Perspectives on Challenge-Driven Engineering Education for a Sustainable Future

J. Hedvall, H. Lindberg, A. Rosén and L. Gumaelius

KTH, Royal Institute of Technology, Sweden

lenagu@kth.se

Abstract

Engineering education has changed and evolved over decades in harmony with societies challenges. Today, sustainable development is of greatest importance and one way of equipping future engineers with the competencies to tackle this challenge is through Challenge Driven Education (CDE). This study takes on an exploratory approach when studying the implementation of CDE as it is formed at two different universities, one in Sweden, and one in Tanzania. By interviewing key-actors such as teachers and stakeholders who are in one way or another engaged or are about to become involved in CDE, an investigation has been conducted in order to understand how these key-actors view CDE as a successful pedagogical approach for educating engineers of the future. First, a question was asked on which competencies for sustainability could be considered important in future engineers. Second, the participants were encouraged to tell how CDE could develop from their perspective. Results show that the depiction of key competencies for sustainability correlates well with the participants views of what is important for future engineers, although it is evident that good communication between stakeholders and students/teachers about what is expected to train during a CDE course is paramount. The study also shows the importance of stakeholders trusting each other and having a common picture of what a CDE collaboration should lead to in order to achieve the best possible results of such training.

1. Introduction

The grand challenges for humanity in the 21st century, for example as expressed by UN's 2030 Agenda and the 17 Sustainable Development Goals, are calling for substantial transformations of our global society, to ensure a healthy planet and sustainable living conditions for ourselves and future generations (UN, 2015). These challenges are also drivers of change for our education systems, where the traditional focus on developing students' knowledge and analytical skills within specific disciplines has to be complemented by also developing students' knowledge and key competences for sustainability for example: systems-thinking; critical-thinking; abilities to collaborate across disciplines, cultures and contexts; and integrated problem-solving competences. Several researchers have worked on the concept of key competences for sustainable development. A frequently used description of these is UNESCO's list (2017), which is based on a broader literature review and provides a compilation on a variety of studies. UNESCO describes eight different key competences with some explanatory sentences about each in the book. Such competences cannot be taught through conventional teacher-centred approaches, but instead require students-centred, action-oriented, interdisciplinary, and transformative learning approaches (e.g. UNESCO 2017).

An evolving group of learning approaches for sustainable development are referred to as challenge-driven, challenge-based, or problem- and project-based (e.g. Wiek et al 2014, Malmqvist et al 2015, Ibwe et al 2018, Högfeldt et al 2019). In common for these learning approaches is that learning takes

place in the context of complex real-world issues. They can further be characterized as student-centred, self-directed, and collaborative, and they generally involve interaction with various external stakeholders. These approaches could provide excellent conditions for developing students' key competencies for sustainability, also enhancing the interaction between universities and the surrounding society and allowing students to have impact on the sustainable development of the society already during their studies. However, the real-world issues constituting the context for the learning, the changing roles of students as well as teachers, and the involvement of external stakeholders as a third actor, all adds complexities, making these learning approaches highly demanding to implement.

With the aim of mutual capacity building for global sustainable development, the Royal Institute of Technology (KTH) in Sweden has joined forces with the University of Dar es Salaam (UDSM) in Tanzania, and a few other partner universities within the KTH Global Development Hub (GDH) network. The collaboration involves development of a concept for challenge-driven education (CDE) and related teaching and learning methods, implementation of the CDE concept in courses at the involved universities, a teacher training program, and a joint student exchange program. The CDE concept can be described as a solution- and impact-oriented project-based learning approach where multi-perspective student teams collaborate with various external stakeholders in projects that are addressing societal challenges related to the Sustainable Development Goals in UN's 2030 Agenda. A distinguishing feature of this CDE concept is that it starts earlier and aims farther compared to 'ordinary' project-based learning approaches, in the sense that the starting point for the students' projects and learning are complex ('wicked') societal challenges and that the aim is that the solutions developed by the students can be taken further to impact on the sustainable development of the society.

The addressed challenges are contextualized by involving local stakeholders who can also be potential receivers and exploiters of the results. The assignments have so far constituted of a variety of challenges where, for example, the students have worked on creating a safer environment for those who are outdoors in the evening in a less safe area, or to develop a system that effectively handle received reports of faults on one municipality's water supply.

The here presented study investigates the implementation of CDE at KTH and UDSM. The primary research question is: *To what extent and in what way do teachers and stakeholders involved in CDE express the need for key competencies for sustainable development in future engineers?* The answer to this question is important for the understanding of how CDE can be improved with regards to teachers' and stakeholders' conceptions of key competencies for sustainability which in turn will affect the students learning and development of these competences. The study was performed through semi-structured interviews followed by deductive thematic analysis. In addition to providing data for answering the primary research question, the interviews have also given various other perspectives that can be used for further enhancing CDE and other similar learning approaches.

2. Methodology

A total of 15 external stakeholders and teachers involved in CDE were participating in this study. Two teachers are involved in two different CDE courses at KTH. The other teachers are all involved in one CDE course at UDSM, where three also have earlier experiences as students in this CDE course. The participating external stakeholders are so called challenge-providers, i.e. representatives from companies and other organizations who have provided challenges for students to target in CDE projects. Five Swedish external stakeholders/challenge providers were involved, however it unfortunately turned out to be difficult to reach external stakeholders/challenge providers in Tanzania. The selection is hence for practical reasons somewhat limited and not completely balanced between Sweden and Tanzania. The study and the generated results should therefore be seen as indicative.

A qualitative approach was applied using semi-structured interviews. An interview guide was created consisting of three main question, that were asked to all participants, and several sub-questions, that were not necessarily asked, in order to gather data in a fulfilling manner. The questions were mainly open-ended:

- What would you say are the most important competences engineering students need to acquire to be able to contribute to the SDGs?
- What competencies do you think engineering students develop by taking part in challenge-driven projects?
- What are your experiences and impression of CDE-projects?

The interviews lasted between 30 and 65 minutes. The interviews conducted in Sweden were held in Swedish and the interviews conducted in Tanzania were held in English. All interviews were consensually recorded, and all relevant parts were transcribed verbatim.

All interviews began with the interviewer introducing the 17 Sustainable Development Goals, to frame the interview in the context of sustainable development and explaining the term *competence* as an interplay between knowledge, skills, and attitudes. However, the concept of key competencies for sustainability were not mentioned, since it was later used as framework for the analysis.

The analysis followed the phases of thematic analysis similar to the procedure presented in Braun and Clarke (2006, p.87). Initially the transcribed data was sorted in two main *categories*: 1) statements considering the importance of certain competences, skills or attributes for future engineers and 2) statements about CDE as a phenomenon.

UNESCO:s eight key competences for education for sustainable development were then used as pre-determined themes for category 1, and a deductive approach was taken when mapping the data towards those competencies. Competences mentioned that could not be related to any of the key competencies were sorted under a theme named miscellaneous.

The process of color-coding and sorting all quotes was followed by a process in which the quotes were shortened to form manageable phrases to enable comparisons between quotes and UNESCO's definitions of the key competencies. For example, the quote;

And it's very different if you're at a small company with four employees owned by a person also working there with you, or if you're in a multinational company with sites worldwide... I think that when you have graduated, you are like, so sure of what you will do. And suddenly you end up somewhere and see that people do things in a different way. You may think that's not right since you learned it differently. To, like understand that you are part of a context. That's what I think [is important].

has been abbreviated to

- *understand one's role in a group* and
- *interact in a working context*.

3. Findings

3.1 Expected competences for future engineers

Table 1 summarize what emerged in the deductive analysis for category one, representing competencies, skills and attributes the participants see as important/necessary in future engineers. The phrases are by no means quantitative, why there is no direct correlation in how many phrases are presented in the results and how many participants have mentioned each theme.

Table 1: Competences desired in future engineers according to the participants, mapped against the eight key competencies for sustainability outlined in UNESCO (2017).

Competencies desired in future engineers according to the participants: They need to:	**Mapped key competency**
• possess in-depth expertise within their field but also fit it into a context, because it won't be useful on its own • understand the bigger business • be "like Sherlock with a magnifying glass and at the same time keep an overview perspective" • understand the environment in which solutions are implemented • be able to deal with uncertainty, it is extremely important that "what I think of today will become even more important in the future" • understand that not only one solution can fit all SDG:s • be able to take on complex challenges	Systems-thinking competence
• have competence to see sustainability in the future, the past is the past, but what comes next? • they must be able to make conscious choices for sustainability, which may be difficult as the financial goals are often prioritized for companies • be very socially responsible, not developing solutions which is limited to be good for now/the near future • think about what consequences does a solution have for someone? • be able to develop adaptive solutions	Anticipatory competence
• think sustainably in each subsequent part • not forget about the issue of sensitivity to the environment • have a dynamic awareness of the environment regardless of workplace • have the mindset of a socially responsible engineer	Normative competence
• be innovative • be able to prioritize • use the right competence at right time • be efficient and propose resourcefully responsible solutions • think outside the box • know how to use processes to transform knowledge into useful products, services, or technologies	Strategic competence
• know how to collaborate and work with others • be able to adapt • understand one's role in a group • know how to forward information and make people understand it • be able to form teams • be good at explaining what he or she needs • be able to share skills • be able to lead groups of people • strive towards improving projects management skills • have multidisciplinary competence, which means to learn things not just from one's own profession, but from the other people one encounter in the field • have communication skills • be able to say:" I know this, how can my knowledge help to find a way forward?"	Collaboration competence
• not be yes-sayers but critical thinkers • observe and learn through critical thinking and reasoning • be critical towards unsustainable technical solutions • believe in sustainable development	Critical thinking competence
• have empathy, to see the bigger picture and not just what's profitable for me at this instant • be brave, to dare to bring in fresh knowledge • see the applications of what one is learning • interact in a working context • understand the connection between sustainability goals and one's own professional role	Self-awareness competence
• face a challenge by opening it up and then break it down • have the ability to choose among numbers of opportunities, what is the right problem to solve?	Integrated problem-solving competence
• know the facts within one's domain • be curious and committed • be interested in taking initiatives • be interested and willing to learn and understand • be efficient • be expressful • have endurance • understand the perspective of industry • know market strategies • become a businessperson, willing to start up a company or a business	Miscellaneous competences, skills and attributes

The participants reflected upon what competences future engineers will need both from a general point of view and in relation to sustainability and the SDG:s. A wide range of desired or needed competencies

were expressed where some statements were very concrete, like the ability to form teams and to work together, whereas other statements were broader and more abstract, like the importance of individual attitude and need for social responsibility, and to see the big picture and not just what is profitable right now.

Within the theme of systems thinking, the participants provide a description that is in good agreement with the description given by UNESCO. Although not all stakeholders describe every aspect, the overall picture is that future engineers need this competence. Another theme where the depiction made by UNESCO is matching the quotes from the participants very well is collaboration, which is described relatively exhaustively by the participants. Critical thinking is also expressed by the participants, just as by UNESCO as being able to question prevailing norms and values. The ability to take a stand for sustainable development is also associated to this competence.

The analysis further shows that for some of the themes, it is clear that the participants do not consider competences as extensively as UNESCO, even if certain attributes are demanded. Anticipatory competence is such an example where UNESCO depicts a more complex way of how one may relate to the future, including predicting risks, or being able to predict several different future scenarios that may result in the ability of placing different demands on contemporary solutions. Normative competence is another theme where it can be seen that a more holistic view of norms and values is described by UNESCO compared to what has been expressed by the participants.

On the other hand, other themes are described more extensively by the participants. Even though the core of being strategic is described in similar ways, as being innovative and creative in developing sustainable solutions, the participants add an attribute to the competence, a desire to use the right skills at the right time. Within the theme Self-awareness participants emphasize the importance of having good self-confidence, something that is not clearly described by UNESCO.

The last presented theme is about the competence integrated problem solving. Here are two phrases where the content only partially corresponds to the definition by UNESCO. Nor do these two quotes completely match the description given which could mean that none of the participants see the need for students to have problem-solving ability. However, it may also be that attributes of the problem-solving competence are reminiscent of other competencies, and hence it may be that the participants certainly think that this is an important competence, but they have not expressed it in a whole. As expressed by UNESCO, integrated problem solving can be seen as a meta-competence which is about making integrated use of the other competences.

The participants also expressed a number of desired or needed attributes and skills from graduated engineers that were not possible to match with the key-competencies. The importance of having knowledge in one´s field is emphasized, something that is not seen as a key competence. In any case, knowledge is seen as the basis for being able to act in a sustainable way also according to UNESCO, the key-competencies should be seen as something one need in addition to knowing one's area.

3.2 Other opportunities for refining the CDE concept

All participants are unanimously positive to CDE as an approach for enhancing engineering education and they are positive to further engagement. The interviews give clear indications on that CDE can support students in developing professional skills as well as key competencies for sustainability, where answers in particular can be related to systems-thinking, collaboration, self-awareness, and integrated problem-solving competences. One challenge provider for examples indicates how students apply and develop system-thinking and integrated problem-solving competences in CDE projects as follows:

They [the students] used multiple methods to reach different kinds of conclusions. So they didn't choose just one method, they didn't just do interviews and settled for that, but they looked at multiple ways to gather information and multiple ways to process the data they gathered.

Hence, the general experience is positive, and all interviewees see large potentials and mutual benefits in CDE. However, several differences in conceptions between participants were also identified, which highlights potential barriers, needs and opportunities for further refinements of the CDE concept and its implementation. Several participants for example expressed the need for building trust between academia and industry as crucial for succeeding with engaging industry representatives as challenge-providers in CDE projects. One Tanzanian teacher for example expresses that:

The first thing is to build trust. The trust from the industry … they don't even know we[academia] exist in terms of offering solutions to them. What they know is we only offer them the skills they can tap in terms of employment. So, our relationship is only because they hire people from the university to work for them.

Some of the interviews indicate that approaches taken for building trust is to direct the students' projects towards 'pleasing' the challenge-providers in the sense that the students' solutions should be directly realizable and implementable. One teacher for example expresses that:

…[the students] come up with really practical solutions … not something abstract or imaginary that cannot be implemented, but something that is really down to the ground.

whereas another teacher describes that:

CDE is solely and entirely dedicated to solve their [the challenge-providers'] problems … not anyone else but theirs.

On the other hand, another teacher who also has earlier experience from CDE as a student, highlights limitations in such approach:

…you have to solve that problem, but in the end, you have to have a contribution to the knowledge … the general knowledge … so you might find that "ok, I can do this and that … but that solution is already there, maybe somewhere else" … so what is your contribution?

More open-ended approaches can be traced in the interviews, where it is indicated that teachers have instructed external stakeholders/challenge-providers not to intervene too much in the students' processes, as for example expressed by one of the Swedish challenge-providers:

...one of the most important aspects was that I was not to intervene. My task was to supply them [the students] with data without affecting them. I was not to give them the answer, because that's the main issue. That we have often already answered the question before we asked it, without knowing if it's the right answer … we just suppose it's right … [but we should] try to be open to our preconceived notions being wrong.

Such approaches could however also be problematic, as expressed by another challenge-provider:

I think it's important to know … why should I spend time on this? … what will I gain? … why should I work with you specifically? … why you can do it better than we can ourselves … what's your method to reach a good solution … are you making a product? … does it involve softer values like mapping a culture? … what can I expect to get at the end?

Stakeholders also express that engagement in CDE projects can be very time consuming, and one suggested that the teachers should be clearer about what efforts are expected from them:

Also, clarify what's expected of you. If you don't, I think there's a risk that people won't dare doing it since they don't have the time. But if you say "we expect 20 hours of your time over 15 weeks", you can probably live with that. But if you get the impression that it's 20% over 15 weeks, then you won't have the time. So just the fact that you don't know might make you pass the opportunity.

5. Conclusions

The primary purpose of this study is to increase the understanding of how teachers' and external stakeholders', involved in CDE, views of future competencies match the depiction of key competencies for sustainability, but also, when applicable, to develop the description of each key-competencies by introducing new aspects that stakeholders may provide. These results indicate that teachers' and external stakeholders' views and the UNESCO's key-competencies are in good agreement, however, it should be emphasized that even though it seems that virtually all competencies have been mentioned by the participants, it is far from everyone who has mentioned all competencies. Through this analysis, one can understand the importance of that stakeholders, both from university and industry, discuss and agree on the desired competences of future engineers in order to create consensus on what can be achieved with, for example, challenge-driven education.

Another aim was to better understand how the CDE concept can be refined to better fit stakeholders' expectations. Limiting the students to work on commission by one single challenge-provider, only addressing and developing a tailored solution to one specific problem within that organization, could provide short sighted values for the challenge-provider and opportunities for students to apply their disciplinary knowledge and develop professional skills. However, to reach the full potential of CDE regarding development of students' key competencies for sustainability and solutions to the addressed challenges with potential for innovation and actually impact on sustainable development beyond the horizon of one specific challenge-provider, may require more open-ended challenges for the students to work with, more open and dynamic relations between the students and stakeholders, and allowing for larger risks regarding the practical usefulness of the project outcomes. The key for success will be good dialogue and trust building between all involved actors (teachers, students, and external stakeholders) and clarification of what is expected by each party and what can be expected with emphasis on long-term capacity building and innovation for sustainable development.

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