How does 'matter' matter in engineering education?

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ABSTRACT

Practical activities are at the core of learning in engineering. Therefore, such activities are included as important parts of education and curricula. Entities, from simple equipment to advanced instruments, require knowledge of when, why and for what they can and should be used. Emotional outcomes from practical activities may be feelings of success and satisfaction, or disappointment and worries. Such feelings may be crucial for a student's decision to start, or continue, their science/technology studies.

This project explores how practical activities shape learning processes in two different experimental setups within engineering education. The purpose is to examine how students' and teachers' emotional embodiment of scientific/technology practices, through entangled intra-actions with each other and matter/material, influence both teaching and learning. Three methods of data collection were employed: observations, micro-interviews, and interviews.

By using Barad's theory of agential realism (Barad 2007) and Sara Ahmed's 'Cultural Politics of Emotion' (Ahmed 2004/2012) in the analysis, we found that practical lab activities require many different abilities of the students to be able to navigate in the lab rooms crammed with artefacts. 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. When a practical moment is repeated, the emotions are transformed or even fade away.

In the discussion we argue that the degree of agency has a substantial impact on the emotional outcomes and that students utilise emotions in order to experience agency.

Key Words: Agential realism, Emotions, Practical activities, Engineering Education.

1. INTRODUCTION

Experimental activities are at the core of learning in science and engineering. The practical conduct of experiments is also something that arouses diverse emotions in students that may affect their learning. Their initial encounters with new materials, whether in school or in higher education, can generate emotions such as desire, excitement, expectation ... or worry, fear of exposing clumsiness, destroying expensive equipment etcetera. While there exists considerable research on experimental work in engineering education, only relatively few studies address the impact of hands-on-activities on students' learning, based on what the non-human material does and what differences in emotion it evokes. We aim to explore how experimental practices shape learning processes, beyond human-human interaction, including the importance of emotions that may arise in connection with these activities in university educational programs. The research questions are: how can student-teacher-material-emotions intra-actions be understood, and what context-specific views of practical skills are expressed, and how?

2. LITERATURE REVIEW

2.1. Agential realism and emotional politics

This project is grounded in physicist and science philosopher Karen Barad’s onto-epistemology agential realism (Barad 2007) where the agency of matter is central and arises through intra-actions with humans. The intra-active nature of agency implies that it is not aligned with human intentionality or subjectivity and not limited to human action. Instead, agency is a doing or being, something enacted, and not a property or something that someone or something has. Intra-actions are entangled within what Barad (2003) refers to as phenomena. This means that the primary ontological units are not students, teachers and materials separately and individually, but the phenomena produced through their entangled intra-actions. In agential realism, boundaries between objects are not given once and for all, but constantly contested or confirmed in an iterative way.

Since emotions are part of the phenomena, we also lean on Ahmed's theories of emotional politics (Ahmed 2004/2012) which suggests that emotions can be used as economy, because they become attached to material objects that join some people together while separating others (Ahmed 2006).

Combining emotional politics with the intra-active nature of knowledge production we can analyse the role of emotions in practical activities.

2.2. Laboratory exercises in science and technology education

In comparison between physical and virtual laboratories, De Jong et al. (2013) demonstrate that physical laboratories are understood to have merits and shortcomings. Despite the strong belief in educational contexts and policy documents worldwide regarding the positive significance of hands-on activities in science and engineering, some studies show no improvement in conceptual knowledge outcomes compared to using simulations, which can be partly explained by messy data produced in the lab. For example, first-year secondary school students who conducted virtual chemistry experiments outperformed those who performed physical laboratories in terms of conceptual understanding, partially due to cluttered data produced in the physical lab (Pyatt & Sims 2012). Some studies also indicate that tactile information is unnecessary for developing conceptual knowledge or inquiry skills unless it involves younger children who lack sufficient experience with physical activities (Triona & Klahr 2003). Also, many students perceive experimental exercises as unimportant in their learning (Hofstein & Lunetta 2004). However, knowledge about the messiness of laboratory work also has advantages, as it provides insights into the complexity of scientific work and technological methods, such as handling unexpected events and interpreting measurement errors (Bybee 2000). Other advantages of physical laboratories include acquiring practical skills that in themselves constitute a separate area of knowledge. Another often used argument is that the practical activities make the subject fun and interesting (Lombardi et al. 2014). Nevertheless, the role of instruments, learners' engagement with the material or the intra-actions that support the development of scientific practices remained unexplored. Instead, research on laboratory learning of science focused on language and discourse as the role of argumentation (Driver et al. 2000), students' perceptions of the environment (Hofstein et al. 2001) and social discourse to promote learning in cooperative groups (Jobér 2017). However, more recently, science educators have considered how material feminisms can relate to learning (Otrel-Cass & Cowie 2019), for example by considering how the apparatus in a college science classroom supports the 'intra-action' of students and nature (Milne 2019, Milne & Scantlebury 2019, Taylor & Ivinson 2013, Wink 2020).

2.3. Embodied knowledge and emotions

There is some research exploring student-material interactions in preschool (Günther Hanssen 2018) or in a specific subject. Within craft education research there are examples of how student–material relations emerge (Hofverberg 2019). Such relations can create embodied stories that may involve both pleasurable and unpleasurable experiences and emotions, that effect beliefs and behaviours related to gendered expectancies (Sigurdsson 2014). A corresponding (stereotypical) connection between gender and expectations of practical dexterity have been identified within science education, especially in male-dominated subjects like physics and technology (Danielsson et al. 2018, Gonsalves et al. 2016).

Researchers address different aspects of emotions, including emotional climate in the classroom (Bellocchi et al. 2013), and the intersection of feelings with conceptual and epistemological inquiry (Jaber and Hammer 2016). Their results suggest that feelings are situated and practice-linked and develop in interaction with contextual factors. This aligns with Ahmed's description of emotions as cultural practices, shaped by spaces, objects and people and come into being in contact with others (Ahmed 2004/2012), where this *other* can include the non-human. An illustrative example involves postdoctoral scientists struggling to calibrate mass spectrometers (Lorenz-Meyer 2014). To succeed requires training but also to reach a kind of entanglement, a 'feeling' for the instrument, a skill that is hard to verbalize and instruct. In moments of failure, socio-material relations embedded and embodied in particular practices tend to become visible (Lorenz-Meyer 2014).

3. METHODOLOGY

3.1. Empirical design and analysis

Data collection for this study took place in two different laboratory contexts at university level, one in nuclear physics and one in a genetic engineering course. In order to ‘get sight of’ the human-material intra-activity as well as the overarching intentions and beliefs of people involved in the activities, we used three complementary methods; observations through video, micro-interviews and individual interviews. The video recording focused on the intra-action between students and the instruments/material/equipment they handled; intra-actions between students and lab assistants; intra-actions between students and lab-instructions. Micro-interviews were performed during the lab sessions where we asked the participants questions about their activities or possible emotions that emerged.

In the nuclear physics laboratory, 37 male and 19 female students worked one day (eight hours) in the lab. The students were supposed to use a gamma-spectrometer to produce a plot with peaks in order to identify some radioactive material. In the genetic engineering course, 25 students with equal gender distribution, had a four-day laboration with the purpose to alter bacteria genome using many different biochemical methods. In both cases, the students were expected to produce a lab report to be assessed. The data material consists of 40 hours of video-recordings, micro-interviews, and complementary field notes for each of the two laboratories.

During analysis of the video-recordings, micro-interviews, and field notes, we used Barad’s concept of intra-action to look for entanglements between student-student-lab-assistants-instruments-emotions-gender-communication (Barad 2007). The second step was to highlight similarities and differences between our two different lab contexts, a method described by Barad 2007 to find patterns and objects in webs of intra-actions. In the third step we picked two situations to illustrate results from the analysis and discuss it together with the theoretical concepts. In this step we use Ahmeds politics of emotions to identify how emotions interplay with instructions, materials, and students.

4. RESULTS

4.1. Crowded spaces crammed with artefacts

Vignette 1: The laboratory of genetic engineering 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 searching for the equipment or apparatus they need. Students use around 80 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.

Vignette 2: The laboratory equipment in the nuclear physics lab is arranged on tables with two chairs at each unit. As soon as the students enter the room, they pair up and position themselves at 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.

The equipment consists of 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.

In the room, there is a blue cabinet with warning text indicating the presence of radioactive material to be used in the experiment. The material should not be used longer than necessary, and students may need assistance from the teacher to locate the appropriate material in the cabinet.

In both settings, students are expected to explore and decipher the functionality of the instruments and all the materials themselves, without extensive instructions. Students must sort through the impressions to decide how much of the instruments and materials they will attempt to understand and at what level. Instruments that do not need to be understood in detail function as black boxes. In the cramped genetic engineering lab, the students meet regularly between the groups, discuss and ask each other questions in order to move forward with their experiments. This differs from the physics setting, where students are assigned to stations with limited interaction between different pairs. However, some groups challenge these boundaries, engaging in collective discussions and knowledge-sharing. This boundary-crossing demonstrates an assertion of agency and a desire for collaboration.

4.2. Human bodies-material-emotions-learning intra-actions

Vignette 3: There are two electrophoresis apparatuses in the lab, used to separate and visualise the bacteria DNA-fragments. The students queue up to apply their DNA-samples. Teacher 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 and press down their samples to sink them into the wells. The student must handle the pipette with skill, to not 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. 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, the automatic pipette containing a tiny DNA sample; the student's questions to Doris answered with words but also physically as Doris moves her head close to the student to see what the student sees.

A device initially entangled with emotions is the centrifuge, that students are instructed 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 fear that they haven't done it correctly. They also listen attentively for sounds of malfunction, as the teachers have advised them to switch the centrifuge off if they hear if something is wrong. In the end of the week the students' fear diminishes, and they swiftly handle the centrifuge without further discussion. At this point the students master the instrument, and the centrifuge is no longer intra-acting with students' emotions.

Vignette 4: 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 tinkle, except not exceed a given level of the high voltage.

Initially, the students try to understand and learn the instrument. They experiment by turning various knobs and connecting cables. Several students, like Rahid, express frustration as time passes without providing 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 desired outcomes, as peaks on the computer screen, other feelings come in to 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 in the physics experimental hall, as 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. For instance, student Malva expressed intense sounds of fear while carrying the radioactive material. At a first glimpse, it seemed as if she really was afraid, but during the 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 feel scared about it."

Vignettes 3 and 4 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 fear, 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.

5. DISCUSSION

In our examples the laboratories are crammed with artefacts. The student must distinguish what artefacts they should use or not and at which level of understanding. The instruments that don't require detailed understanding, are blackboxed as in the situation with the centrifuge. In accordance with agential realism, (Barad 2007) the boundaries around the blackboxed material are not fixed, in time and space, nor are they the same for all students. An apparatus that is initially used casually may require better understanding later for the students to continue their practical work. Students need skills in actively handling the instruments but also in actively ignoring irrelevant artefacts or details. For teachers who are used to the experimental hall, those artefacts are taken for granted, and therefore there is no explicit instruction about what the students should pay attention to and not. The ability to efficiently make sense of the milieu gives agency to the student in their own learning process. Therefore, it's important to thoughtfully address taken-for-granted knowledge of instruments and material.

In the nuclear measurements setup, the task is to produce results on a computer screen. Everything before that moment is completely new to the students, so they depend on the teachers. The students express this low agency as boredom and waste of time. In the end of the lab, the students can connect the results to the theory they have learned. This part, as they experienced agency, they refer to as the best part of the lab.

In the vignettes, students' emotions are constantly intra-actively negotiated and shape the practical activity in many different ways, in line with Ahmed (2004/2012). As an example, Malva uses fear as a tool for proper handling of radioactive materials and student use feelings of meaning or boredom for seeking agency. Teachers have agency in this entanglement, in scaffolding the students.

In a broader sense, emotions are entangled with the process of becoming part of the community of practice (Lave & Wenger, 1991). The results from the nuclear measurements setup suggest that emotions play a role in shaping students' perceptions of their own agency and the value of their learning experiences. They also suggest that agency and empowerment are contingent on the ability to make meaningful connections between theory, instruments, and material outcomes. As discussed by Berge et al. (2019) the tinkering student, has an advantage in the integration into the community. Feelings of lust lead to tinkering. Tinkering creates feelings of lust in case of success. If the students don't have enough knowledge and skill to succeed this can create feelings of frustration. Frustration in itself can lead to either motivation to continue or to alienation.

Overall, this analysis through the lens of agential realism highlights the entanglement of materialities, student agency, and knowledge production. It underscores the importance of recognizing the active role of both human and non-human entities in shaping educational experiences and the formation of knowledge in engineering education.

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