Transformation-Driving Education: Perspectives Emerging in a Dialogue between Teachers with Experiences from Challenge-Driven Education

Anders Rosén, Anne-Kathrin Peters
Dept. of Learning
KTH Royal Institute of Technology
Stockholm, Sweden
aro@kth.se, akpeters@kth.se

Mats Daniels
Dept.of Information Technology
Uppsala University
Uppsala, Sweden
mats.daniels@it.uu.se

Mats Danielsson
Dept. of Computer and Systems Sciences
Stockholm University
Stockholm, Sweden
mats.danielson@su.se

Jens Hemphälä
Dept. of Machine Design
KTH Royal Institute of Technology
Stockholm, Sweden
hemphala@kth.se

Maria Håkansson
Dept. of Urban Planning and Environment
KTH Royal Institute of Technology
Stockholm, Sweden
maria.hakansson@abe.kth.se

Gunilla Ölundh Sandström
Dept. of Machine Design
KTH Royal Institute of Technology
Stockholm, Sweden
gunillaos@kth.se

***Abstract*— This Research Full Paper explores different implementations of and teachers' experiences from challenge-driven education and similar learning approaches in engineering education and other higher education contexts. Through an action research approach key concerns among the teachers and similarities and differences between the studied courses can be identified. The study highlights the potential in these learning approaches, as means for breaking and going beyond the traditional boundaries of higher education, enhancing and cross-fertilizing engineering education with other disciplines, and empowering students both as professionals and humans. It also indicates potential barriers and in-built tensions that are crucial to handle for successful implementation. The study further shows on great opportunities for mutual learning and collaboration between teachers from diverse contexts and backgrounds. The findings are discussed in relation to research within domains such as sustainability education, transformative learning, and futures studies, and opportunities for further research and development are outlined.**

Keywords—challenge-driven education, challenge-based learning, sustainability, action research, teachers' experiences, mutual learning, collaboration

I. INTRODUCTION

There is a growing interest in learning approaches where students are collaborating with other students across or beyond disciplines, interacting with external stakeholders, in open-ended projects that are addressing complex real-world challenges, often related to sustainable development or sustainability transformations of society. Such approaches can be referred to as challenge-driven education 'CDE' (e.g. [1]), challenge-based learning 'CBL' (e.g. [2]), or problem- and project-based learning 'PPBL' (e.g. [3]). They can also be associated with concepts and terms such as experiential learning, service learning, community-based learning, inquiry-based learning, value-driven learning, and hybrid learning (e.g. [4]). The situation is complicated further by each of these terms and concepts being interpreted and implemented in many different and sometimes even contradictory ways (e.g. [5], [6]). There are also many implementations of these kinds of learning approaches that are not explicitly associated with any of these terms or concepts, for example because they are rooted in 'regular' problem-based, project-based, or design-based, learning (e.g. [7]) within a specific discipline but have then evolved to concern more complex projects, sustainability, closer interaction with external stakeholders, and opening up for enrolment of students from different disciplines.

Hence, it can be described as somewhat of a jungle. A question is whether this 'definitional muddying' and varied range of approaches and frameworks presents problems for practitioners and researchers, [5]? Or do we have to, and would we even prefer to, staying with the trouble of multitude and ambiguous terms, and instead focus on how we can live and act co-creatively in this jungle of ideas and intentions?

In the study presented in this research full paper we have taken the second question as a starting point and narrowed it down to: *What are the opportunities of and conditions for mutual learning and collaboration, between teachers who are working with different implementations of challenge-driven education and similar learning approaches in different higher education contexts?* To explore this question, and to bring further light to these learning approaches (which we hereafter for simplicity are referring to as CDE), we have used an action research approach where two researchers and five teachers have come together to share, discuss, and analyse experiences and key concerns.

II. RESEARCH SETUP AND APPROACH

The aims behind this study were two-fold. First, the idea was to create opportunities for mutual learning and educational development among teachers and researchers around CDE. Second, it was to do research on the mutual learning among teachers and educators.

Action research is a useful framework for projects that are not only about conducting research but that also seek to develop practices. Reference [8] describe different topics in action research projects in education, and in this case we use action research mainly for teacher's and researcher's

development. Action research is commonly targeting one specific object, in education it can for example be one specific course or module. Unique with this study is, however, that it targets four different courses and five teachers in parallel, with the aim of both stimulating development of these courses through experience sharing and exploring new ways of mutual learning and collaboration.

Action research is typically done in several cycles of planning, acting, observing, and reflecting, [9]. Each cycle should integrate practice and research. The present paper presents a first cycle of action research, [10], in which we initiate a mutual learning process exploring shared interests and questions and researching the different experiences that are brought into dialogue. We also outline potential continuations following this first circle.

The study was initiated by two researchers in the fields of engineering and computing education (the two first authors). With the intention of gaining diverse perspectives, they invited five teachers from three universities with experiences from four different courses, to participate in the study and also contribute as co-authors. These four courses have been identified to implement many of the features that are generally considered to be central in CDE, CBL, etc (e.g. as outlined in [11]). The study is biased towards engineering, with three of the courses rooted in engineering and the teachers having engineering backgrounds, however, the fourth course and one of the teachers also provide social science and other perspectives. Some global perspectives are also considered in that all four courses involve international students from basically all corners of the world. The two researchers also have engineering backgrounds and extensive teaching experience. The second author has for example earlier been a teacher in the course at Uppsala University that is included in this study. The first author has extensive experience from teaching in project-based and transdisciplinary courses and has been collaborating with and supporting CDE teachers through Openlab's working group, the KTH Global Development Hub, and teacher training.

The researchers planned and facilitated a three-hour online workshop for co-construction of knowledge on CDE. The guiding principle in the planning of the workshop was that it should be open and allow and stimulate the teachers to bring up issues that they found most important. The teachers were asked to prepare short 4-5 minutes presentations of their respective courses, for sharing some basic information and experiences. These presentations were the starting point for the workshop, and after a first round of presentations there were several following rounds where the teachers were encouraged to respond to each other's presentations and bring up additional concerns. In the second part of the workshop all participants, including the researchers, reflected individually on the first part, documenting their thoughts on sticky notes on a digital whiteboard. The researchers here also included research perspectives on education, sustainability, engineering, and computing. The participants were then asked to share their individual reflections by putting forward and explaining the sticky notes, and successively either building clusters by adding notes to existing or suggesting new topics to build on. In the fourth and concluding part of the workshop, impressions of the workshop process were shared and ideas of joint as well as individual ways ahead were discussed.

The workshop was audio recorded and the digital whiteboard was saved. The researchers transcribed the audio recordings and made an initial thematic analysis of the transcription and the digital whiteboard, identifying key concerns and their relationships. This initial analysis was then shared with the teachers for feedback and refinement, and opportunities for continuing joint development and research were outlined.

III. Results

As described, the involved teachers come from different educational contexts and some of them had never met before the workshop. Still, there were lively conversations, and the teachers could easily relate to each other's experiences. They had many experiences and questions in common, but there were also some significant differences. Four interlinked themes that capture the teachers' key concerns could be identified, as illustrated in figure 1.

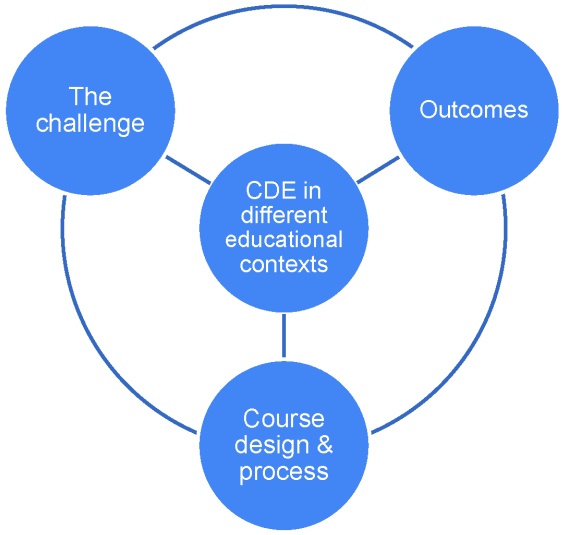

Fig. 1. Identified key concerns.

A. CDE in Different Educational Contexts

The workshop confirmed some common key characteristics of the studied courses that can be seen as framing CDE, some of which are indicated in Table 1. All courses are for example highly student-centred, action-oriented, large (15-22.5 ECTS credits), and project-based, where student teams are interacting with various external stakeholders in projects that in different ways are related to complex real world societal challenges.

The courses A, B, and C are similar in that they are originally rooted in specific engineering disciplines, however with some significant differences. The teacher in course A for example described that this kind of learning approach, with complex real-world challenges in collaboration with external stakeholders, has long traditions within urban planning education. On the contrary, the teachers in courses B and C shared experiences of how they have been confronting and breaking several barriers when establishing and evolving these courses beyond the mechanical engineering (B) and ICT engineering (C) education traditions. Such barriers can be related to preconceptions and expectations from university management, external stakeholders, colleagues, as well as students, of what an engineer is and what engineering education should include. The teacher in course B for example described that traditional mechanical engineering capstone

TABLE 1 SOME KEY CHARACTERISTICS OF THE FOUR COURSES INCLUDED IN THE STUDY. SEE MORE INFORMATION THROUGH THE COURSE TITLE LINKS.

Course name	A) Project Sustainable Urban Planning	B) Innovation and Product Development[1]	C) IT in Society	D) Challenges for Emerging Cities
University	KTH	KTH	Uppsala University	Openlab (KI, KTH, SH, SU collaboration)[2]
Education level	MSc	MSc	MSc	MSc
Disciplinary roots	Civil engineering	Mechanical engineering	Computing	Transdisciplinary
Course extent	15 ECTS credits over one semester	22.5 ECTS over one semester	15 ECTS credits over one semester	15 ECTS credits over one semester
Students' backgrounds	Swedish as well as international students, mainly from the KTH MSc program Sustainable Urban Planning and Design[3]	Swedish as well as international students, mainly from the KTH MSc program Integrated Product Design[3]	Swedish as well as international students, from different computing programmes such as Computer Science, IT Engineering, Sociotechnical Systems Engineering (STS)	Swedish as well as international students, from any education at any of Openlab's four partner universities[2,3]
Number of students in project teams	3-6	5-7	all students (ca 17 in average) work in one project	5-8
Typical key external stakeholders	A municipality (*kommun*) in the Stockholm area	Manufacturing industry, sometimes public institutions, sometimes students come up with project ideas themselves	The academic hospital in Uppsala	The City of Stockholm or the Region of Stockholm (Openlab partners)
Typical projects	Public transport Rainwater management	Second life opportunities for industry tools Mitigate hospital acquired infections	Various challenges within the hospital, for example "What should primary health care look like in 2030?"	How to create a more secure public transport How to reach out with diabetes care to immigrant groups

1) Running in parallel with the course Challenge Driven Innovation for Sustainable Development which also enrolls students with other disciplinary backgrounds.
2) Karolinska Institutet, Royal Institute of Technology, Södertörn University, and Stockholm University, all located in the Stockholm area.
3) Sometimes also students from KTH Global Development Hub partner universities: Strathmore University in Kenya, UDSM in Tanzania, and Botho University in Botswana.

courses generally concern well-specified projects where the students should design some technical product, system, or component. They have however gradually evolved course B towards more complex open-ended projects where sometimes neither the problem nor the context is possible to specify clearly, and the students can address the challenge in many different ways, for example by developing a product, a service, some kind of intervention, or just a better understanding of the challenge and possible approaches to tackling it. The teachers here want the students to become capable of doing something else, which renders those courses as somewhat odd in their traditional contexts. Doing something else lifts these courses as special, but it also marginalises or puts them under threat, as expressed by the teacher in course B:

"Is this really mechanical engineering we do? It is a question of legitimacy, I would say. There are many, including myself, that think: 'This is not mechanical engineering! It is more industrial management'. It plays a role in the financing of the courses. Technology is ranked higher than social science or the humanities. It plays a role in how many courses we may have; we must have a certain share of mechanical engineering in our programs." (teacher in course B)

The teacher in course C recognised the experiences described by the teacher in course B and argued that CDE should be seen as natural part of computing and engineering. This is something he repeatedly needs to argue for:

"Yes, that which you talk about is what I am so tired of and frustrated about, that people say that this is not really engineering. As if engineers only work with technical things. Then you get solutions correspondingly. As if engineers only get instructions on what they should do. We need to fight to get people to understand that this is a part of engineering!" (teacher in course C)

The teachers in courses B and C also emphasised the importance of enhancing the social science and humanities perspectives in engineering education, but also here shared experiences of barriers.

The courses A and B are mandatory capstone courses towards the end of two MSc programmes, whereas C and D are elective. Course C enrols students from several different ICT programs. In contrast to the other courses, course D does not have any disciplinary roots. It is a transdisciplinary course that has been developed in collaboration within the Openlab initiative, between four different universities and the City of Stockholm and the Region of Stockholm (two different levels of the local public administration). It involves teachers from all four universities and students with a bachelor's degree from any education at any of the four universities (including engineers from KTH).

Some of the similarities and consequences of the educational context differences between the four courses are elaborated further in the following subsections.

B. The Challenge

The challenge that the students engage in is central in CDE as it constitutes the target for the project and the context for the learning. Finding and shaping challenges that are feasible as grounds for CDE projects, was something that the teachers brought up as crucial but also difficult, and they reflected on and discussed what characterises a feasible challenge. In all courses, the students are supposed to contribute to societal development. The teachers shared several challenges their students have worked with, where some examples are listed in Table 1.

The teacher in course D pointed to real societal challenges that the city or municipality may encounter. Improving the elevators in a hospital is, for example, not a feasible challenge because it is an optimisation problem at a specific hospital

rather than a societal challenge. The teacher in course C pointed out one "*especially fun project*" where the students were confronted with a change in legislation that gave patients access to their medical records. The hospital merely told the students to "look at that", and they did that for one whole semester.

The teachers in the context of mechanical engineering and computing (courses B and C) pointed out that CDE challenges are very different from the assignments in the rest of the education. As reflected in the previous section, these teachers oppose dominant structures arguing that working with wicked problems give students opportunities to develop competences not gained in regular engineering education. The teacher in course A also recognised the discussion from her own education and pointed out that all people should realise that the students very likely will have to deal with "wicked problems" in their future career. She gave an example from the field of urban planning where course A is situated. After graduation, students will work with developing society, dealing with great complexity and uncertainties, taking into account many different local and international actors as well as different fields of knowledge. She also pointed to her university's guidelines that include that students should be prepared to work with wicked problems.

Finding feasible challenges was described as a process that teachers, students, and external stakeholders, can be involved with in different ways. Interestingly there are quite large differences in how challenges are chosen and how the students' projects are shaped, not only between the courses but also from project to project within the same course. Some of the courses for example have established long term relations with one or a few external key stakeholders, who provide concerns and contexts within or related to their organizations and activities as grounds for identifying challenges and shaping projects. In contrast, one of the courses instead invites different key stakeholders from year to year and for differ projects. In courses A and C, identifying and framing the challenge and shaping the project is given a substantial amount of the project time. The teacher in course A explained that the project also depends on what the students can do and would like to develop within, as well as their analysis of the municipalities' situation. During the first three weeks of the course, the students prepare proposals for projects that evolve from their analysis. These are then discussed and decided upon by all involved (students, teachers, and external stakeholders). The students have a lot of agency and independence in this course. Similarly, also the students in course C spend several weeks learning about the challenge and identifying or clarifying the issues they want to work with. In course D, the students usually spend as much as half of the project time on understanding the challenge through analysis and reframing. A difficulty in this early process of defining the challenge is getting access to the right persons in the external stakeholder organisation to comprehend the issues and possible ways to approach them in a project. In course B it happens that students pitch their own ideas for projects and different external stakeholders can be engaged through the project.

Another issue mentioned was that the students narrow or close down the project, reducing too much of the complexity (teacher C). In that case, the role of the teacher may be to increase the complexity of the challenge. The opposite can be the case, that the students have difficulties specifying the challenge, struggling with too broad or high-level questions such as '*How to solve poverty?*' (teacher in course D). In such a case, the teacher can stimulate the students by asking "*Isn't there at least something that you can do?*".

What was also seen as important is that the challenge and project should allow the students to build on their previous experiences and give them opportunities to develop in new ways. The project should allow the students to apply competencies in a real professional context and experience that they can make a real and valuable contribution to society.

In summary, choosing and defining the challenge is seen as an important and also difficult part of CDE. The following quote shows some of the many questions that were raised at the workshop:

"Should it be one societal actor that the project should be relevant for, or should it be of a different complexity? That I think is thrilling, how to define the challenge. How many stakeholders should be involved? How much should it be about societal benefits? Should the students solve an unsolved problem or is it enough that they contribute with a little mini piece of the puzzle? Or should it be a bigger part of the puzzle?" (teacher in course B)

The teacher in course B also reflected on that many teachers may think that they do CDE but in fact they do not. There may be many interpretations. Considering the earlier discussions of disciplinary identity, we should also be aware that socialisation, disciplinary identity and disciplinary decadence affect how we formulate or see challenges and also make decisions on what to include or not include in the problem descriptions. When thinking about what a good challenge is, then we should consider the outcome we want to achieve, the teacher in course B reflected.

C. *Outcomes*

One of the teachers' key concerns during the workshop was the outcomes of CDE, and the experience sharing and discussions in the workshop evolved around: 1) project outcomes, i.e. the solutions or deliverables resulting from CDE projects; 2) learning outcomes for the students; and 3) other gains or changes.

Regarding project outcomes, the teachers discussed what it should *not* be. The teacher in course D for example talked about "the app trap", referring to that it is common that students suggest developing yet another app as a solution to the addressed challenge, when what actually is needed might be changes in behaviour, communication, or organisation. The teacher exemplified with a challenge that concerned senior citizens who are living alone and suffering from isolation and loneliness, and that they are probably not helped by another app.

The teacher in course C added that students should realise that the interactions in a real context are complex and involve many different stakeholders. Even challenges that seem straightforward to begin with, grow in complexity if engaged with in more depth. When the challenge is a complex societal issue, it generally cannot be solved by one single solution. However, engineering students are generally not good at contributing with anything but concrete solutions, the teacher in course C reflected. It happens that CDE projects result in solutions that can be taken further for implementation with a direct impact on the addressed challenge. However, more commonly impacts from CDE projects are indirect, for

example through the development or emergence of new insights and new perspectives on the challenge. The students can contribute to new understandings with their new and different ways of looking at the challenge (teachers in courses A and C). The teacher in course A expressed that an external stakeholder that has provided a challenge might not apply the results all the way, but they can gain new ideas, and shared the following example:

"A few years ago, a group of students worked on public transport for [the municipality that provided the challenge]. They explored whether it would be a good idea to replace a bus line with a tram line. It is politically interesting with trams. The students however quite quickly understood that it is probably a very bad idea. But they continued with all kinds of tests and investigations, and finally concluded that a tram line in this case would be much more costly, requiring demolition of houses, and resulting in fewer passengers. And this is a very good project outcome, because what intuitively seemed to be a good solution to the politicians turned out to be a quite bad solution." (teacher in course A)

The teacher in course B described how they encourage their students to focus on what values could be created in relation to the needs they identify in the challenge, and to see the products or services or whatever it is they are developing in their projects, more as examples of how these values can be realised rather than as some final solutions.

Regarding learning outcomes, the teachers talked about different knowledge, skills, and competencies. CDE provides possibilities for students to further develop, deepen and contextualise their previously gained knowledge and skills and develop various competences. The teacher in course B mentioned knowledge and skills to apply methods such as *dashboards*, *lean startup*, and *triple-layered business model canvas*. The students can also learn new methods such as *design thinking* (course D). The students also learn a lot about the particular challenge and context they engage with and thereby often gain knowledge that goes beyond their own field of study.

The teacher in course C talked about "*professional competences*" that go beyond technical knowledge and skills, exemplifying communication skills, thinking skills, and working in teams and with people from different cultures. Sometimes students believe they cannot develop those skills ("*you either have those skills or not*") but by making them reflect on the skills and giving them a language to reflect on their development, they often realise that they can find methods or tools that help them to learn. The teacher in course C shared an example of a student who reflected that he was good at thinking within existing structures but that he was not good at "*thinking outside the box*" and would never be able to develop such a skill. However, he committed to exploring ways of developing his thinking skills and realised towards the end of the course that he in fact had learnt strategies for thinking "*in more open ways*". CDE can hence provide opportunities for students to develop competencies that they do not develop in other courses. This is something the students may not realise from the start, having been socialised with certain disciplinary practices and focuses, as expressed by the teacher in course C:

"We want them to collaborate in a much broader sense than they are used to, with different stakeholders and across disciplinary boundaries. They are not good at that. Their attitude is often like 'I will go in and program!'" (teacher in course C)

The students can also try out new roles, for example being a leader. The teachers also expressed that the students gain vocabulary and approaches for reflecting on their learning and issues such as group dynamics and project processes.

Regarding other gains or changes that emerge through CDE, the teachers shared various examples. The teacher in course A has for example experienced that students often have a high stress level, questioning themselves for not being competent enough to work professionally. The teachers shared examples where students were shy and uncertain at the beginning of the courses but became more self-confident and aware of their strengths and possibilities to contribute during the course. The students become more independent and gain confidence in making decisions themselves and become comfortable taking on challenges even if there are no clear models or processes to approach the challenge. When the students present their results towards the end of the course, get feedback, and realise that their work is appreciated by the municipalities or politicians who have provided the challenge, then their self-confidence grows.

The teachers can support the students' development by seeing the individual student and encouraging them to take up space and contribute. The students can also support each other's development. The teacher in course B reflected that students who have limited confidence from the start sometimes learn that they are appreciated and can contribute the way they are; they realise it is ok and of value to be different:

"We had a student, quite introvert, and she got the feedback from her peers in a team exercise that she needs to take space and say things because the things she says are very good. The student reflected a lot on her role in the team and felt she had to change but towards the end of the course, the student had accepted herself as introvert and how that impacted the role she takes in a group. The dynamics of the group should accept and adjust to different personalities, all can be different. Sometimes you see great personal development and that is fantastic." (teacher in course B)

D. Course Design and Process

The choice and handling of challenges and the intended project and learning outcomes, that were considered in the preceding two subsections, constitute major elements of the course design and process in CDE. In addition, the teachers brought up several other important issues.

The teacher in course A used the word 'course infrastructure' when describing an underlying and surrounding scaffolding as crucial for supporting students' self-directedness in CDE. The teacher in course B agreed on the importance of such a structure and reflected on difficulties in creating a structure that works for different students and in different project phases. The teacher in course C elaborated further on the intricate balance between, on the one hand having too much structure that might violate the open-endedness of the project and the self-directedness of the students' learning, and on the other hand having too little structure with the risk of some students getting lost or dropping out.

One important component in such a structure, or scaffolding, that all teachers elaborated on, is the way the

intertwined project and learning processes are driven and managed. Here, there are some significant differences between the courses that have been touched upon in the previous sections. Courses A and B have the roles as compulsory capstones in the third semester of specific master's programs. In each of these courses, all students have quite similar knowledge backgrounds from the first year of the respective program, which they are supposed to make use of when organising themselves in project teams and engaging in their respective projects. There are however generally several parallel projects in these courses, where different student teams are working with different challenges and interacting with different stakeholders. Which particular parts of their background knowledge and methods that each team chooses to implement might differ and as a consequence the different teams might experience quite different project processes as well as learning processes. Courses C and D, on the other hand, are elective for students from several different programmes. Course D enrols students from four different universities and no previous knowledge in extension to a bachelor's degree of whatever kind is required to attend. Hence, there might be very large differences in background knowledge among the participants. To manage this diversity and promote transdisciplinarity, course D is stipulating one single process - *design thinking* - that all student teams should apply and which all students are thoroughly introduced to in the beginning of the course to establish a common ground.

One teacher emphasised that engineering students in general are very unused to working with truly open-ended problems. Another teacher described how design thinking, and similar methods, can help engineering students avoid their immediate reaction to start simplifying problems to make them solvable, and instead staying with the trouble of handling complexity and uncertainty to better understand also the deeper layers of the challenge that they are working with.

The teacher in course D described another technique that they use:

"At the beginning of each working day, we have a meeting with the students where there is a reserved time called 'back-channel', where students can feed in ideas that concern issues treated in previous days. Sometimes the really good ideas come from more introverted, thoughtful students who get this second chance." (teacher in course D)

This teacher also described how their students have access to a dedicated maker space, where each team has its own whiteboard and trolley with various materials. When exploring challenges, they make use of various techniques such as storyboards, role plays, and a lot of prototyping using paper, wire, Lego, and other simple techniques. The teacher emphasised the usefulness of simple prototypes, since they are quick and easy to build and communicate to the stakeholders, and also easier for the stakeholders to criticise than more advanced prototypes. This is good for idea generation as well as for testing and validation.

Another component, that all teachers highlighted the importance of in CDE, is to have the students reflecting both on their own learning process, on their team dynamics and project process, and also on the other teams' processes for peer learning, peer feedback, and peer assessment. The teacher in course C for example expressed:

"I think we need these reflections to stimulate the students to actually think by themselves and also to provide them with vocabulary to do so." (teacher in course C)

The teacher in course A described how the students the first week of the course as part of a formative assessment assignment, should write a 'self-inventory' where they are elaborating on questions such as:

"What have I studied? What am I capable of? What am I interested in? What do I want to develop?" (teacher in course A)

Then as part of the summative assessment towards the end of the course, the students should write a reflection on

"…their own role in the project, how the team functioned, what other choices they would have made if they in the beginning of the project would have had their current knowledge level … so it is kind of a meta reflection on what they have learnt" (teacher in course A)

The teacher in course D described that they have their students keeping diaries where they after each course meeting should write very brief reflections about what they have done and what they have learnt. The students then use these diary notes as a basis for reflective assignments, one mid-term and one at the end of the course.

The teacher in course B described how they let the student teams provide feedback on the other teams' processes, by using a technique that they call 'I like/I wish'. Instead of expressing what they think the other teams are good or bad at, they should express what they like and what they wish could have been different, and there should always be more 'I like' than 'I wish'.

IV. Discussions

In this section, we summarise and discuss our findings in relation to the four identified themes, opportunities and conditions for mutual learning and collaboration (see Section 1), previous research, and outlines further research and development opportunities.

One of the teachers' major concerns was the challenges that are addressed in the students' projects and serves as contexts for their learning. All teachers agreed that a good challenge should concern a societal issue, for example problems in the health care or public transport systems, or the environmental impact of industry products or activities. The teachers also agreed that the challenge should be 'wicked' enough to promote students' development of abilities to manage complexity and uncertainty and interdisciplinary or transdisciplinary perspectives, but on the other hand not too large in scale and complexity to leave the students in despair. The teachers described different techniques and processes that are used in their courses for identifying and framing challenges through pre-studies, dialogues, and negotiations between students, teachers, and key external stakeholders. Reflecting more on and refining the processes of finding and defining feasible challenges was identified as one possible continuation of this action research project. Here perspectives from the ongoing wicked problem discourse could be useful (e.g. [12], [13], [14]).

The teachers used terms such as 'clients' and 'challenge-providers' to refer to the key external stakeholders. In other contexts, the term 'challenge-owner' is also being used (e.g.

[11]). We want to raise concerns about the usage of these terms. They have certain connotations. For example, 'challenge-provider' (and even more 'challenge-owner') renders the external stakeholder as the agent in defining the challenge as well as the learning, and the teachers and the students as respondents. The word "client" has economic connotations with the risk that higher education turns into a "free" service. Using those terms can affect the dynamics and diversity of engagement and interactions with different stakeholders, which teachers, students, and external stakeholders might be unaware of. Language and discourses are powerful, shaping how people think and (inter)act and therefore need to be carefully considered, [15]. Further, if the purpose of CDE is to empower students to live with and tackle wicked problems, it is important to consider the multi-stakeholder perspectives inherent in such problems (e.g. [12], [16]). However, stakeholder identification and engagement in problem structuring interventions is an under-researched issue, [17].

Hence, the selection and framing of challenges, and the role of and interaction with external stakeholders, are crucial and complex issues in CDE with opportunities and needs for further research and development. Reference [5] also indicate that this is an issue that has been given limited attention in the literature. Another issue where the teachers could share many experiences concerned the outcomes of CDE. In more traditional project-based learning, there are both examples where the major focus is on the project outcome and other examples where the teachers merely consider the project as an instrument for the students' learning. The teachers in this study expressed strong concerns for the students learning as well as for the potential societal impact of the projects, hence considering the project outcomes and the learning outcomes as equally important. In addition, yet a third potential outcome from CDE emerged in the dialogue between the teachers, which concerned other gains and changes, for example enhancement of the students' self-confidence and their sense of agency and being in and contributing to the world. How the individual "*comes into existence*" as a unique human being has been conceptualised with the term "subjectification", which in [18] & [19] is described as one of three purposes of education, besides qualification and socialisation. Contrary to socialisation and qualification, subjectification is not about integration into pre-existing orders but about being, acting, and growing in ways that are unique as all individuals have different experiences and identities. Subjectification is seen to be systematically undermined in contemporary higher education that has been increasingly standardised and monitored as an instrument for training of pre-defined competencies, [20] & [21].

The teachers expressed criticism against the prevailing dominating focus on and valuing of reductionistic approaches to problem-solving in contemporary engineering education. The teachers' experiences and struggles with the engineering and computing culture is confirmed by decades of research that problematise the orientation towards reductionism and solving technical or mathematic problems in those fields (e.g. [22], [23], [24]). However, the teacher with social science background also expressed great appreciation for engineering students' pragmatic abilities and attitudes in contrast to students within social science or humanities who commonly tend to over-problematize the challenges they are facing. The teachers described the learning approaches they were working with as opportunities for counteracting stereotypes and disciplinary decadence, [25], complementing the prevailing approaches in higher education, and empowering the students both as professionals and humans. As described, three of the four courses included in this study are rooted in engineering, and most implementations of CDE found in the literature are also in the context of STEM, [5]. To further broadening the disciplinary scope, opening up for social science and humanities perspectives in engineering education and vice versa, and creating conditions for students to meet and collaborate across disciplinary, cultural and other borders, as the teachers in this study are striving for, are areas with great potential for further development and research.

Regarding the course design, the teachers had common ideas and experiences of that these learning approaches are quite different from more traditional project-based learning. Discussions revolved around the intricate balance in establishing a scaffolding that on the one hand provide the students with appropriate structure and guidance and on the other hand embrace uncertainty and complexity and promote project-open-endedness and students' self-directedness. As observed in [7] in the context of design-based learning, the present study has highlighted a number of ontological as well as epistemological tensions inherent in CDE. One example is this tension between structure and freedom in the students learning and the potential differences in expectations on the learning and project outcomes, and even the purpose of education at large, between students, teachers, and other stakeholders. Another example is the level of complexity and wickedness of the addressed challenges in relation to the students' abilities and motivations. Such tensions are critical to handle, but they can also provide interesting opportunities for learning and research.

Despite the vivid conversations there were several topics that the participating researchers were prepared to discuss but that were not or hardly brought up by the teachers. There are obvious practical reasons for this, considering the multi-dimensionality of CDE and that the workshop was limited to three hours. However, it could also indicate areas with potential or need for further learning, research, and development.

Sustainability (sustainable development, sustainability transformations, etc) was immanent in the teachers' discussions on the role of CDE and what characterizes a good challenge but was given limited explicit treatment in the workshop. Related areas for further research and development could for example be: the perceptions of and attitudes towards sustainability among students, teachers, and external stakeholders; how sustainability is considered in the choice and framing of challenges, in the students learning and project outcomes; the underlying ontologies that are influencing the choice of challenges and decisions made in the projects; and the sustainability agency of students post-graduation; (e.g. [26], [27]).

Young people are increasingly concerned and anxious about sustainability. Education can be a place that allows for action and "critical hope", [28]. The unique potential of education in caring for the future lies in bringing together diverse actors, imagining and inventing futures, allowing for the possibility of the impossible not yet imagined, [29]. Such theories of education have already inspired interventions in and research on CDE, [30]. Ways of utilising diversity and allowing for diverse competence development have been explored, [31]. With this work, we have created conditions to

learnt about and experiment with such ideas in different courses, contexts, and actors in CDE.

The opportunities with CDE in developing students' competences, i.e. advanced interplays between knowledge, skills, attitudes, and values, was something that was touched upon but not discussed in depth between the teachers. Communication skills, working in teams, and abilities to deal with complexity and uncertainties while taking into account many different stakeholders, were discussed. However, key competencies for sustainability, such as holistic systems thinking competencies and normative critical thinking competences, were not explicitly mentioned in the workshop. Such key competencies are currently gaining large attention within the sustainability education discourse (e.g. [32], [33], [34], [35]). As emphasised by [36], the learning of such competences requires conscious efforts to working with each competency's set of concepts, methods, and skills, not only by students but also by teachers. However, in addition to acquiring knowledge and training skills, students and teachers must also be enabled and empowered to question prevailing norms and practices as well as their own ways of seeing and thinking about and acting in the world through transformative learning (e.g. [33], [34], [37], [38]). As indicated by [39], transformative learning is however rare in engineering education. To explore and unleash the transformative learning potential in CDE is another interesting area for research and development.

There are urgent calls for transformative systemic change and rapid far-reaching and unprecedented changes in all aspects of society to limit global warming and manage other global as well as local systemic dysfunctions (e.g. [40], [41], [42]). The growing interest in CDE, CBL, and similar learning approaches, can be seen as part of a growing concern for transformations both in and through education. Despite the differences between and lack of definitional clarity in the learning approaches they are working with, the teachers involved in this study could easily share and jointly elaborate on various key concerns. They all expressed concerns for and gave examples of opposing and going beyond disciplinary boundaries. They encourage and enable their students to explore alternatives to the prevailing reductionistic approaches to problem solving and make space for and allow project outcomes as well as learning outcomes that are not stipulated or even imagined beforehand. Based on the insights from this study we would like to stimulate further dialogue, collaboration, and research, by introducing yet another term that we think more clearly captures the potential in these kinds of learning approaches: *transformation-driving education*, i.e. learning approaches that are driving sustainability transformations in and through education.

V. Concluding remarks

In this study an action research approach has been used for bringing together five teachers and two researchers to share, discuss, and analyse experiences from and key concerns in challenge-driven education and similar learning approaches. Despite significant differences in educational contexts, backgrounds, and other preconditions, the teachers could easily connect with one another's experiences, concerns, and ideas. Through thematic analysis four interlinked key concerns could be identified. The findings have been discussed with related research in domains such as sustainability education, transformative learning, and futures studies, and opportunities for further research and development have been identified.

The study shows great opportunities for mutual learning and collaboration between teachers despite differences between and lack of definitional clarity in the learning approaches they are working with. In following cycles of action research, the involved teachers and researchers could jointly develop interventions related to some of the identified research opportunities, implement those interventions in the different courses, and jointly observe, reflected upon, and compare the outcomes.

In this study, we brought together a handful of teachers who are experimenting with different ways of breaking and going beyond the traditional boundaries of higher education. Processes can be created for involving more teachers from other courses, and also students and external stakeholders, for mutual learning and collaboration around *transformation-driving education*.

References

[1] A. K. Högfeldt, A. Rosén, C. Mwase, A. Lantz, L. Gumaelius, E. Shayo, S. Lujara, N. Mvungi, "Mutual capacity building through north-south collaboration using challenge-driven education". Sustainability, 11(24), 2019.

[2] K. Kohn Rådberg, U. Lundqvist, J. Malmqvist, O. Hagvall Svensson, "From CDIO to challenge-based learning experiences – expanding student learning as well as societal impact?", European Journal of Engineering Education, 45(1), pp. 22-37 2018, doi: 10.1080/03043797.2018.1441265.

[3] A. Wiek, A. Xiong, K. Brundiers, S. van der Leeuw, "Integrating problem- and project-based learning into sustainability programs", Int. J. Sustain. High. Educ., 15(4), pp. 431–449, 2014.

[4] A. Jamison, A. Kolmos, J. E. Holgaard, "Hybrid learning: An integrative approach to engineering education", Journal of Engineering Education, 103(2), pp. 253–273, 2014, doi:10.1002/jee.20041.

[5] S. E. Gallagher, T. Savage, "Challenge-based learning in higher education: An exploratory literature review", Teaching in Higher Education, 2020, doi: 10.1080/13562517.2020.1863354.

[6] M. Leijon, P. Gudmundsson, P. Staaf, C. Christersson, "Challenge based learning in higher education – A systematic literature review", Innovations in Education and Teaching International. Published online: 19 Mar 2021. doi: 10.1080/14703297.2021.1892503.

[7] J. Bernhard, K. Edström, A. Kolmos. "Learning through design–implement experiences: A literature review". Proceedings of the 12th International CDIO Conference, Turku University of Applied Sciences, June 2016.

[8] I. Laudonia, et al. "Action research in science education – an analytical review of the literature", Educational Action Research, 26(3), pp. 480-495, 2018.

[9] P. Reason, H. Bradbury, "Handbook of Action Research", SAGE Publications, 2006.

[10] S. Kemmis, et al., "The Action Research Planner. Doing Critical Participatory Action Research". Springer, 2014.

[11] A. Van den Beemt, G. van de Watering, M. Bots, "Conceptualising variety in challenge-based learning in higher education: The CBL-compass", European Journal of Engineering Education, 2022, doi: 10.1080/03043797.2022.2078181.

[12] J. Alford, B.W. Head. "Wicked and less wicked problems: A typology and a contingency framework", Policy and Society, 36(3), pp. 397–413, 2017, doi:10.1080/14494035.2017.1361634.

[13] N. Turnbull, R. Hoppe, "Problematizing 'wickedness': A critique of the wicked problems concept, from philosophy to practice", Policy and Society, 38(2), pp. 315-337, 2019, doi: 10.1080/14494035.2018.1488796.

[14] J. Lönngren, K. van Poeck, "Wicked problems: a mapping review of the literature", Int. Journal of Sustainable Development & World Ecology, 28(6), pp. 481-502, 2021, doi: 10.1080/13504509.2020.1859415

[15] M. Jorgensen, L. J. Phillips, "Discourse analysis as theory and method, SAGE Publications, 2002, https://dx.doi.org/10.4135/9781849208871.

[16] H. W. J. Rittel, M. M. Webber, "Dilemmas in a general theory of planning", Policy Sciences, vol. 4, pp. 155–169, 1973.

[17] A. J. Gregory, J. P. Atkins, G. Midgley, A. M. Hodgson, "Stakeholder identification and engagement in problem structuring interventions", European Journal of Operational Research vol. 283, pp. 321–340, 2020.

[18] G. Biesta. "Good education in an age of measurement: On the need to reconnect with the question of purpose in education". Educ Asse Eval Acc 21, pp. 33–46, 2009, https://doi.org/10.1007/s11092-008-9064-9.

[19] G. Biesta. "Risking ourselves in education: Qualification, socialization, and subjectification revisited", Educational Theory, 70(1), pp. 89–104, 2020.

[20] D. Osberg, G. Biesta, "Beyond curriculum: Groundwork for a non-instrumental theory of education", Educational Philosophy and Theory, 2020.

[21] H. Mendick, A.-K. Peters, "How post-Bologna policies construct the purposes of higher education and students' transitions into Masters programmes", European Educational Research Journal, 2022, https://doi.org/10.1177/14749041221076633.

[22] A.-K. Peters, "Learning computing at university: Participation and identity: A Longitudinal Study", PhD Thesis, Uppsala University, Sweden, 2017.

[23] J. Lönngren "Wicked problems in engineering education – Preparing future engineers to work for sustainability", PhD Thesis, ISBN 978-91-7597-602-0, Chalmers University of Technology, Sweden, 2017.

[24] A. Ottemo, M. Berge, E. Silver, "Contextualizing technology: Between gender pluralization and class reproduction", Science Education, 104(4), pp. 693-713, 2020.

[25] L. R. Gordon, "Disciplinary decadence and the decolonisation of knowledge", Africa Development, vol. XXXIX, no. 1, pp. 81-92, 2014.

[26] F. W. Geels, "Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective", Research Policy, 39(4), pp. 495-510, 2010, https://doi.org/10.1016/j.respol.2010.01.022.

[27] E. A. Cech, "Great problems of grand challenges: Problematizing engineering's understandings of its role in society". International Journal of Engineering, Social Justice, and Peace, 1(2), pp. 85–94, 2012.

[28] M. Ojala, "Hope and anticipation in education for a sustainable future", Futures, vol. 94, 2017.

[29] D. Osberg, "Taking care of the future? The complex responsibility of education and politics", Osberg, Biesta (eds.), Complexity Theory and the Politics of Education, pp. 157-170, 2010.

[30] A.-K. Peters, D. Golay, M. Daniels, "Making futures in computing education. 'Emergentist Education' in an Open-Ended Group Project", Frontiers in Education Conference, 2021.

[31] A.-K. Peters, M. Daniels, Å. Cajander, "Utilising diversity for project work and learning: A study of the learning agreement intervention" in Proceedings Frontiers of Education Conference, 2019.

[32] A. Wiek, M.J. Bernstein, R.W. Foley, M. Cohen, N. Forrest, C. Kuzdas, B. Kay, L.W. Keeler, "Operationalising competencies in higher education for sustainable development", pp. 239-260 in M. Barth, G. Michelsen, M. Rieckmann, I. Thomas (Eds), "Routledge Handbook of Higher Education for Sustainable Development", Routledge, 2016.

[33] M. Rieckmann, "Learning to transform the world: key competencies in Education for Sustainable Development", ch. 2 in UNESCO "Issues and trends in Education for Sustainable Development". A. Leicht, J. Heiss and W. J. Byun (eds) ISBN 978-92-3-100244-1, 2018.

[34] M. Pacis, R. VanWynsberghe, "Key sustainability competencies for education for sustainability: Creating a living, learning and adaptive tool for widespread use", International Journal of Sustainability in Higher Education. 21(3), 2020.

[35] EOP, "The engineering for one planet framework: Essential learning outcomes for engineering education", 2020.

[36] K. Brundiers, et al., "Key competencies in sustainability in higher education: Toward an agreed-upon reference framework", Sustainability Science, 16(1), pp. 13-29, 2021.

[37] S. Sterling, "Transformative learning and sustainability: Sketching the conceptual ground", Learning and Teaching in Higher Education 5(11), pp. 17–33, 2011.

[38] A.K. Holfelder, "Towards a sustainable future with education?", Sustainability Science, 14(4), 2019.

[39] D. T. K. Tien, S. N. Namasivayam, L. S. Ponniah, "A review of transformative learning theory with regards to its potential application in engineering education", Proceedings AIP conference, vol.2137(1), 2019.

[40] UN, "Transforming our world: The 2030 agenda for sustainable development", United Nations Resolution A/RES/70/1, 2015.

[41] IPCC, "Global Warming of 1.5°C". An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, et al. (eds.)], 2018.

[42] WWF, "Living Planet Report 2020 - Bending the curve of biodiversity loss", World Wildlife Foundation, 2020.