Structured and open Challenge-Based Learning in Engineering Ethics Education.

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***Abstract*—Challenge-based learning (CBL) is an educational method in which an external stakeholder (company, community, NGO, …) brings in a real-life complex problem. CBL becomes increasingly popular in engineering education in general. The application of CBL in engineering ethics education, however, is lacking behind, as it requires specific design specifications. An ethics CBL course has commonalities with CBL courses without specific ethics learning goals, but they also need specific considerations in the design. A structural approach how and why to apply CBL in engineering ethics education is needed, both from an educational research and educational support perspective. This contribution will explore this gap. With the research questions: "What are particularities of CBL pedagogies in engineering ethics education?" These pedagogies will be described by using van den Akker's spider-web curriculum model and Ethics Goal Model. We describe specificities for CBL engineering ethics courses for the different course components. We conclude that the tension between structured and open CBL approaches is crucial and that more research can be done in the different curriculum aspects described in the model of van den Akker.**

Keywords: Engineering ethics education, challenge-based learning, open, structure, scaffolding

I. Introduction

Challenge-Based Learning is a new and promising approach in engineering education, but the application to engineering ethics education is still underdeveloped. This contribution addresses this gap by exploring structured and open approaches.

Challenge-based learning (CBL) is an educational approach in which an external stakeholder (company, community, NGO, …) brings a real-life complex problem in the classroom [1]. Students are asked to solve a challenge of an external stakeholder that contributes at the same time to a societal challenge. Examples are: a university student team (a group of students that is supported by the university to work extracurricular on a technical project and for which 10-20 students take a year off) that develops a smart-grid energy measuring platform of a university to contribute to the sustainability discussions of the university and beyond; or a university research team developing brain-on-chip (BoC) to contribute to health-care improvements and avoiding animal testing. CBL becomes increasingly popular in engineering education in general. Research recently focused on a wealth of topics to improve this education, such as how to motivate students [2], how to increase competences [3] and how to upscale this education [4], [5]. As CBL courses fundamentally aim to train their students for the global challenges of the 21st century, they incorporate complex, sociotechnical innovation challenges [6] including human sciences [7] or ethics [8], [9] in their courses.

The application of CBL in engineering ethics education, however, is lacking behind [10], as it requires specific design specifications. An ethics CBL course has commonalities with CBL courses without specific ethics learning goals, but they also need specific considerations in the design. A structural approach how and why to apply CBL in engineering ethics education is needed, both from an educational research and educational support perspective. This contribution will therefore focus on how existing CBL formats can incorporate ethics in their set-up (from CBL to ethics CBL). In order to do so, it will also refer to how engineering ethics education can be adapted to CBL (from ethics to ethics CBL).

We first sketch the background of CBL and two models: the pedagogical components model or curriculum spider web model of van den Akker [11], and the adapted ethics goal model of Martin [12]. We describe our methodology and context in section 3. In section 4 we will provide results on structured ad open approaches of CBL in engineering ethics education. We end with conclusions on the difference between structured and open CBL approaches.

II. Background

A. Challenge-Based Learning

During the last decade, challenge-based learning (CBL) became popular in Engineering Education. Malmvqist et al. describe CBL in [13] as: "Challenge-based learning takes place through the identification, analysis and design of a solution to a sociotechnical problem. CBL groups a number of different approaches, but the learning experience is typically multidisciplinary, involves different stakeholder perspectives, and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable". We consider the role of the "external stakeholder" as a key difference in comparison with comparable approaches as project based learning [6], next to a broad range of aspects that have been mentioned in the literature [14]–[16]. A company, city community, academic research group, non-governmental organization, non-organized group of citizens, or any other organization can ask students to help solve a challenge for them. As a consequence, the learning and instructions becomes far less fixed, the role of the teacher becomes much more a mix of many different roles as coach and event organizer, this for all the other people involved, like students, teaching assistants, or the members of the external stakeholder organization. Educational pedagogies have to be organized in a more adaptable way to be able to adjust the learning process students and external stakeholders go through. This flexibility then has an important impact on what is possible as learning goals in a CBL course. The learning goals cannot be narrowly defined, but should be framed in a way it gives guidance to the students and at the same time supports the open-endedness of the CBL process.

CBL in general has specific requirements that are important for course designers and teachers to know and master. Of course, CBL applied to specific fields (as mathematics [17], physics ethics, …) creates further needs for knowhow about how to optimize CBL courses. In this contribution, we therefore focus on both the general CBL aspects and specific CBL aspects when applied in engineering ethics courses.

B. Pedagogical Components Model applied to CBL

CBL wants to bring students into contact with the real-life engineering work and therefore brings in real-life stakeholders in the classroom [18]. Of course, the challenge is still embedded in an educational context.

To analyze and describe the general and ethics aspects of a CBL course, we use the curriculum spider web model introduced by Van den Akker [11], [19] as an overview model for educational practices. The model starts with (I) the rationale (Why are students learning?) as the fundamental point in the design. Based on this, the model describes nine interconnected threads of the spider web that are nine components of a course or curriculum. Each component is a decisive element in a course or curriculum: (II) the aims and objectives (Towards which goals are students learning?), (III) the content (What are students learning?), (IV) the learning activities (How are students learning?), (V) the role of the teacher (How is the teacher/coach facilitating students' learning?), (VI) the materials and resources (With what are students learning?), (VII) the grouping (With whom are students learning?), (VIII) the location (Where are students learning?), (IX) the time (When are students learning?) and (X) the assessment (How is students' learning assessed?). These ten components should be aligned to increase consistency and coherence of the course or curriculum.

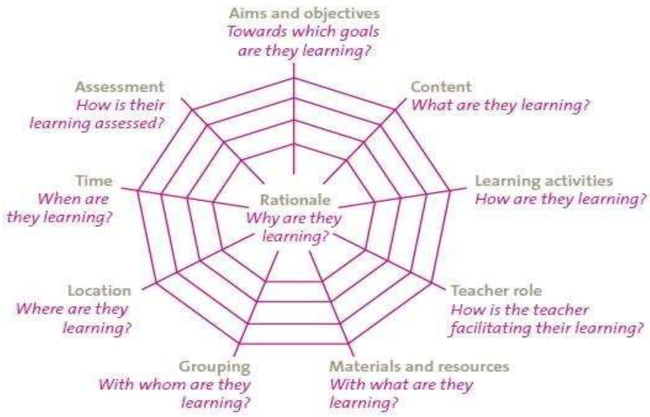

Figure 1 Curricular spider web [11] as presented by [17: 59].

C. Ethics Goals Model applied to CBL

We also want to focus on the specificities of engineering ethics in CBL. As CBL focusses on real-life challenges and as it is a strength for CBL courses to increase the possibilities as to what students can and are expected to do, the learning objectives become more open-ended. [21] A good overview to indicate what they are learning becomes important in CBL in general and in CBL engineering ethics education in particular.

Ethics courses can have very different learning goals. Martin and colleagues proposed twelve goals for engineering ethics education, as described briefly in section IV.B. and explained in more detail in [12]: (1) moral sensibility, (2) moral analysis, (3) moral creativity, (4) moral judgement, (5) moral decision-making; (6) moral argumentation, (7) moral knowledge, (8) moral design, (9) moral agency, (10) moral character, (11) moral emotional development and (12) moral situatedness. The authors state that "There is limited research exploring the prevalence of each learning goal in engineering ethics instruction or on the teaching methods and content to achieve them, which raises questions on how to ensure curricular alignment. Furthermore, there is little known on how specific learning goals might convey to students an understanding of the societal mission of engineering, as captured by the broader theoretical frameworks used to conceptualize engineering ethics education.".

We applied this model in an ethics CBL course [19] and mentioned that two goals were missing in the original model. First, the goals are formulated in an individual way for individual students. Sometimes, however, students specifically refer to learning as a group. [22] We therefore add *group dynamics* (13) as a learning objective. Second, students also refer to the different way of learning ethics compared to their learning of more monodisciplinary engineering courses. We therefor also add *cognition* (14) as a particular aspect relevant for ethics learning.

D. Research Question

The pedagogies of CBL in general are only explored recently, the applications of CBL to ethics courses in particular is currently much underexplored. This contribution will provide a first exploration to answer this gap. The research questions of this contribution is:

"What are particularities of CBL pedagogies in engineering ethics education?" These pedagogies will be described by using van den Akker's spider-web curriculum model [11] and Ethics Goal Model [12].

III. METHOD

A. Methodology

In this study, we adopted a qualitative approach. We collected empirical information on CBL engineering ethics education by reviewing educational materials and by conducting explorative discussions with teachers involved in these courses. For the document analysis, we reviewed information shared in the university website, study guides, assessment guides and the universities educational vision document. A collaborative process was established between the researchers and the teaching staff of the CBL ethics courses. The author team consisted of an ethics teacher of the courses mentioned below (author 1), together with the ethics educational researcher (author 2) and the educational psychology researcher (author 3). We performed the research and reflected together with other involved teachers on the ethics CBL courses. Informal discussions with teachers took place during the courses during peer to peer meetings in which research and teaching staff was discussing the progress of the course.

To analyze the collected data, we followed a deductive, theory-driven approach and the theoretical framework of van den Akker's curriculum model [11] and the adjusted Martin et al.'s ethics goal model [12] were used as guides to formulate our themes and to structure the results and identify why and how CBL is designed in engineering ethics education.

B. *Context*

Three courses at Eindhoven University of Technology (TU/e), the Netherlands, are used in this research for empirical data. The first one, USE-CC, is a first-year's, 5 ECTS, 8 weeks introductory course on ethics of technology. It is monodisciplinary. The focus is on co-creation of innovation processes and engaging local publics [23]. There are 240 students and 10 stakeholder enrolled. Stakeholders are large companies in the universities ecosystem, co-creation organizations or students teams. An example of a challenge is a TU/e student team that builds affordable, flexible and sustainable houses. One group of students discussed the stakeholders question to use microphones in the houses. They proposed places where to record and where not in the house and Fourier transformations of the data to protect privacy but being able to contribute to well-being.

The second course is a first-year's, 10 ECTS, 8 weeks introductory course on data-analytics and ethics of technology. It is interdisciplinary course. The focus is on data analytics. There are 45 students and 1 to 3 stakeholder enrolled. Stakeholders are TU/e students teams or TU/e research teams. An example of a challenge is a TU/e research group doing research on Brain on Chip (BoC). [24] Students receive a complex data set from the BoC research and have to analyze it after an introductory course on data analytics. The ethics links to privacy of stem cells, informed consent, moral enhancement, brain organoids, animal testing replacement and so forth. The BoC researcher ask students to come with technical solutions that also answer ethical issues implied.

The third course is a second and third-year's, 15 ECTS, 24 weeks course on physics of social systems, psychology and ethics of technology. It is interdisciplinary course. There are 45 students and 1 to 3 stakeholder enrolled. Stakeholders are companies or research teams. An example of a challenge is the Dutch railway responsible ProRail doing research on pedestrian movement. [25] Students receive a complex data set from ProRail and have to model pedestrian movements, set up a nudge in a Dutch railway station and measure the outcomes of their nudge. The ethics links to informed consent as students have to write their own ethics review board approval. But students also have to incorporate ethical aspects, such as responsibility and care for others' safety and comfort, into the model and have to think how they can use these insights in nudging crowds to be more ethical.

IV. RESULTS

We describe specificities for CBL engineering ethics courses for the different course components using van den Akker's spider-web curriculum model [11] and Ethics Goal Model [12].

A. *Rationale*

The first tread in the educational spider web refers to the rationale of courses or curricula. It concerns the questions "Why are students learning?" as the fundamental point in the design. The TU/e's current educational vision links CBL with the T-shaped engineer. "The engineers of 2030 face a faster pace of technology development and increasingly complex problems and challenges. Because of the great impact of technology on our society, engineers need to develop a comprehensive view of how technology is shaping the environment we live in. They need both in-depth disciplinary expertise and cross-disciplinary insights and approaches. Our university also expects a group of learners of more diverse backgrounds, ages, nationalities and cultural heritage with equally diverse motivations, learning styles and educational needs. TU/e sets five major goals for our learning processes: educate engineers for the future, serve diverse learners, offer personal learning paths, transform from teaching to learning and challenge-based learning. (p28)" Students are said to learn to acquire basic knowledge and address open-ended problems and link it to ongoing research. "From day one, acquiring and applying knowledge will be balanced. In the Bachelor's degree phase, students will use challenge-based learning to acquire basic knowledge and address open-ended problems. In the Master's degree phase, more complex challenge-based projects will engage students deeper in research. To be able to implement these innovations, we will allocate financial means and create classrooms and labs that allow for experiments with new pedagogies. (p30)" Diversity is seen as an important element. "We aim to involve students and staff of various institutions in our challenge-based education facilities […]. Students, graduates and R&D-professionals will work together in teams of various nationalities, disciplines, levels of education and cultural backgrounds. This creates an optimal experience for students and a maximum involvement of talent." (p58) CBL is said to involve "team work, interdisciplinarity and a systems-level approach." (p30) The educational vision stresses the importance of students learning in the universities' ecosystem. "Academic education is increasingly a team effort of universities, companies and societal organizations. To enhance our educational capacity and challenge-based projects, we will explore opportunities for teaching capacity provided by our partners, for example to coach students in challenge-based learning assignments and to provide advice regarding student career development." (p32) "Relate learning to real-life research and challenges and increase the share of challenge-based education, by intensifying collaborations within our ecosystem through the Innovation Space, to offer cross-disciplinary challenge-based projects both at TU/e campus and at regional educational institutions and industry. (p33)"

Ethics is explicitly mentioned in the educational vision. "Technology and its role in society will become increasingly complex. Engineers of the future need to approach technology development not only from the perspective of technology, but also that of users and systems. Our students will need to be equipped with both in-depth knowledge and skills to operate in a diverse and rapidly changing world. They need to be able to work in multidisciplinary teams, take a systems perspective and be solution and innovation driven. They need to consider technological, societal and ethical contexts as well, including regulations, policies and markets. Engineers of the future need a broad, open and cooperative mindset to meet the UN sustainable development goals, contribute to the technological revolution and create impact for society in a responsible and sustainable way. This implies reflection, analysis and participation in academic and public debates about technology and its impact. (p15)" "Within the Bachelor College, TU/e currently offers three-year Bachelor's degree programs which contain engineering basics like mathematics, physics and engineering design, a disciplinary major, but also non-technology subjects like ethics, entrepreneurship and responsible innovation. (p27)"

These quotes illustrate that Eindhoven University of Technology puts CBL up and front in its educational vision and explains the rationale question "Why are students learning?" of a T- or π-shaped engineering in a network or ecosystem. In terms of learning, CBL aims to motivate engineering students to reflect on ethics by "doing technology". The aim of the CBL in general and of CBL ethics is to support deep(er) learning, self-regulation, interdisciplinarity and real-life experiences. [26]

An important rationale question is who is in the lead here. Is it the university in a *structured* way that defines how important engineering, ethics or responsibility is and what the important aspects are that have to be learned? Or do the student determine their paths in an *open* way and deciding for themselves how much or how little ethics it should entail. We notice that in a CBL discourse, this is not an easy question and should be further debated. We are inclined to look for a middle position in which the university indicates what it a minimal open ethical discussion, but the student get the possibility to develop their own ethics within the broad boundaries of the societally acceptable.

B. Aims and objectives

Second, the aims and objectives ("Towards which goals are students learning?") are a direct translation of the rationale. CBL has the potential to address many ethical moral learning objectives. Below, we use the ethics goal model to give an overview of the 12 ethics goals [12] and the two extra possible objectives.

1-*Moral sensibility* = encouraging students to take ethics seriously. CBL has the potential to make students experience ethics directly in what their interactions with stakeholders or the delicacy of the topics they are discussing. Ideally, it is not the ethics teacher anymore who has to "preach" that ethics is important, it could be the case that speaks up. Students working on BoC might experience that the way they analyze their data can have a huge impact on the lives of the patients they might be talking to.

2-*Moral analysis* = analyzing moral problems in terms of multiple or competing facts, values, stakeholders and their interests. CBL starts from a complex, ambiguous and wicked challenge. Competing facts, values and stakeholders are omnipresent. BoC-students deal with patients privacy, animal rights, hospital business models and return on investments, passionate researchers, patient protection organizations, and so forth.

3-*Moral creativity* = envisioning different options for action or design in the light of moral values and relevant facts. Different students teams in a BoC project come up with different projects, like operationalizing data analysis software, solutions to abolish animal testing, stem cell data base regulations, and so forth.

4-*Moral judgment* = making moral judgments based on different ethical theories or frameworks, including professional ethics and common-sense morality. This is not per se part of CBL. The set-up can scaffold moral judgement by providing a substantial overview of ethical theories that are asked to be applied. But CBL can also leave open what ethical theory students have to apply how. This increases students ability to find ethical theories, but largely lowers the depth of their discussions.

5-*Moral decision-making* = enabling students to make decisions based on different ethical theories and frameworks. Same as for moral judgement, this depends on the objectives of the course and how this is scaffolded.

6-*Moral argumentation* = developing the ability to morally justify one's actions and views and to discuss and evaluate them. CBL nudges students to do this in an engineering context in which they communicate to the stakeholder that their result is a good result. They have to argue that their technical solution is also an morally justified solution.

7-*Moral knowledge* = giving students access to the language, concepts and theories of ethics to express and support one's moral views adequately to other. Again, this is a choice of the CBL course objectives and related set-up.

8-*Moral design* = considering how values can be inscribed into engineering artefacts at the design stage. CBL is a strong method to realize this ethics learning objective, as this is exactly what students are asked to do for the stakeholder. If they want to increase the privacy of BoC, they have to come up with technical design specifications and convince the professional that their solutions actually realize this.

9-*Moral agency and action* = responding wisely and responsibly to situations in a way that satisfies as many potentially competing constraints as possible; and responding in a responsible manner to morally bad or unjust situations. Students practice this in a real-life case. They might not receive certain data or have to wait longer than they expected for an answer of a stakeholder. As such, CBL optimizes day day-to-day aspects of the engineering profession instead of extreme cases like the Challenger launch experiment. [3], [27]

10-*Moral character* = increasing students' ethical willpower, sense of professional identity, and virtues. Here, the evidence of the impact is not very clear. Going through a CBL course creates quite some frustration that students have to cope with. [1] We can expect that they train their willpower and develop their professional identity and virtues, but we do not have evidence on this.

11-*Moral emotional development* = reflecting on the role of emotions in the development and acceptability of technologies, engineering artefacts or policies. CBL is a demanding approach, so emotions come into play [19], and a good teacher-student relation can have high impacts on moral emotional development. [28]

12-*Moral situatedness* = promoting participatory engagement, understanding social relations of expertise in connection with technology management and decision-making. CBL is also very well suited for this learning objective, as student have to engage in participation and social relations. In doing so, students have to go beyond their evident views of certain stakeholders.

13 *Group dynamics* = system of behavioral processes occurring within or between social groups. Group dynamics is an important aspect of CBL work. In reflection exercises, students refer to the moral difficulties in the group work, such as fairness of division of work, spending time helping other groups, and so forth. [19]

14-*Cognitive aspects* = Norms as "social rules that mark out what is appropriate, allowed, required, or forbidden in different situations for various community members" [29] is different from cognitive ways of processing mathematics or engineering subjects. Students encounter these differences in CBL courses as students are asked to combine these ways of thinking [19], whereas in non-CBL they can probably keep the two cognitions separate.

Many engineering bachelor students' struggle with addressing the learning objectives of ethics courses. [2], [8] Those students benefit from clear scaffolding to obtain these objectives. [30] Profound scaffolding asks time, focus and energy. Especially in light of the long list of potential ethics learning objectives as described above, courses in general and a CBL ethics courses in particular clearly have to make choices on aims and objectives. In CBL, there are two possible ways. First, the *structured* way is to carefully select a few learning objectives and align the course design to optimize this. Second, the *open* way is to let go of the specific learning goals and "let the CBL process speak" or "bring the students in the lead". This open way asks for a very different way of dealing with personal learning objectives and opens the discussion of individual versus class aims and objectives. [31]

Both structured and open aims and objectives in CBL have to address the differences between product and learning process. The stakeholder's question to develop a product brings the students' focus on finalizing a desirable technical *product*. This focus is one of the important motors of the CBL method, as it creates enthusiasm of students to make a real thing. If this "drive" becomes too strong, students have to be remined that it is a course and the ethics learning *processes* are also important. The aims and objectives therefore should find a balance between the product and the process. [32]

Another CBL driving aspect is *frustration*. [27] CBL is difficult and will certainly create frustration with students. Many CBL courses aim to end with a *success experience*, often a celebratory presentation of all the results together with the stakeholders.

Last point in CBL is that the challenge and the stakeholder can and will influence the aims and objectives. A brain-on-chip case might induce other activities and therefore other aims than a zero-waste project. This insight again can be taken in two ways: a case can be chosen in terms of the ethics aims and objectives, or the aims can follow from the case.

C. Content

Third, the content (What are students learning?) should be aligned with aims and objectives. [33] The elaboration above indicates that it is not straightforward for an ethics CBL course what exactly students should or will be learning.

A *structured* approach can bring in relevant ethics theories for the particular case. In any case, the focus is not on reproduction of ethical theories, but in the application of complex real-life situations. A more *open* approach does not bring in relevant ethics theories. Students have to look relevant arguments for themselves. It is our experience that for ethics, this has a huge impact. Student come up with far less materials and most groups with weaker resources. We see several reasons for this. The most evident one is that many engineering students, especially bachelor program students, have no background and no idea of what a qualitative ethics source is. So this process needs to be scaffolded.

Several aspects make this endeavor more difficult. Several engineering students have lower language ability skills and it is not evident for students to "discover" ethical aspects in an interdisciplinary socio-technical challenge. [34] It needs a sufficient level of the moral design learning objective to find ethical aspects in a smart-grid digital platform. And the practical aspects of CBL, like planning and group work are quintessential. This means that CBL requires much more for the content next to reproducing ethics theories. [35]

Stakeholders and their challenges co-determines what the content is. Of course, they are most often engineering, but no ethics specialists. The stakeholder can be briefed to remain in certain ethics content-boundaries in a more structured approach, or not in an open approach. For the CBL format to be motivating and activating for the students (especially the students with a strong technology focus and a very weak social focus), the ethics part should be as inescapable as possible. A smart-grid digital platform was less convincing compared to data analytics of brain-on-chip that might cause huge quality of life differences. So the case has to be delicate or sensitive enough to be useful for ethics. But it should also find the middle ground to be critical to the stakeholder. In some cases, students mentioned organizational weaknesses that made the individual employee feel very uncomfortable. In other cases, a teacher might decide not to cooperate with a stakeholder because of ethical reasons, for example when the company is involved in weapon production, voting manipulation or community manipulation in the global south.

D. Learning Activities

This brings us, forth, with the learning activities (How are students learning?). Both in the structured and open versions of CBL, students do learn theories. In order to keep as much contact time for actual activating discussions and CBL work, getting acquainted with the theories is often organized in a flipped-classroom way. It is our experience that it is useful to provide materials of different levels of difficulty. As a first level, we use short introducing online videos of ethical theories. A second level is a more in-depth pre-recorded lecture and some handbook readings. A third level is the original work of a philosopher or an in-depth article on a certain topic.

During the contact moments, students practice in applying the ethical theories to their technical cases. Making posters, explaining to and discussing with each other have proven to be successful methods that are appreciated by the students. [3]

Preparations in group and individually constitutes most work of the students. As said, they need to be scaffolded to find good ethics sources. Most engineering students like designing and making things. This entails a lot of group work and planning on their own, but also interactions with stakeholders or finding out how to use questionnaires or other methodologies that might be useful. At the end of the project, they also present their work to external stakeholders.

Reflection is also very important. It is not necessary per se, a CBL course can do without reflection. [36] But spending time to increase awareness of what and how things are learned, increased the learning gains. We reported earlier a method based on self-regulated learning in which students are asked to weekly give a learning experience, state why this is important and how it will make their learning different the subsequent week. [19] But reflection can be more focused on the group work, on the progress of the ethics learning, or on the product evaluation. We believe that all these reflection topics improve the learning from the CBL process.

These CBL activities are all very time consuming and should therefore be designed realistically. In general, the more structured, the more scalable; the more open, the more time consuming. Classical solutions could be searched for here, like peer-feedback, students as teaching-assistants (paid or older master students in other courses), …

Lastly, the students are obviously not paid for this work, the external stakeholder has a more educational attitude when giving feedback compared to real-life situations, students get more time than a real real-life case would provide, and so forth. The CBL learning context is clearly a ethics learning activity, but we noticed that with students working on a product, it is important to repeat enough.

E. Teacher Role

Fifth, the role of the "teacher" (How is the teacher/coach facilitating students' learning?) becomes much broader in ethics CBL courses. First of all, and important to stress, the teacher can still teach. In a fully *open* CBL, the teacher can decide not to teach anything and leave it all to the students. In a more *structured* approach, the teacher will still teach, either prerecorded and flipped-classroom to save contact-hours for other activities, or in-class teaching. The teacher also organizes other educational activities as group discussions, peer-feedback, or coaching sessions. Teachers are also event-organizers if it comes to end-events in which students present their work to the external stakeholders.

These roles have clear particularities in CBL ethics courses. If an ethics CBL course has many cases, it is not easy for an ethics teacher to be on top of everything, like ethics of AI, bioethics, sustainability, neuro-ethics, robot ethics, etc. Different cases can have really refer to different fields in ethics. A teacher can be of course be ignorant [37], but it is so much stronger if a teacher knows at least the basics about the relevant ethics fields. The same goes for the other disciplines involved. Again, an ethics teacher does not have to know the technical details of data analytics work the students are asked to perform. But when more familiar, the teacher can nudge more about interdisciplinary thinking. [38] As experiences can be intense, coaching can become very personal in CBL, which is a strength for fostering deep learning [39], but boundaries with counseling have to be safeguarded.

As event-organizer, the teacher has to support the pedagogical flow of the course, managing unexpected outcomes on the fly, often due to the interaction with the stakeholders. Differences between stakeholders give different dynamics. Student teams are often unexperienced themselves and can require strong coaching from the teacher. University colleagues sometimes confuse students because their double role as they request a product, but also communicate in an educational way. Purely external stakeholders are most often not used to deal with ethics in their daily lives and might need some preparatory discussions, but sometimes teachers might need to be a moderator when students mentioned organizational weaknesses that made the individual employee of the stakeholder company feel very uncomfortable.

This is a lot for a single ethics teacher. In practice, some roles can be outsourced. Teaching Assistants (TA, master students, sometimes form other non-technical universities), PhD or postdoctoral students can take over organizational and pedagogical roles. The extra workload in some cases pays off because of the strong link with the teacher's research.

F. Materials and Resources

Sixth, the materials and resources (With what are students learning?) can largely differ in a CBL ethics course. Classical materials remain basic: primary and secondary texts of philosophers, can be combined with online available videos about philosophers, (Wikipedia-)websites. As students have to apply ethics to a real case, argument mapping software can be very helpful. The assignment description can either be long, detailed and structured, or very open. In principle, no fixed learning materials exist, but if provided, they provide more structure. Previous year's examples can play the same role, but can limit the creativity and openness of the student work and might create confusion if the stakeholder has slightly different requirements. In interdisciplinary courses, labs to design and develop the product that enacts the values, can be relevant. Stakeholder can bring in materials (instruments, reports, networks, …) that the own university has not. End events benefit from good conference rooms, either clearly concealed or clearly attracting other (accidently passing) students to increase the audience.

CBL education needs more resources. The financial consequences of staffing are in line with project courses [3]. However, extra resources should be considered. Experiments might require extra time for teachers to set-up the courses and to do small-scale experiments. Teachers can use support from the university's teacher support, which has to build the expertise as well; and they can use practical support to find external stakeholders, manage the agendas, set-up the end-events and so forth. Open courses are more supportive intense compared to structured courses.

G. Groupings

Seventh, the relevance of the grouping (With whom are students learning?) aspect for CBL follows from the core element of the external stakeholder. Students are learning with their peers, their teachers and external stakeholders. Learning with peers is comparable with other project work in project groups. In ethics courses, stakeholders indicate that the number of groups should be high enough to get a number of out-of-the-box ideas, but low enough to make it feasible. The number of groups can be regulated by the number of students per group, of course too many students per group complicating the group process. Groups can be constituted with diversity in mind (gender, national and international students, or backgrounds). Differences in ambition level of students might create friction and influence co-learning.

Of course, students learn with the external stakeholder. Students learn from the external stakeholders but in ethics CBL can bring in ethics elements that are useful for the external stakeholder. The more open the challenge, the more unplanned co-learning can take place.

H. Location

Eighth, the location (Where are students learning?) is specific for ethics CBL courses. Students have contact moments in rooms that are designed to favor discussions with peers, teachers and external stakeholders. They might also work in labs or maker spaces [40] or at the location of the companies to develop the technological parts of their challenge. The more open the challenge, the more students will come with specific questions of locations; the more structured, the less these questions pop up.

I. Time

Ninth, the time (When are students learning?) is specific in CBL. Students clearly need time to find out what CBL entails and how they want to do their project, they need time to develop a solution and to make a communication about it. [1] However intense, a short quarter has disadvantages as incorporating ethics takes time. Contact hours for students can be low, but is often high for teachers as most contact moments are small scale. The external stakeholders's time is also scarce and the use should be well organized. The available time of stakeholder is often a bottleneck. Students always indicate they want more time, whereas stakeholder often indicate they cannot spend more than they already do. [3] Structuring expectations more can be of help, but open courses stress more the real-life characteristics of the ethics CBL courses.

J. Assessment

Tenth, assessment (How is students' learning assessed?) in a CBL course also has particularities. [41] [42] Students work towards a technical solution for a challenge and this product is assessed as a group. For ethics, the product often is a report in which students answer specific ethics learning goals (see above). Skills to communication towards specific stakeholders and taking certain values into account can be tested during end presentations. These three aspects can be assessed by the teacher alone, but can also involve the external stakeholders assessment. The learning process itself is more difficult to assess than the product. There is a need to determine a starting level and a process. This can be done at the individual or the collective level.

Assessment in structured CBL ethics approaches is easier. Students, teachers and stakeholders engage in a process that is more known. Rubrics and assessment methods can be determined more precisely in advance. This is more difficult in open approaches, as it is less clear what students come up with. Our experience with the more open approach, however, is that students do not complain about unclarity in rubrics.

V. Conclusion

We analyzed particularities of CBL in engineering ethics education using van den Akker's curriculum model [11] and the Ethics Goal Model [12]. We focused on how CBL formats can incorporate ethics in their set-up (from CBL to ethics CBL) and how engineering ethics education can be adapted to CBL (from ethics to ethics CBL). For all treads of the spider web, we provided specificities for CBL in engineering ethics education and how they should all be aligned to increase consistency and coherence of the course or curriculum.

One aspect emerged in all treads. Design of CBL in general and ethics CBL in particular has to make choices on how open or closed the pedagogies would be. We do not link this to the quality [43] of the CBL education as both are valuable in terms of educational quality. On the one hand, a more structured approach (narrow rationale, aims, and objectives; specific and predefined content, preestablished learning activities, a more fixed teacher role, clear groupings and location, and a narrow assessment) can be helpful for all parties. It can give students more comfort and guidance, is it is more predictable for teachers and external stakeholders. Ethics learning goes more in-depth. On the other hand, a more open approach gives more room for creativity, provides the students more to practice in real-life, wicked challenges. It is more demanding for all involved, and more costly as it needs more scaffolding, making upscaling [4] less evident.

This tension between structured and open approaches in general and engineering ethics specific CBL courses shows several avenues for future research. What are CBL pedagogies and how broad is the range from very structured to very open? How can the different aspects (rationale, aims and objectives, content, learning activities, teacher roles, materials and resources, groupings, locations, time, assessments) be optimized for better learning? What does this better learning mean in general and with respect to ethics? How is (engineering ethics) CBL scalable? Are student differences (learning preferences, personality, …) important in CBL? And what is the effect on the wider university as an organization if a substantial part of the curriculum becomes CBL?

These are but a few important questions emerging from the experiences with the current CBL courses. We consider CBL as a promising method in higher education in general and engineering education more specifically. More research can still make substantial contributions to make CBL practice a successful component of higher education curricula.

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