levels in the two settings. In the genetic engineering laboratory there are so many items that they become overwhelming. Whereas in the nuclear physics laboratory, the challenge lies in selecting the right combination and order for handling the very similar knobs and buttons of the instrumentation. Students need skills when actively handling the instruments but also when actively ignoring irrelevant artifacts or details. According to Barad's theory of agency of matter, all material attracts the students' attention, including material that is later excluded (Barad, 2007). The intra-actions with relevant material increases the ability to efficiently make sense of the milieu, thereby giving agency to the students in their own learning process. The choice of material, when, how, and by whom it should be used, is an important part of learning.

We noted that the attention between the student and the material fluctuated over time. For instance, the centrifuge initially received a lot of attention, but through usage the students' concern about it gradually diminished. Hence, instruments that do not need to be understood in detail are black boxed. To cite Latour (1999), black boxing is "the way scientific and technical work is made invisible by its own success. When a machine runs efficiently, when a matter of fact is settled, one needs to focus only on its inputs and outputs and not on its internal complexity" (Latour, 1999, p.304). In accordance with agential realism (Barad, 2007), the boundaries around the black boxed material are not fixed, in time or space, and nor are they the same for all students. An instrument that is initially used casually, and thereby black boxed, may require better understanding at a later stage for the student to be able to continue their practical work. For teachers who are used to the experimental hall, different artifacts have become internalized as embodied knowledge. As a result, they may overlook giving explicit instructions about what the students should pay attention to and not. Drawing on Bernhard's argument (2015) on the cognitive value of experimental (practical) work, the aspect of giving explicit instructions about handling the instruments is an essential instructional objective for teaching and learning.

In the agential cuts, students' emotions we observed being constantly intra-actively negotiated and shaped the practical activity in many different ways, which is in line with the work of Ahmed (2014). For example, Malva uses fear as a tool for proper handling of radioactive materials. As another example, Rahid expresses the moments of agency as "the best part of the lab" whereas everything up to that point is expressed using words like "boredom" and "waste of time." In the episode with a student, the teacher assistant Curt, and a centrifuge, the conversations revealed a shift from initial anxiety to a sense of composure and amazement. The teacher and his emotions play a crucial role in this entanglement, elucidating for the students what matters in this scientific context and which emotions can be openly expressed. This observed entanglement is in line with Davis & Bellocchi (2020) in the way that the students learn which emotions are possible to share with peers in this community of practice (Lave & Wenger, 1991). Ahmed (2014) points out that emotions can *stick* and leave permanent marks when they are experienced multiple times. If the emotions are positive, further intra-actions with the equipment are unproblematic or even exciting. To the contrary, if the situations are repeatedly unpleasant, handling the equipment can generate negative feelings, not just for the practice work, but it can also be extrapolated to the physical space and the subject. In our study the handling of the centrifuge created feelings of anxiety in the beginning, but those negative feelings faded away when the students began to master the instrument. The fading negative emotions are now substituted by *the stickiness* of mastering the centrifuge.

Up to now we have focused on the equipment that the students use in laboratory work. In producing emotions and meaning making, the agency of the room provides a structure for communication. In the cramped genetic engineering lab, bodies move and collide. In the situation with the electrophoresis apparatus, it became evident that the restraint of emotions was important to master the application of samples. There, the teacher scaffolded the students with bodily and verbal instructions. Both students and teacher Doris crossed the usual integrity boarder without acting on it. Students in the genetic engineering lab would meet regularly between groups to discuss tasks and ask each other questions in order to receive information on what material to use and how to carry out their experiments. These collaborations differ from the physics setting, where students are assigned to stations and fixed within the room with limited interaction between different pairs, due to the spatial arrangement. This setting demands more of the students if they want to communicate with other groups. Some students may challenge the boundaries by moving across the room and engaging in collective discussions and knowledge-sharing. However, most students comply with the implicit spatial rules and stay in the assigned station.

Crosscutting Practices

This study was conducted in Sweden within a European context, where science is an integrated part of undergraduate engineering education. The results are relevant to an American context as an exemplar of crosscutting practices. Data were collected in a nuclear physics course and genetic engineering course, both of which engaged students in practical (experimental) activities requiring the manipulation of materials, tools, equipment, and machinery. Although the content of these course is clearly science-dense, the engineering context is very much reflective of the type of practical activities found in undergraduate technology education (TE), technology and engineering education (TEE), and design and technology education (DTE) programs. Furthermore, the context reflects the global trend toward promoting integrative STEM practices spanning all levels of education from elementary to post-secondary. Specifically, in response to projected 21st century workforce preparation requirements, educational systems across the globe have been increasingly promoting integrative approaches for teaching STEM content and practices.

Efforts toward integrative practices are clearly evident in the changes made to national education standards in the STEM education disciplines for intentionally incorporating the content and practices of disciplines other than their own (NGSS Lead States, 2013; ITEA/ITEEA, 2007; Honey et. al., 2014). Most notable and consistent among these changes is the inclusion of technological/engineering design practices for improving the learning of science concepts. The goal in doing so is to achieve performance expectations by crossing the content to be learned with the practices that best demonstrates an understanding of the targeted content (Wells, 2010). A clear example of this is found in the Next Generation Science Standards (NGSS) which outlines three dimensions (disciplinary core ideas – content, scientific and engineering practices, and crosscutting concepts,) intended to provide the context for learning science (NGSS Lead States, 2013). The NGSS specifically state that practices refer to what scientists employ when investigating natural phenomena, and what engineers employ as they design and construct systems. Such practices are viewed as indicators of achievement, and when coupled with content, generates the context for learning. Underpinning the NGSS is the premise that the learner must directly experience the practices to more fully grasp disciplinary content and recognize that concepts have application across all domains. However, engineering practices are not those traditionally taught as part of science teacher preparation. Furthermore, acquiring engineering skills and practices is but one pedagogical challenge confronting science educators. As highlighted through this research, another significant challenge is designing instruction to anticipate how teaching and learning of these practices concurrently produces emotions that can and will affect the learning processes. Clearly, the intra-actions of students in the nuclear physics and genetic engineering lab courses are the same types of intra-actions students would have in any TE, TEE, and/or DTE lab course. In recognition of this, taking into account the emotional aspects must be integral to the design of instruction not only in science education, but equally in technology education, technology and engineering education, and design and technology education.

Overall, this analysis of concurrent science and engineering practical activities through the lens of agential realism highlights the entanglement of materialities, student agency, and knowledge production guided by emotions. More importantly, it underscores the significance of recognizing the active role of both human and non-human entities in shaping educational experiences and the formation of disciplinary and practical knowledge in engineering and science education.

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