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Sustainability Matters: The Evolution of Sustainability Awareness, Interest and Engagement in PBL Engineering Students

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ABSTRACT

The purpose of this study was to identify patterns of change in students' awareness of, interest in and engagement with sustainability issues during the process of acclimatisation to their PBL engineering studies, and to look for differences between engineering disciplines with respect to these aspects. This study used a longitudinal qualitative approach with a theory-led thematic analysis. There were 16 participants in total, interviewed at 3 intervals during a period of 18 months at a faculty of engineering in Denmark. The authors found a pattern of increase in sustainability awareness, interest, and engagement throughout the three semesters of the study. Some differences between engineering disciplines were visible, especially between sustainability-oriented engineering and the others. Most students who increased their sustainability awareness and interest were also likely to engage further with the topic. That engagement built up from individual engagement, to professional engagement and for some, into institutional and public sphere engagement. The findings are timely given the pressure faced by engineering education to incorporate sustainability issues. It provides avenues for educating engineering graduates who will display interest, awareness, and engagement with sustainability issues. It suggests institutional engagement as a potential avenue to explore for engineering educators.

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INTRODUCTION

Sustainability issues are increasingly at the heart of engineering education design and implementation. Guidance from international bodies such as the United Nations (UNSDGs) has prompted engineering curriculum designers to review how to integrate sustainability into the learning process. There has also been increasing pressure for change from students (Ralph & Stubbs, 2014) at a time of high media interest in sustainability and the publication of alarming reports on climate change (IPCC, 2021) and biodiversity loss (IPBES, 2019).

For over two decades, the Education for Sustainable Development (ESD) literature has advocated for change from education *about* sustainability to education *for* sustainability (Blake et al., 2013; Filho et al., 2018). As a result, there has been increasing interest in the potential of pedagogy, particularly forms of project-based, problem-based and active learning, to foster interdisciplinary sustainability awareness, interest and engagement (e.g. Holgaard et al., 2016; Mintz & Tal, 2018; Noordegraaf-Eelens et al., 2019). Interest in the student perspective on sustainability education is relatively recent, including in engineering education (Watson et al., 2013; Berdanier et al., 2018), and remains relatively understudied, with an over-representation of quantitative studies (Cebrián et al., 2019).

Recent publications have advocated the use of problem-oriented project-based learning (PBL) to develop sustainability competences in engineering education (Holgaard et al., 2016; Guerra, 2017), including "contextual knowledge, cultural awareness and sustainability agency as well as professional identity and scientific-technical competence" (Holgaard et al, 2016, p. 3480). In engineering education, PBL is a learning approach in which students work in group projects based on real-life problems in every semester (Kolmos et al., 2004). Systemic PBL refers to the implementation of PBL across an entire institution, with 50% of study credits allocated to project work. This is currently only being implemented fully at Aalborg University in Denmark (Kolmos, 2017). But the impact of PBL on engineering students' awareness, interest and engagement with sustainability remains understudied. Beginning in 2010, Kolmos and Holgaard (2017) performed a longitudinal quantitative study across all the engineering schools of Denmark with the goal of identifying the progression of students' generic sustainability competences over the course of their studies. They assessed variables related to sustainability competences, including self-reported "readiness" with regards to environmental impact and social responsibility. By their final semester, a higher percentage of students at a systemic PBL university in Denmark assessed themselves as "very well prepared" for tackling sustainability issues, and had increased confidence in

their sustainability competences (Kolmos et al., 2020). However, the connection between PBL and the increase in sustainability awareness, interest and engagement was not explored, and differences between engineering disciplines were not analysed. A longitudinal qualitative research might usefully provide insights into the entanglements between student learning trajectories, PBL and sustainability issues. Our study therefore looks at the period in which undergraduate students *acclimatise* to PBL throughout the first three semesters, a period during which they develop core PBL competences, including sustainability competences (see Methodology section; Servant-Miklos & Kolmos, 2022). We will address the following research questions:

- What are the patterns of change in students' awareness, interest, and engagement with sustainability issues during the process of acclimatisation to their PBL engineering studies? What does this tell us about the awareness, interest and engagement with sustainability?
- Do we see differences across different engineering disciplines, and what can we learn from this about engineering students' professional identity development?

The following literature review will, besides presenting an overview of findings from previous studies on students' awareness, interest, and engagement with sustainability, point to different perspectives of awareness, interest and engagement to evaluated in the light of the analysis of our empirical data.

EMPIRICAL UNDERPINNINGS

The purpose of a theory-led thematic analysis being to relate categories developed in the established literature in the field to new data, we parsed through the Education for Sustainable Development (ESD) literature to identify key frameworks for describing how students relate to sustainability. From our analysis of the literature, three categories of relations emerged: awareness, interest and engagement. Engagement was further divided into four categories: private, institutional, professional and political. These categories form the theoretical underpinnings of our theory-led thematic data analysis (Braun & Clarke, 2012) by providing the ground-work for coding the data.

Student awareness of sustainability

Based on Sammalisto et al (2016) and Oberrauch et al (2021), we define sustainability awareness as student knowledgeability about sustainability issues, including awareness of the urgency of moving towards more sustainable development.

Theory and Practice. This relates to whether students' sustainability knowledge is mainly theoretical, or complemented by practice, and is important with regards to the the topic of our study because it connects awareness with engagement. Meyers (2006) challenged the idea that theory and practice in environmental education are opposable approaches, suggesting a pragmatic continuum between the two. Aguilar and Krasny (2010) proposed that the classroom itself could be a community of practice in-the-making, where joint enterprise and mutual engagement on learning goals create a shared repertoire of theoretical-practical understandings. More recently, the literature has offered broader definitions of the terms, with "theory" comprising various forms of theory-in-the-making including action research (Paredes-Chi & Viga-de Alva, 2020), and research-meets-professional-practice (Pizmony-Levy et al., 2021). "Practice" has come to include normative commitments to social justice (Ceaser, 2012; McGregor & Christie, 2021), decolonial praxis (Rodriguez, 2020) and ecofeminism (Gough & Whitehouse, 2020).

In a meta-analysis of sustainability education pedagogies, Lozano et al. (2017) identified the best pedagogical approaches to bridge theory and practice, including problem-and-project based learning, jigsawing, and service-learning. Affolderbach (2020) showcased this in practice, in a problem-and-project based approach to geography education in the UK that gives students the power to design, pitch and potentially implement green-economy projects. Recently, interest has emerged in more experimental pedagogies to bridge theory and practice, such as garden-based learning (Zuiker & Riske, 2021), community volunteering (Eiseman et al., 2020), and place-based learning (Cincera, et. al., 2019).

Systemic *vs.* Domain-specific awareness. This relates to the question of whether sustainability is understood by students as transdisciplinary and systemic, or narrowly embedded within one or several disciplines. Bajracharya and Maskey (2016) conducted a survey of 373 American students' awareness, knowledge, values, and perceptions of environmental sustainability, suggesting that students were reasonably aware of sustainability issues. However, approximately 20% of the participants perceived sustainability as outside their disciplinary remit, while 30% of the participants agreed that sustainability should be integrated into core courses, pointing to the concerning conclusion that students perceived sustainability as neither core to their studies, nor interdisciplinary.

Recent studies suggest that interdisciplinary approaches to education fare better than disciplinary ones in promoting a systemic understanding of sustainability issues (Servant-Miklos & Noordzij, 2021; Walsh et al., 2021). In particular, interdisciplinarity is better able to convey concerns on systemic sustainability and intersectionality (Maina-Okori et al., 2018).

Student interest in sustainability

Interest relates to students' motivation to learn more about sustainability and take responsibility for their own learning around sustainability issues.

In a survey of American students' perceptions of sustainability education, Watson, Noyes and Rodgers (2013) found that 70,6% of students indicated a strong interest in sustainability, however, they lacked confidence in their ability to speak knowledgeably about sustainability. Another survey from Texas (Msengi, et al., 2019) indicated an even larger detachment between interest and awareness: while 95,8% of participants believed that sustainability was important, only 30% encountered sustainability in their study programmes. In other words, even when students show interest in sustainability, the lack of options for studying sustainability leads to awareness trailing behind interest. Where integrating sustainability within the curriculum is not possible, there are options to offer extra-curricular or elective sustainability courses (Spalding et al., 2014). Teachers could also give room for sustainability concerns in student-directed pedagogies. For instance, project work gives students a chance to integrates sustainable thinking in their problem analysis (Guerra & Holgaard, 2019).

Students' engagement in sustainability

Engagement relates to acting towards sustainable development. By engaging, students take responsibility for sustainable practices in different spheres of their lives. As we have shown, the lines between sustainability education and normative engagement are increasingly blurred. The modes of engagement emerging from this normative commitment are still being defined, with a paradigmatic divide forming between a pragmatic view and a relational view. The pragmatic view compartmentalizes engagement into distinct categories, such as individual, professional, or public and tackles each one in turn, with oppositions between private and professional spheres, and institutional and political spheres, and some convergences possible between institutional and professional (e.g. sustainability officers), private and institutional (e.g. installing recycling stations in the university for private use), private and political (e.g. donating to an activist group), and political and professional (e.g. becoming a green party politician). The relational view, on the other hand, understands all forms of engagement in sustainability education as related and inherently political (Ferreira, 2019; Walsh et al., 2021). In this view, the boundaries within which professional, institutional and private choices are made are politically determined, complicating attempts to distinguish between spheres of action. The relational view dominates in the humanities, whereas the pragmatic view tends to characterize engineering education.

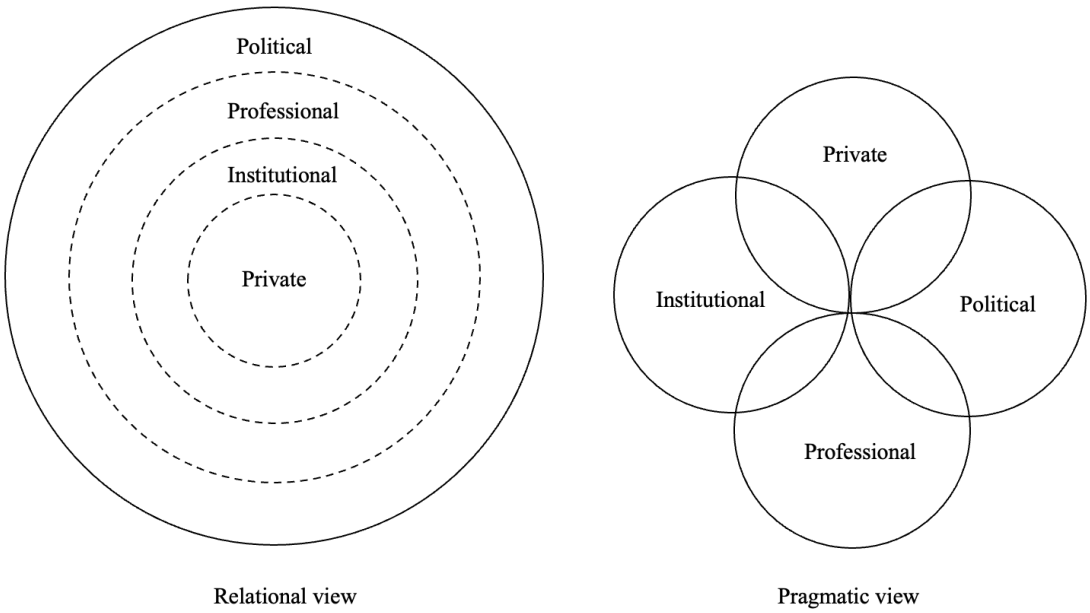

Figure 1. Visual representation of the relational and pragmatic views on the relationships between sustainability engagement categories.

Private engagement. Whilst exclusive focus on action in the private sphere has been justifiably decried as insufficient to enact systemic change (Ferreira, 2019), it is nonetheless understood that individual change is necessary for system-level change (Lafuite et al., 2017). Sustainability education has been identified as a key factor in developing individual engagement (Varela-Candamio et al., 2018). However, the understanding of what changes support "sustainable lifestyles" tends to be narrow. A study of British students showed that they strongly, if not exclusively, associated sustainability with recycling, despite the low impact of recycling on sustainability outcomes (Chaplin & Wyton, 2014). In the United Arab Emirates, students associated sustainability with minor lifestyle adjustments like purchasing reusable containers and less frequent use of the washing-machine (Al-Naqbi & Alshannaq, 2018). A study from the Netherlands showed that while some students were willing to consider vegetarian diets, larger behavioural changes such as giving up international air travel were off the table (Servant-Miklos & Noordzij, 2021).

Institutional engagement. Some studies report on student engagement within the institutional sphere, namely trying to change higher education from the inside, by engaging within schools and universities through official channels such as board, councils, committees, campus magazines, student associations and other official organs, to push for more sustainable policies and practices. At Portland State University, 20 student representatives were selected to form a "Student Sustainability Leadership Council" that developed a student sustainability vision and provided feedback to faculty

(Spalding, Williams & Wise, 2014). The same paradigmatic tensions operate at the level of institutional engagement, with some scholar investigating institutional engagement as a discrete sphere of action, while other understand institutional engagement as a localized form of political action (Hoover & Harder, 2015). Van Poeck and Östman (2018) investigated the circumstance under which the politicisation or de-politicisation of institutional questions emerge in sustainability education. They concluded that de-politicisation happens when educators control the narrative on which normative concerns to address and how to address them, while politicisation emerges when education is conceived as an open space where conflicts can be analysed and debated.

Professional engagement. Professional engagement is one example of gearing normative concerns towards a given solution. In engaging through the professional sphere, students are encouraged to plan their careers around sustainability issues, generally understood within a market-based framework with companies as primary actors. The discourse on sustainability education as professional learning is not new (Stevenson, 2007), however, the seismic shifts in business interests in sustainability over the last decade have increased the uptake of this view.

Central to the professional engagement premise is the early input of private stakeholders and "real-life problems" in the education process, usually through project learning (e.g. Kricsfalusy et al., 2018). Here, a distinction is made between interdisciplinary learning projects that integrate various parts of the curriculum, and transdisciplinary projects, where students learn to work with external stakeholders (Segalás, et al., 2010), a participatory form of transdisciplinarity also known as *mode 2* research (Andersen & Kjeldsen, 2015). In Denmark, PBL students do both, working with companies, municipalities and other third parties on projects to address current sustainability problems in industry (Kolmos & Holgaard, 2019).

Political Engagement. A critical body of literature rejects the de-politicisation of sustainability education, gearing the narrative towards political solutions instead. These scholars understand environmental issues as inherently conflictual arenas where individual, private interests clash with collective, public goods (Ferreira, 2019; Van Poeck & Östman; 2018). Within this view, personal and social responsibility are intertwined with institutional decision-making (Boyd & Brackmann, 2012). Håkansson, Kronlid and Östman (2019) identified three forms of political engagement in sustainability education: socially-critical, social learning, and radical democracy. The first is linked with a structural, social justice reading of systemic sustainability. The second offers a more participatory, bottom-up reading with a strong emphasis on emotional processing and reflexivity. The last tries to eschew the perceived normative biases of the first two with open, deliberative practices that do not take positionings on sustainability for granted. Student sustainability campus activism tends to fall into the

first category, occasionally the second, and rarely the third. As a discrete sphere of operation, political engagement could be understood as public sphere engagement, differentiated from institutional engagement by the fact that students do not work through official university organs, but rather act as an oppositional force to university institutions by leaning on political organisations (e.g. political parties, activist groups) that work in the local, national and international public sphere. For instance, student activism resulted in Cornell University declaring sustainability as a core value in research, education, outreach and campus management (Too & Bajracharya, 2015). Recently, in the Netherlands, several major universities were occupied during student-led political protests. The protests led to police interventions on campuses, prompting debates about the ties between universities and the fossil fuel industry within the university communities (Erasmus Magazine, 2023).

Disengagement. The examples highlighted above might give the impression that student engagement is the norm, but there are numerous studies showing student disengagement. For example, Eagle et. al. (2015) reported that undergraduate business students regard societal issues as beyond their personal control, and consequently outside their responsibility. These findings are consistent with the "attitude-behavioral gap" identified by Owens and Driffill (2008) and the "identity dissonance" identified by Servant-Miklos and Noordzij (2021). The latter showed that although most sustainability students expressed a moral identity geared towards environmental care, this did not translate into shifting unsustainable pre-existing beliefs and behaviors. As such, awareness is a precondition for informed concern and action – Sammalisto et al (2016) showed a significant correlation between increasing awareness and taking action. But increasing student awareness about sustainability is not sufficient to ensure sustainability engagement. For instance, both Sammalisto et al (2016) and Oberrauch et al (2021) showed that gender strongly influences the likelihood of action: at the same level of awareness, students identifying as women are more likely to take action than students identifying as men.

In the following, we will use these concepts from the literature review as lenses to analyse students' awareness, interest, and engagement in sustainability in a PBL engineering programme.

	Categories of student relations to sustainability issues		
	Awareness	Interest	Engagement (pragmatic view)
Sub-categories of relations	Theory v. practice		Private
	Domain-specific v. systemic		Institutional
			Professional
			Political / Public

Table 1. Overview of categories of student relations to sustainability found in the ESD literature and used for the data analysis of this study.

METHODOLOGY

Our study used a qualitative thematic analysis approach (Braun & Clarke, 2012), characterised by relatively small sample sizes, rich data analysis, and a focus on transferability rather than generalizability. This thematic analysis was "theory-led" (Braun & Clarke, 2012) in that the thematic categories were guided by the literature presented in our review. Thematic analysis is an epistemologically flexible methodology, though epistemological assumptions should be clarified up-front. We operated within a social-constructivist epistemology, meaning that we were not looking for "objective" descriptions of social phenomena with essential qualities, but for the ways in which participants constructed meanings and understood their place within social phenomena whose interpretation is subjective to participants and researchers alike (Bailey & Douglas, 2014).

Participants

We used purposive sampling (Etikan, 2016) to gather participants from different types of engineering studies within the same engineering faculty of a systemic PBL university in Denmark: electronic engineering, mechanical engineering, tech-oriented engineering (a media-tech design programme called "medialogy"), and sustainability-oriented engineering, for which we chose a planning programme in environmental management (BEM). We recruited male and female participants at the start of their programmes, in proportions which reflect roughly the student population in each programme. Six participants signed up for each programme, and two dropped out in between the first and second interview, bringing the total number of participants to 16 over the entire study, listed in Table 2.

Grouped per engineering degree programme			
Student (Pseudonyms)	Age (at the start)	Gender	Degree Programme
Elena	19	Female	Electronic Engineering
Jan	33	Male	Electronic Engineering
Claus	23	Male	Electronic Engineering
Vincent	32	Male	Mechanical Engineering
Jens	29	Male	Mechanical Engineering
Peter	19	Male	Medialogy
Helga	22	Female	Medialogy
Tomas	20	Male	Medialogy
Erik	22	Male	Medialogy
Kasper	19	Male	Medialogy
Johan	19	Male	Medialogy
Maria	21	Female	BEM
Poul	18	Male	BEM
Lykke	21	Female	BEM
Ana	20	Female	BEM
Cecilia	22	Female	BEM

Table 2. Participants in the study, grouped per engineering programme.

Interviews

All participants were interviewed in their first, second and third semesters. All participants were provided with a slide deck explaining the purpose of the study, the number of interviews, and how the data would be handled. They provided consent to record the interview and use the data before each interview. There were three rounds of interviews, shown in Table 4: one round at the beginning of the undergraduate programme during the introductory project period known as P0 (semester 1), one round after students completed their first full project, at the beginning of the project period known as P2 (Semester 2), and a final round at the end of P3 (semester 3), by which point students have completed their first full independent team project, are considered acclimatized to PBL as a learning method.

P0	P1	P2	P3+
• 1 month long • Focus on structural and problem-oriented competences. • Learning to write a report • Learning group-based assessment	• 2 months long • Focus on metacognitive and interpersonal competences. • Disciplinary scientific contents begins to be integrated	• 1 semester long • Project is oriented towards disciplinary scientific contents • Written evaluation of PBL competences	• 1 project per semester • Focus is exclusively on disciplinary scientific contents

Table 3. Structure and contents of student projects from P0 to P3 (adapted from Servant-Miklos & Kolmos, 2022).

Interview Round	Interview Structure	Question themes (based on categories from the literature)
R1 (Start P0)	Semi-structured, 45 minutes, same structure for all students. Questions not sent in advance.	Personal history; Reasons for choosing engineering; Sustainability awareness and interest; Sustainability actions related to 4 spheres of engagement
R2 (Start P2)	Unstructured, 45 minutes – 1 hour, following on from answers from R1. Questions not sent in advance.	Students asked to reflect on previous responses, and anonymous responses of others.
R3 (End P3)	Semi-structured, 45 minutes – 1 hour, but structure is personalised for each student based on previous answers. Questions sent in advance.	Sustainability awareness and interest Sustainability actions related to 4 spheres of engagement Reflections on relationship between students' specific field of engineering and sustainability Future perspectives on sustainability

Table 4. Structure of the longitudinal interview rounds.

All interviews were run by the first author, in English, to accommodate the language preferences of all participants and authors. The interviewer used a semi-structured approach: a list of key themes was kept in view during the interviews but no structured phrasing or order of questions was enforced (Waller et al., 2016). This was done to invite participants to lead the interview process, providing space for marginalized perspectives and participant agency (Lee, 2011; Sochacka et al, 2018).

Analysis

Thematic analysis does not require verbatim transcripts (Braun & Clarke, 2012), so the researchers used the audio recordings to not be weighed down by the large amount of data, with note-taking as a primary means of identifying important information.

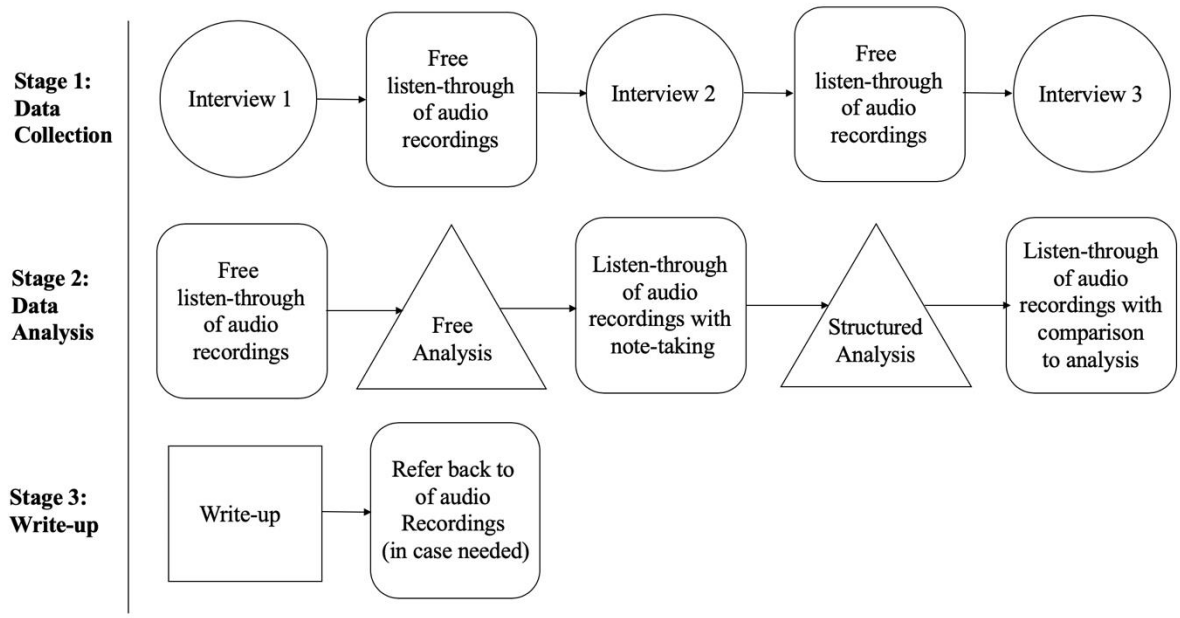

Figure 2: Longitudinal qualitative thematic analysis research method process map.

The interviewer (first author) listened through to the recordings between each round and drafted questions for the next round, as shown in Figure 2. Once all interviews were conducted, the first author listened to the audio files to perform a free analysis, meaning that initial ideas and thoughts were memo'ed without attempting to organize the analysis into codes. Then, the first author performed a structured listening round (looking for the theory-led categories mentioned above) and took systematic notes, summarizing key points made by participants, transcribing interesting quotes verbatim and operationalizing them into the established categories. The interview notes were shared with the other authors, then organised thematically in a collaborative process designed to increase the reliability of the findings. The themes from the literature and the data extracts were matched. The recordings were listened through a final time to ensure that the categories convincingly corresponded to the data, discrepancies were corrected by aligning the interpretation more closely with the data. During the write-up phase, if some quotes were missing or some interpretation was unclear, we referred to the audio files. The second and third authors acted as devils' advocated in the data analysis process to reduce researcher bias in the analysis process. The authors are from different institutions, different countries, and different disciplines which allowed for a diversity of perspectives to be reflected in the analysis. The first author is a psychologist from the Netherlands, while the second and third authors are engineering educators from Denmark, Having a

researcher external to the institution where the research was conducted as interviewer and first author reduced the risk of bias in the interview process (less likely to ask leading questions), and in the analysis (less likely to expect certain outcomes). Having internal researchers as second and third authors provided the analysis with an insider perspective and insider tacit knowledge to clarify difficulties in interpretation.

FINDINGS

Whereas the literature examined the categories of student relation to sustainability as discrete sphere, our findings present them as an evolutionary process of student sustainability awareness and interest on the one hand, and engagement on the other. The link between the two will be considered in the discussion section.

Increased sustainability interest and awareness

Our participants fell into four graduated categories of awareness and interest, based on the gradient criteria shown in Table 5. There was a propensity for them to shift from one category to the next as they progressed through their studies.

Category	Description	Illustrative quotes
Category 1: No interest, limited awareness	Students express no interest and little knowledge of sustainability issues.	**Johan (M; R2):** "I know it's a thing, but I don't know what to do about it… well, it's partly my own fault because I haven't looked up what I could do about it, but … this global warming, I don't know what I could do to help… *ignorance is bliss.*"
Category 2: Limited interest, basic awareness	Students show interest in sustainability issues, and express curiosity about the topic. They understand some of the drivers of those issues, and that these issues are getting worse, but are not interested enough to challenge their basic belief systems.	**Tomas (M; R2):** "I know about the effects that the meat industry has on a global scale, but I would never really consider becoming a vegetarian because I like the taste of meat... I think it's part of a healthy diet and all the like, and perhaps it's also a bit… we have climbed our way to the top of the food chain, we have opposable thumbs, we deserve to eat meat."

Category 3: basic interest, basic systemic awareness, high domain-specific (disciplinary) awareness	Students are sufficiently motivated to actively seek out news on sustainability, to pick up on the issue when it is raised in their studies, and to involve it in their PBL projects. While they have a good basic awareness of sustainability issues, they tend to focus on disciplinary aspects of sustainability, often at the expense of more systemic understanding.	**Helga (M; R2):** "In the 2nd semester we had the options of working with exercise or food waste, and I was very excited about working with food waste and I actually got to do that and that sparked an interest in how I could continue to work with these things."
Category 4: High interest, high systemic awareness	Students are actively interested in sustainability issues, and try to integrate these issues in their studies and as part of their lives. They show a good understanding of the scale and scope of sustainability issues, and understand the complex systems in play in tackling sustainability issues.	**Lykke (BEM; R2):** "there's a lot of individual people, or small groups, especially with plastic or with how you need to stop using plastic straws or something, there's a lot of small, individual groups of people saying – "this is bad" (…) but it's not only the plastic straws that need to be dealt with, it's the whole plastic industry."

Table 5. Categories of sustainability interest and awareness in students.

Figure 3 below depicts the evolution of sustainability interest and awareness throughout the study:

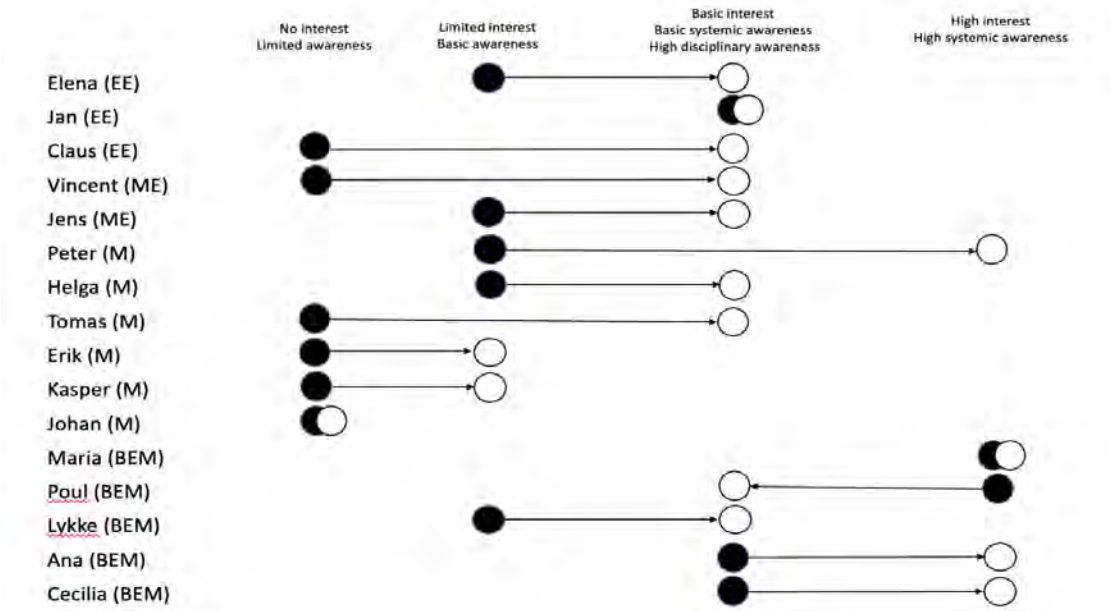

Figure 3. Evolution of sustainability interest and awareness between R1 and R3. Black circles mark the starting point, white circles mark the end point.

Interpretation of the findings

Category 1: no interest, limited awareness. Six of the students interviewed could be classified in Category 1 at the start of P0, and only one could be classified as such by the end of P3. There were three rationales offered for this initial lack of interest and awareness. The first was that the students were devoting so much cognitive bandwidth to their studies that they didn't have time or energy to get informed about sustainability issues.

The second was that personal issues meant that the students were more focused on their immediate worries than about global problems. They consider sustainability to be a luxury problem compared with immediate issues like financial worries:

> **Claus (EE; R1):** I don't really know what I would do if my house was submerged in water. I mean it's not really things that I worry about daily. I have other things to worry about, like how I survive the end of the month.

The third was that in the absence of obvious strategies to solve sustainability problems, students prefer not to worry about it, as a kind of learned helplessness.

> **Vincent (ME; R1):** Pfff, I haven't really given [sustainability] much thought, and I don't… I try not to interfere with stuff that's out of my reach.

Students in Category 1 tried to keep sustainability concerns at bay, out of their studies and out of their lives. We saw a large shift away from this category as students acclimatized to PBL.

Category 2: **limited interest, basic awareness**. Five participants could be classified in Category 2 at the start of P0, and two could be classified as such at the end of P3, demonstrating another shift towards increased yet limited sustainability interest and awareness. For these students, we noted expressions of cognitive dissonance associated with this knowledge. Cognitive dissonance can be defined as an attempt to reconcile incompatible beliefs and actions and is a common reaction to increased sustainability awareness (Stoll-Kleeman et al., 2001), as noted in the above-quote from Tomas (M). One strategy to resolve cognitive dissonance was providing moral mitigation to make the belief-system fit with actions: "we deserve to eat meat". Another reaction to this basic level of awareness was conflicted emotions, and technological escapism:

> **Elena (EE, R2):** I've been in this denial thing, "oh this will affect my children, my grandchildren", but then I've learned that it is happening now, so it is affecting me, so I've gone to "I sort my plastic, I sort the waste and I don't use plastic straws and all that stuff". It's not enough to make it OK. So, I'm also a bit in despair, well, we're kinda screwed, let's go to Mars!

In contrast to the first category, students in Category 2 expressed sustainability concerns, but resorted to psychological deflection to avoid delving too deep into the subject. Whilst this was the endpoint of the sustainability journey for two of the medialogy students, the rest also shifted towards further increased awareness and interest.

Category 3: **basic interest, basic systemic awareness, disciplinary awareness.** Three participants could be classified in Category 3 at the start of P0, and nine could be classified as such by the end of P3. This was the most common status of sustainability awareness and interest for students by the end of P3. One of the drivers for this was the prominence of sustainability issues and eco-celebrities in mainstream media:

> **Jan (EE; R3):** I think it's great to have someone with a network like Greta Thunberg has got now. The network she has built, the organisation around her, it moves something.
>
> **Jens (ME; R2):** Maybe I'm listening too much to Elon Musk. He thinks we can solve all the world's problems by shooting rockets to Mars.

The result was a foundational knowledge base on sustainability issues, and an interest in finding out more. In this category, there was also specific knowledge and interest in one or several disciplinary domains. This specific interest appeared to be triggered by a PBL project on a sustainability theme, or a class on sustainability within the curriculum.

> **Vincent (ME; R3)**: We had a lot on the mechanical properties of plastics, we had a lot on microplastics - the lecture definitely was an eye opener for me. I'm definitely thinking about it more than I used to.

However, the more students focused on their domain of interest, the more they tended to lose sight of the systemic picture.

Category 4: High interest, high systemic awareness. Only two participants could be classified in Category 4 at the start of P0, and four could be classified as such by the end of P3. All the students who achieved this level of interest and awareness were already interested and aware before their studies, but pushed it further during their degree programme.

> **Peter (M; R3):** I've realised how much of a huge deal it is, it's bigger than all of us…. When I saw how close we are, that we have a deadline, by 2040, we need to change. And that kind of woke me up, like, yeah, this is really messed up.

This level of awareness correlated strongly, but not exactly, with public sphere engagement, as we shall see in the next section. Systemic awareness was most prominent in the BEM group, and Cecilia (BEM) credited the study programme for this:

> **Cecilia (BEM; R2):** I think there's a lot in my personal life, but also, I think also the studies because you read about all these things that are being done and the possibilities on what more can be done, and that motivates you.

There was likely a selection-bias at the start of the programme, as students who are already aware and interested in sustainability are more likely to opt for environmentally-oriented studies (Prevot, Clayton & Mathevet, 2016).

Interpretation of Exceptions. Overall, there was an increase by one or two categories among the participants. There were three exceptions, which could be explained individually. Johan (M) was truly afraid to delve into the subject and lived by his motto than "ignorance is bliss". He would rather not know at all, than know, and then need time to build up sustainability competences to address his anxiety. Jan (EE) was already aware of sustainability issues, but he found the subject too depressing to go further, given his other personal issues. Therefore, these students did not progress in their sustainability interest and awareness for personal reasons. Poul is an interesting case: he became less systemically aware of his own volition to focus on energy, from the disciplinary standpoint of theoretical physics. He explained this change as a result of conflicts with his BEM project team, prompting him to leave the BEM programme altogether – this is further explored in the next section.

Broadening engagement

Viewed from a pragmatic lens, we identified a progression from disengagement to private sphere engagement, to professional engagement and in some cases, public and institutional engagement, shown in Table 6. The relevance of these findings for a relational lens will be addressed in the discussion.

Type of Engagement	Description	Illustrative quote
Disengagement	Students are unwilling to get involved in action for sustainability.	**Johan (M; R3)**: "I don't want to focus on this, I don't want this to be who I am, even though it might be necessary for our survival. It's just difficult, yeah?"
Private Sphere	Students take private actions towards "sustainable lifestyles", primarily by making responsible consumer choices, minor adjustments to their lifestyles, voting "green" and donating to environmental charities.	**Elena (EE; R3):** "I don't think it's something I'm going to spend a lot of money on, or a lot of time on, like actively going to protests… But I will do what I can from where I am now, when I vote for political parties or just generally talk to other people about this".

Professional sphere	Students incorporate sustainability into their professional plans, defining themselves as working towards sustainability as technical experts.	**Jens (ME, R3):** "When I'm done with my education I would like to work with some company who takes their responsibilities."
Institutional sphere	Students form groups to pressure the university into adopting sustainability policies.	**Peter (M, R3):** "I'm starting my organisation because I don't think the study is focusing on [sustainability] enough. I don't think any study is"
Public sphere	Students join environmental movements in and out of the university, seeking to push for change on sustainability through changes in politics and civil society.	**Maria (BEM; R3):** "I have been taking part in critical mass rides, where you are blocking the roads as a cyclist."

Table 6. Categories of sustainability engagement among students.

We saw a tendency towards a build-up through the categories, with students going from disengagement to private engagement, then in nine cases adding professional engagement, then in three cases adding institutional and public engagement on top of the previous two. However, this does not imply a progressive process in which public engagement is the outcome, as shown in Figure 3.

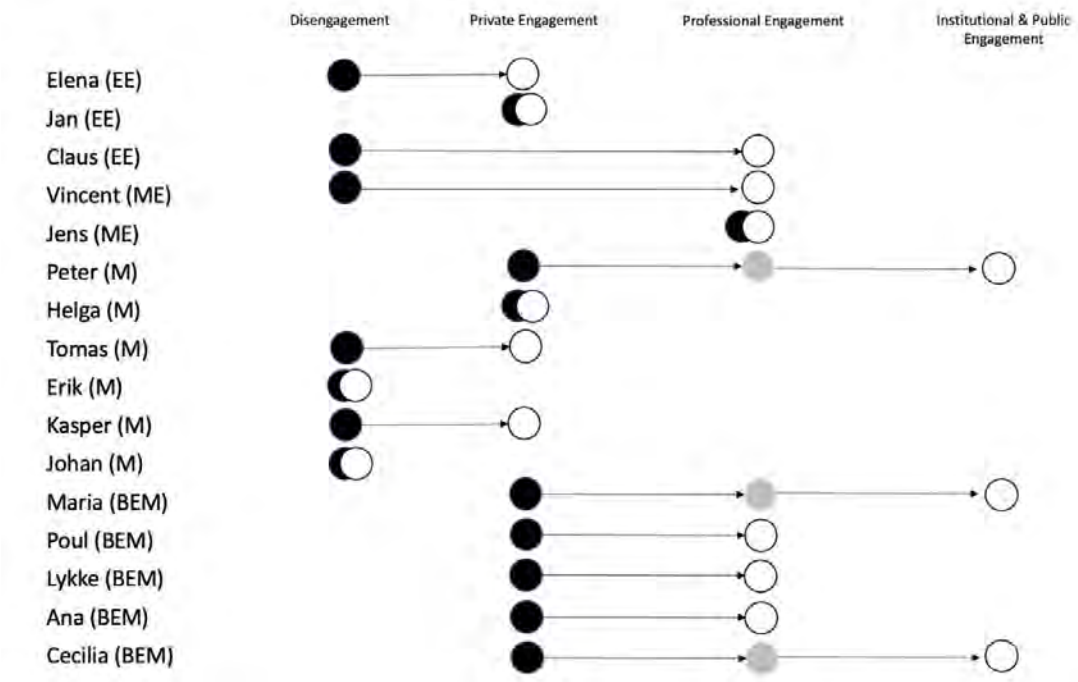

Figure 4. Evolution of sustainability engagement between R1 and R3. Black circles mark the starting point, white circles mark the end point, grey circles mark an intermediary position.

Interpretations of the findings

Disengagement. Seven of the participants were "disengaged" at the start of P0. This correlated strongly but not exactly with participants who also had no interest and limited awareness of sustainability issues. Disengagement was explained mainly as a lack of (knowledge about) possibilities – students felt that there was nothing they *could* do:

> **Vincent (ME;R1)**: During the past year we have read a lot of texts and received a lot of information about global warming and stuff like that and of course that's a worry of mine but there is nothing I can do about it right now.

By the end of P3, only two students were still disengaged, the shift towards engagement coinciding with the shift towards greater awareness and interest. The two remaining disengaged students *knew* what could be done, but feared that if they engaged, they would confront themselves with the colossal scale of the problem, and that would disturb their core professional identity, e.g. as a video game developer:

> **Johan (M; R3):** I guess I'm worried that I'm going to focus too much [on sustainability]… I'm worried I'll feel compelled to do something about it and that compulsion will divert me from doing games, and I don't want to do that.

All other participants engaged with sustainability to some extent by the end of their acclimatization period. But the scope of engagement differed among them.

Private engagement. Eight participants were engaged in this manner at the start of P0, including all the BEM students. By the end of P3, three participants who were previously disengaged had also begun to engage in the private sphere – primarily through voting for green parties, donating money to environmental charities, recycling and eating less meat.

> **Tomas (M; R3):** You can donate one dollar to that charity, and they'll plant a tree for it. […] I've donated to it because, again, obviously, as a student I can't do that much but I've done something, I've done my part.

All participants who engaged privately at the start of their studies continued to do so as they expanded the scope of their engagement. Broader forms of engagement therefore built on top of, rather than replacing private engagement. There were two exceptions to this – Vincent (ME) and Claus (EE) went straight from disengagement to professional engagement. In some sense, because they discovered the severity of sustainability problems during their studies, they immediately channelled these concerns into their professional potential as engineers.

Professional engagement. Only one participant was professionally engaged with sustainability issues at the start of P0. This was an older student, who joined engineering education later in life precisely because of his admiration for the power of engineers to transform the world through technology:

> **Jens (ME, R1):** I'm just going to be a small pawn in the big game but I still want to play my role in trying to solve problems like that. I want to leave a legacy with my engineering job, if possible.

The other participants did not have clear ideas about how they could contribute sustainability through their engineering careers at P0. However, nine of them developed concrete aspirations to work within professional sustainability pathways by P3. Six out of these nine participants did not develop other forms of engagement, and did not want to do so. They expressed a strong preference for solutions that optimize existing processes, with a focus on rapid technological change:

> **Lykke (BEM; R3):** I would like to make environmental solutions to existing problems. […] I personally feel like that's the way that is easier to transition into. In my opinion the problem is that you have to get everybody involved in it, and not just a few doing something radical. The easiest way to do that is to get the technology transition... It's the everyday technology.

Three participants who engaged professionally also engaged institutionally or publicly. Their professional-sphere engagement was less focused on technology, and more focused on societal change.

> **Cecilia (BEM, R2):** I still think there needs to be some kind of political intervention about how we are doing or how we are living, we can't just rely on the technology to improve that much in the time we have.

Institutional sphere. One student, Peter (M), founded an organization within the university to pressure the study boards into including sustainability contents into the curriculum.

> **Peter (M, R3):** The reason I'm starting my organisation is because I don't think the study is focusing on [sustainability] enough. I don't think any study is.

Institutional engagement did not seem to be a prominent feature of this engineering Faculty's "culture". None of the other students mentioned it.

Public sphere engagement. There were no participants who engaged in the public sphere at P0. Some of the BEM participants expressed a desire to do so, but were not sure how to go about it. By the end of P3, two BEM participants were engaged with environmental movements. Their engagement correlated with systemic sustainability interest and awareness. Cecilia (BEM) joined the *Grønne Studenterbevægelse* (Green Student Movement), a political group focused on creating societal pressure for change through education and information. Maria (BEM) joined Extinction Rebellion, a civil disobedience environmental group. They both also expressed commitment to a career in sustainability management. Their public sphere engagement added to their professional

engagement, rather than replacing it. They justified public sphere action as a frustration with the slow pace of change compared with the urgency of the crises, and the perceived inadequacy of their studies in rising to the challenge.

> **Maria (BEM; R3):** I feel less alone, I feel like I have a place, and people who want to do just as much as me…. On another level than the studies.
>
> **Cecilia (BEM; R3):** I've been looking for this community of other people who think this is important because I didn't find it here in my studies.

They both expressed frustration about not finding like-minded people in their studies. In fact, public sphere engagement was generally viewed negatively by other participants:

> **Lykke (BEM; R3):** I was in a meeting for the Student Green Group, I heard what they said, it was OK, but I also felt that what they said was more… just to bring attention to the problem and not doing anything about it.
>
> **Ana (BEM; R3):** I don't like Extinction Rebellion. I don't like Greta Thunberg. She had some beautiful views in the start but she was corrupted. She has done some good things but now she should stop. Instead, we should educate people. Education is the best thing we can do. I think some of the extremes we have are very extreme and that's going to backfire.

In summary, two of BEM participants engaged in the public sphere by their third semester. However, they were out of step with other participants who trusted in individual action and professional engagement only. Institutional engagement was almost non-existent.

DISCUSSION

The outcome of a theory-led thematic analysis being to relate categories developed in the established literature in the field to the interpretations that emerge from new data, we will evaluate the contribution of our data to concept development in the field.

A dynamic interpretation of interest, awareness, and engagement

While the categories of interest, awareness and engagement in the ESD literature reviewed in our empirical underpinnings section have been treated as discrete, we uncovered a progression in interest, awareness, and engagement for most participants. There was an alignment between the development of interest and awareness, and engagement – although engagement was concentrated in the individual and professional spheres. We can suggest two causes for these shifts.

The first might be traced to what mainstream media termed a "Greta-effect" (Nevett, 2019), according to which the media presence of prominent climate campaigners spurred a world-wide increase in awareness and interest in sustainability among young people.

As extreme weather intensifies with climate change, it may also be harder to stay insulated from awareness of the problem.

Secondly, the literature suggests that PBL may have an advantage in raising sustainability awareness and interest among students (Affolderbach, 2020; Lozano et al., 2017). While our findings seem to support this, it was not clear whether PBL had an advantage over regular lectures in introducing students to sustainability issues, since both were mentioned by students as factors triggering interest. Based on Lozano et al.'s 2017 analysis of the impact of pedagogy on sustainability awareness, however, we could infer that the "real-world" nature of the PBL project problems encouraged awareness and interest, as shown for instance by the quote from Helga (M, R2) but this is hypothetical.

We identified several differences between the engineering disciplines we examined: there were higher levels of systemic awareness among BEM students, whose sustainability-focused programme includes inputs from social sciences. Perhaps broader interdisciplinarity that includes social sciences and humanities inputs might further encourage systemic sustainability awareness (Servant-Miklos & Noordzij, 2021; Maina-Okori, Koushik & Wilson, 2018; Walsh, Böhme & Wamsler, 2021). While there is a selection bias towards environmentally aware students within the BEM programme (Prévot, Clayton, & Mathevet, 2017), other engineering disciplines could still offer appealing sustainability problems and contents within their field. The institution has taken some steps towards this: for instance, through "Mega Projects" that engage teams from different engineering disciplines to address wicked sustainability problems, but this remains engineering-focused (Kolmos, Bertel, Holgaard, & Routhe, 2020).

Engineering identity and dimensions of sustainability engagement

A core debate in the literature on student sustainability engagement also played out in our data: what counts as engagement? What the extant literature that we examined left out but which came out of our analysis, is the role of professional identity in defining engagement (e.g. Maria, Lykke, Ana).

The pragmatic view generally held in engineering education compartmentalises engagement within discrete spheres, as shown in our literature review. In this view, engineering faculties have a responsibility to foster professional engagement by training engineers who understand the stakes, are conversant in the latest technological breakthroughs, and can operate within a sustainability-driven global market. In line with this view, sustainability competences have been added to the package of generic engineering competences expected of graduates (Holgaard & Kolmos, 2019).

Our findings indicate that this professional emphasis impacts students' engineering identity formation, as shown in the conflicting viewpoints brough forward by Maria,

Lykke and Ana in the section on public engagement. Tonso's (2006) seminal study on engineering identity showed that university campuses were cradles for identity formation, and "campus culture" (p. 35) was critical to determining the engineering identities that emerged. In that regard, the history of the institution we studied is illuminating. Historically, the Faculty of Engineering has distanced itself from political discourse, emphasizing its ability to create work-ready engineers as a unique selling point among Danish engineering programmes (Servant-Miklos & Spliid, 2017). The faculty's focus on professional competences has yielded positive results, with students rating their sustainability competences higher than other Danish engineering graduates (Kolmos et al., 2020). However, our findings suggest that students may narrowly focus on professional engagement: some of the students we interviewed expressed indifference, suspicion, or outright hostility towards other forms of engagement. The most vociferous arguments about professional and public sphere engagement occurred *between* members of the BEM programme, suggesting that identity questions flare up around sustainability engagement when interdisciplinarity increases. Such arguments may negatively affect students' study experience - as shown by Poul's decision to leave BEM entirely. Alongside increasing interdisciplinarity, it might therefore also be good practice to explicitly address engineering identity formation through appropriate reflection practices.

The relational view argues that pragmatic distinctions between spheres of engagement obscure the political relatedness of all forms of engagement, thereby impeding collective action for change (Ferreira, 2019; Walsh et al., 2021). A critical analysis might suggest that views ostensibly described as "pragmatic" support a status quo which thrives on the separation of spheres of action and depoliticization. However, while relational discourses may resonate with humanities and social sciences students who are used to thinking the personal in political terms, there may be too wide a cultural gap within engineering education for this to land. Yet, a growing consensus around engaging education to push social tipping-points for the sustainability transition leaves no doubt as to the necessity and urgency of widening the scope of engagement, including in engineering education (Otto et al., 2020).

One avenue to explore to bridge pragmatic and relational viewpoints in engineering education could be institutional engagement. Van Poeck and Östman (2018) and Håkansson et al. (2019) suggested that the democratization of norm-setting within the institution could create space to discuss contentious issues without a pre-established normative agenda. Offering possibilities and encouraging students to engage within the Faculty, through democratic student bodies, academic affairs councils and other dedicated groups could create space for students to experiment with their own agency, modulating between different spheres of engagement. This could challenge the exclusionary dominance of professional engagement within the campus culture shown in

the "public engagement" section of the results. Peter offers an example of how this might work: he built a group within the Medialogy programme to advocate for more sustainability contents in the courses – with none of the backlash that students engaged with political movements experienced. There are experiences from the literature one could borrow from (e.g. Spalding, Williams & Wise, 2014). Thus, practical competences for engineering students could be broadened to include norm-building within academic institutions, aligning engineering education with recent theory-practice developments on norm-building in sustainability education (McGregor & Christie, 2021).

CONCLUSION

We found a pattern of increased sustainability awareness, interest, and engagement throughout the three semesters of this study. The data offered a more dynamic inderstanding of the relationship between the three categories of awareness, interest and engagement. Differences between engineering disciplines were visible, especially between sustainability-oriented engineering and the others, but there were also differences within the BEM group. Most students who increased their sustainability awareness and interest were also likely to take some form of action. Engagement built up from private engagement to professional engagement, and for some, into institutional and public sphere engagement. However, a large group of students resisted public engagement, likely related to engineering identity and "campus culture". We suggested developing institutional engagement as a potential bridge between these conflicting norms and identities.

Practical Implications

There a several implications for PBL engineering education from these findings. First, since increased awareness and interest tends to increase engagement, it might be productive to increase emphasis on sustainability issues at the start of students' studies, particularly in more traditional engineering programmes that don't focus on sustainability. Second, professional identity development might usefully figure more explicitly and prominently in the PBL process. Servant-Miklos & Kolmos (2022) have suggested that this could be integrated in broader reflection practices around the projects. Third, institutional engagement might be made more accessible to students, for instance, by publicizing the work of committees, councils and other university organs working on sustainability, while offering concrete avenues for students to participate in institutional work on sustainability, including through their PBL projects.

Limitations and Future Perspectives

This study was limited by the qualitative design, which renders the results transferrable, but not generalizable, due to the small sample size and purposive sampling method. But

such a qualitative study sets the scene for future research to delve deeper into the specific issues raised herein, such as a study focused on the impact of PBL projects in fostering sustainability awareness and interest at the various stages of the project, and the impact of engineering identity and "campus cultures" in affecting modes of sustainability engagement, including institutional engagement. It would also be beneficial to design quantitative studies to investigate the generalizability of the of the findings presented in this paper. The study is also limited by the pre-covid data collection: sustainability is a fast moving field and covid may have impacted perceptions of sustainability issues. A follow-up post-covid study would therefore be of scientific interest.

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