CREATING THE CONDITIONS FOR AN ONLINE CHALLENGE-BASED LEARNING ENVIRONMENT TO ENHANCE STUDENTS' LEARNING

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ABSTRACT

In addition to relevant knowledge, today's graduates also need problem-solving skills, interdisciplinary skills, communication skills (also termed 21st-century skills) and the ability to identify and acquire the new knowledge necessary to solve problems. Therefore, we require an educational framework that provides enough freedom and flexibility for students to choose their own focuses and, at the same time, enough structure and direction to ensure the institutional-wide quality of education. Challenge-based learning (CBL) is a promising innovative educational approach that combines these desirable features. However, experience from previous pilots has also revealed some limitations; for example, the lack of structure sometimes seems far outside the comfort zone of students and teachers. In this paper, we show how our experience from the Autumn Challenge Programme at the University of Twente, offered fully online, led to some promising suggestions for a CBL course design in which students had to take control over their own learning processes in a structured learning environment, with a coach playing a prominent role in ensuring that the learning outcomes were successfully achieved.

1 INTRODUCTION

1.1 Why a New Educational Approach for Engineering Education

The needs of society and industry are changing rapidly—at such a pace that it is becoming increasingly difficult for engineering education, in its current form, to adapt at the same speed [1]. Thus, the time has come to reconsider the format in which we offer education. Technological developments, among other things, have opened up more and more ways of transmitting knowledge [2]. For example, the physical

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presence of a lecturer is no longer necessary when lecturing; this provides the opportunity to teach larger numbers of students at the same time and creates space and time for the teacher to focus on parts of the curricula where students benefit most from the physical presence of a lecturer [3]. Universities must examine how education can be designed in such a way that students still graduate with a solid knowledge base but have also developed the so-called transferable and lifelong learning competencies industry, and society wants them to develop. Challenge-based learning (CBL) offers a framework that can support the transition to future-proof higher education without compromising quality. Universities that implement the necessary changes in this phase are therefore likely to gain a strong competitive edge [4].

1.2 Challenge-Based Learning

The CBL framework was developed to help students gain a fundamental understanding that would last longer. Even though CBL addresses this specific need, it is also based on educational theories, such as social constructivism [5] CBL has some specific features that make it a pedagogy on its own. A main feature of CBL is
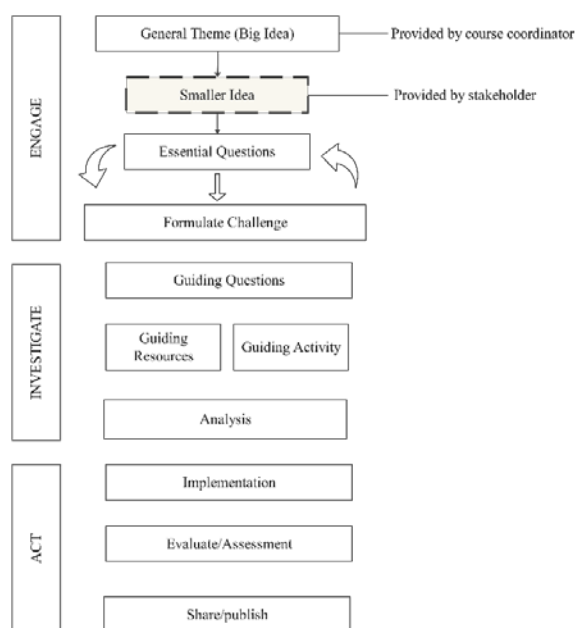

Fig. 1. Cbl framework based on the framework proposed by apple inc. (2010) adapted for use during the Autumn Challenge

that students get to work at a real-life problem; according to experiential learning theory, skills are learned best if the learner can practise the skills in an environment that resembles the real-life situation [6]. Although this idea is not new in education, with CBL, the purpose goes beyond the intended learning effect; the assumption is that students can actually contribute something substantial right now. Furthermore, the focus is on the development of so-called transferable skills whereby the skills are deliberately taught, including interdisciplinary collaboration skills. In summary, CBL is an approach in which students are involved in their learning through formulating questions (essential and guiding), investigating widely in cooperation with stakeholders and

collaborating with different disciplines to build new understanding, meaning and knowledge, all while working towards a solution that is environmentally, socially, and economically sustainable. Sustainability is not just another topic to be added to the curriculum to build awareness, as building awareness will not automatically lead to change. The CBL model makes learning meaningful, offering students large enough challenges to learn the new insights and skills to solve them while at the same time

allowing students to be close enough to the problem to come up with a worthwhile solution [4]. An advantage of allowing students to co-design the learning process is that they can individually build on prior knowledge and experience, which allows them to learn more effectively and individually throughout the process. In addition, students will be much more motivated when they have determined for themselves what knowledge and skills they need [7]. However, CBL does not encourage a curriculum defined by individual students; the curriculum, as well as the learning environment, must be flexible, as does the teaching approach. Yet, there seems to be a missing link between the flexible and customisable framework CBL promises to be and its practical implementation.

1.3 Curriculum Design for Engineering Education

Given the newness and distinctive features of CBL, there is limited knowledge concerning suitable learning environments and supportive systems to achieve desired learning experiences for CBL, and many aspects require further investigation. Furthermore, all other programme characteristics, such as the online, interdisciplinary (ID) and 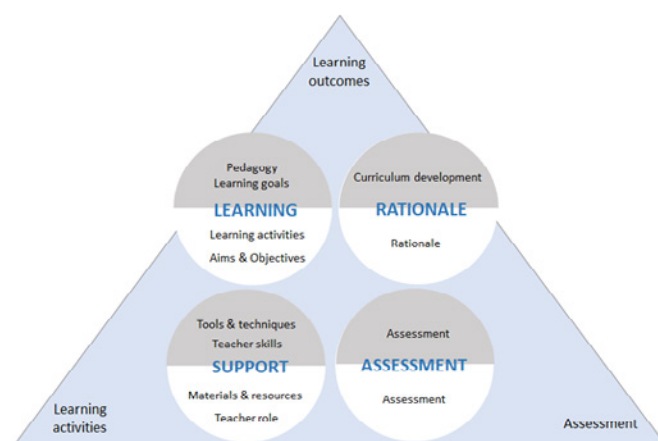multicultural nature of the programme, must be considered in curriculum design. Therefore, three broadly used curriculum frameworks, namely Biggs, van den Akker and the 4TU framework for ID education were reviewed, and shared elements were identified and referred to in this paper as rationale, learning, assessment and support (Figure 2). The reasons for establishing the programme and its main goals are referred to as rationale. The success of learning, and in turn participant development in CBL and ID programmes, is based on

Fig. 2. Identified elements of curriculum design that are shared by three frameworks: Biggs, van den Akker and the 4TU

the constructive alignment between learning goals, learning activities and well-designed assessment tools [8]. Unlike in other educational designs, the focus in CBL should be on how to use flexible learning goals so that the students are encouraged to determine their paths to achieve them. To offer a fully experiential learning experience a major project that is challenging and relevant to the learning is an essential component of a programme, as it sets a clear goal for the learners . All learning activities should be directly related to the project and offer learners autonomy to steer their learning paths [9]. This will create a learning environment in which learners can develop 21st-century skills, such as critical thinking and teamwork, and be prepared for the future and constantly changing world. Yet, it is still relatively unclear how to assess 21st-century skills, and assessment is considered crucial in any context, including in CBL [10]. Assessment in CBL should

not only focus on its summative format but also on a formative one to guide learners towards self-regulation. Including metacognition in the assessment as a form of reflection on the learning process that the students co-designed themselves is vital. To ensure uniformity in terms of the assessment criteria that are important for motivation, well-designed assessment rubrics are essential [8]. Support, including initial structure and guidance, in an ID learning environment with open-ended problems, plays an important role in helping learners towards self-regulation [11]

2   IMPLEMENTATION

The Autumn Challenge Programme2 is an extracurricular and short-term CBL programme organised and offered by the University of Twente. This programme was the first of its kind to be piloted by the UT in a completely online setting between October 2020 and January 2021. The programme offered seven different problems (small ideas) under the wider UN SDG's. There were a total of 33 students enrolled in the programme, of which the vast majority were engineering students (64%) from five different universities and eight nationalities. Table 1 shows the number of students per discipline.

Table 1. Overview of students per discipline who enrolled in the Autumn Challenge

Discipline	N
Public Administration / Political Science / Sociology / Law	5
Civil engineering / Sustainable Energy / Spatial Engineering	5
Mechanical Engineering / Industrial Design	4
Business / Finance / Management	4
Psychology	3
Statistics / Data Science	3
Liberal Arts & Sciences	3
Chemical Science / Physics	2
Geosciences / Earth Observation	2
Aeronautical Engineering	1
Biomedical Engineering	1

International, Interdisciplinary online setting

The reasoning behind piloting the programme was to create a learning environment whereby students could work together in a fully online setting, actively learn with each other and from each other in an international and intercultural context and create societal impact. As a result of the Covid-19 outbreak, many students were struggling with shifting to a completely online model of education and had difficulty

https://www.utwente.nl/en/autumn-challenge/

interacting with peers and co-learning. Furthermore, the opportunities to have a physical experience abroad were diminished, which also created a gap in terms of available learning activities to fill their study programme. An innovative programme that could bridge these gaps created by the pandemic and give students a new purpose and motivation to learn, connect and socialise was, therefore, necessary, and because the CBL framework was developed for flexible learning paths, it was the most likely choice. Admitted students were asked to choose an overarching project (challenge) and had to work with various stakeholders, such as the challenge provider and other social groups (i.e., certain communities), to formulate the challenge and design a potential solution. The student teams were formed on the basis of transdisciplinarity and intercultural diversity after the admitted students were asked to choose their preferred challenge topic by ranking them (one to seven). Most teams were formed based on the students' first choice and some on the second choice. The programme was opened to second-and third-year bachelor and master students from all universities[3], as well as strategic partners of the University of Twente. The workload for learners was estimated to be 5 ECTS (5*28 hours = 140 hours), which were divided among various activities.

Fig. 3. programme curriculum organogram

2.1 Curriculum design components

The intended learning outcomes were formulated broadly, as shown in Appendix A, to give autonomy to the students to co-design their learning paths [12]. To ensure that the learning outcomes could be achieved, the programme was structured on the basis of four learning activities: Virtual Teams (organisation), Thematic Weekends (content knowledge), Skill Labs (skills) and Cultural Activities (engage). Assessment criteria were communicated with the students via thoroughly yet broadly structured assessment rubrics (Appendix B). Additionally, there was a formative assessment in which student teams presented their progress to all interested stakeholders. The students were assessed in a non-traditional grading system using a pass-fail standard. To ease communication (i.e., sharing assessment rubrics and syllabus) with the student and at the same time support, self-regulated learning, a learning management system (Canvas) was used. Throughout the programme, the teams

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[3] https://www.eciu.org/member/eciu

regularly consulted on their progress with the problem providers, and the teams' development was also monitored at weekly sessions with team coaches. Based on the outcomes from these sessions, the coach guided the students in reflecting on how it was going, if they did all they could and if they needed additional support, knowledge, or information. Ad hoc scaffolding in terms of additional workshops or support was offered.

3 RESULTS

Developing, implementing and evaluating the CBL approach as a leading educational pedagogy for the Autumn Challenge has led to several insights that may benefit not only UT and ECIU but also other universities in future educational innovation. In the next section, we report the choices made regarding designing a CBL learning environment.

Table 2. The curriculum design component Learning activities, aims and objectives interpreted to CBL-related activities and objectives used in the Autumn Challenge

Learning activities, aims and objectives	
CBL Features [13–16]	**Applied in the Autumn Challenge design**
• Stakeholder collaboration • Students can determine how they wish to achieve the learning outcomes • Failure is part of the learning process • Learning happens in learning communities • Real world wicked problems connected to societal challenges • Self-directed learning • Applicable solution • Critical and higher-order thinking skills • Ethical awareness • Synthesise multiple perspectives	• Weekly meetings with the problem provider (students plan meetings themselves under the supervision of the coach) • Pre-planned thematic lectures (content) • Pre-planned skill labs • Students can indicate whether they need additional knowledge or skills • Broad learning objectives to let students choose their own learning paths • Include the development of academic skills, such as higher-order thinking, enterprise or transferable skills, in the learning objectives • Educating students about the CBL approach regarding their own role (taking responsibility for the learning process)

Table 3 shows that the learning activities were highly appreciated by students. In particular, *Virtual Teams*, which include the organisation, setting and guidance of the teamwork, was highly valued.

Table 3. Student evaluation in terms of how these components contributed to achieving the learning outcomes.
(1 = very poor, 10 = excellent)

	N	M	SD	Min	Max
Skill Labs	24	7.54	1.66	3	10
Thematic Weekends	24	7.20	1.69	4	10
Virtual Teams	24	9.12	1.07	6	10
Cultural Activities	18	7.83	1.97	3	10

Role of the coach

Coaches can help guide students throughout the learning process, which should be tailored to the dynamics and composition of the different student teams [20]. Although teachers should have less control over the learning process and allow learners to make mistakes, the teachers' role in CBL requires a different time commitment and flexibility in comparison to traditional pedagogies [10]. Together with coaching, milestones can serve as a tool to monitor team progress [21], and if any issue is identified, new scaffolding strategies can be implemented. Online learning environments became the new norm during the Covid-19 outbreak, and they introduced more complexity into curriculum design. In addition to using learning management systems, interpersonal relationships—which can be built by providing collaborative and networking opportunities that in turn can support self-directed learning and develop productive life-long learning communities—are important in an online learning environment [22]. The role of the coach was essential. The coaches created a safe and motivating (Table 4) environment while simultaneously guiding the students in their individual learning processes. The three main coaching activities (Table 4) included asking questions, coordinating the learning process and motivating.

Table 4. The most mentioned coaching activities that contributed to the learning experience.

Coaching activities	N	%
Guiding/coaching/tutoring	8	24%
Planning, coordination and organising	6	18%
Motivating	4	12%

Stakeholder involvement

Students indicated that their intensive collaboration with stakeholders led to improved skills in defining the real problem, asking the right questions and gaining specific content knowledge (Table 5).

Table 5. The most mentioned learning gains related to stakeholder interaction.

Learning gains	N	%
Learned to ask the right (number of) questions	6	18%
Understanding the root problem and the challenge	5	15%
Gained specific knowledge about the subject matter	4	12%
Gained interdisciplinary knowledge	4	12%
Networking with professionals	4	12%

Students were given little structure. For example, as to what the solution should be, they were told that it was quite possible that the outcome would not be a product or solution but only a refined problem statement. This was not something to which students were accustomed. Therefore, while it did take more time than expected, it is a crucial step when teaching students how to become learners. Students saw the added value afterwards, but during the first weeks, it was a challenge to stop them from rushing towards a solution, as they had in the past. Table 6 shows how this approach to teaching contributed to the students' learning process.

Table 6. Learning experiences related to the lack of a fixed outcome.

Learning experience	N	%
Better understanding of the root of the problem	8	24%
Taking responsibility for our choices	6	17%
Gained understanding of the learning process itself	5	14%
Became more focused	3	9%
Became more organised	3	9%
Highly motivated	3	9%
Learned how to prioritise	3	9%
Opportunity for better relationships with stakeholders	1	3%
Too difficult if you have no project experience	1	3%
Does not work when the stakeholder has a fixed idea about the outcome	1	3%

Authentic learning

Authentic learning is most beneficial if it fully reflects the real world [17]. Part of the real world is learning how to deal both with and from failure. The literature shows that students who do not get the expected result become more determined to succeed the next time [18,19]. Table 7 shows that 22% of the students indicated that they did not experience any failure. Although the students were educated about CBL in general and about how learning occurs within CBL, it seems that there was still some unclarity as to what failure exactly entails.

Table 7. Percentages of students that experienced failure as part of the learning process.

Failure/no failure	N	%	Comments
Failure	18	78%	'We had to take a step back to rethink our design process'.
			'We had to really understand that our solution did not have to be perfect but rather meaningful'.
			'We took more responsibility'.
			'We experienced our boundaries'.
			'Helped to get more clear vision of the challenge'.
			'Failure made us grow with more ideas'.
			'Helped us understand our limits and errors'.
			'After failure, we really understood the mistakes we made'.
No failure	5	22%	'Feels more like we learned a lot'.
			'Can't comment on this'.

Materials and Resources

Giving students more ownership of their learning will have the greatest effect when they are able to oversee all aspects of the learning process. Providing them with the learning outcomes followed by having them think about ways in which they can demonstrate that they have achieved those learning outcomes will lead them to consider what knowledge and skills are required to achieve those outcomes successfully. In turn, this will lead to them thinking about the materials and resources needed to gain this knowledge.

Table 8. The curriculum design component Learning activities, aims and objectives interpreted to CBL-related activities and objectives used in the Autumn Challenge

Materials and resources	
CBL Features [13–16]	**Autumn Challenge design**
• Open data and information • Materials and resources from other parties can be used • Learning outside the classroom • The real world is the learning environment	• Encouraged the use of open data • Encouraged students to search for relevant learning materials themselves (literature, textbooks, data) • Encouraged students to think about what knowledge and skills they needed to work successfully on the challenge • Provided a network of content specialists and encouraged the students to contact and share their own network • Helped students share their own disciplinary knowledge and skills with the rest of the group

This worked well for some student teams. For example, one group asked for a workshop on how to write scenarios, and another group asked for project management training. The scenario writing workshop was organised by the problem provider. However, the question is whether we can provide students with the necessary facilities on an *ad hoc* basis. Another challenge we encountered was getting students to explore open data and other resources due to the combination of having an international group of students and using local companies as problem providers. Most of the data and materials were only available in Dutch.

Summary

The engineers of the future will play a pivotal role in working towards solutions to the challenges that industry and society face. To prepare students well for their future responsibilities, engineering education will have to reorganise their curriculum in such a way that students are still equipped with a solid knowledge base while at the same time focussing increasingly on developing transferable skills to aptly tackle these challenges. As in the current curriculum, the educator plays an important role in the amended curriculum. CBL provides a learning environment in which teachers do not 'just' provide the content knowledge; students are guided (by the coach, whether or not the teacher) towards thinking for themselves about what knowledge they need and why. This capability will lead to students not only learning during their time at university but also teaching them how to educate themselves, thus laying the foundation for them to become lifelong learners.

Coaching for learning

Imagine a plane crashing down in the Amazon rainforest. A multicultural group of people, all with their own prior unique knowledge and skills sets, survive the crash, and now have to find their way out of the unknown jungle. It seems there are no roads, no lights, no signs of civilisation. The first step they must take is to find out what every person can contribute to the team. One team member knows which berries edible and which ones are poisonous, another team member is very good at scouting and mapping the area, yet another team member is very good at making fires. However, due to the group's small size, they do not have all the skills and knowledge necessary to survive and get out of the jungle. What would such a team, in such an open, free and lawless environment, need to survive, find their way, and redo it if they ever get into a situation like this again? The answer to this question is two-fold: the group needs to work together well, and the members of the group need to acquire the skills and knowledge they lack to survive in the wild and pave their road to civilisation. If this group manages to get out of the jungle on their own without the help of a guide who tells them which way to go and what to eat, but rather a guide who keeps them on their toes and asks them to think carefully and make strategic choices. Then this group not only survived the jungle, but they learned how to look for new knowledge and new solutions in an unknown, complex situation based on existing skills and knowledge.

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APPENDIX A

Learning goals

Learning goals
The most important learning experience for a student in this programme, is the ability to work on solving a complex societal problem in a multicultural and multidisciplinary environment. In order to be able to achieve this main learning objective, six other learning goals are defined on the basis of which this course is designed:

After finishing this programme, the student
1. discusses the UN Sustainable Development Goals (SDGs) and can place them into real life context, connecting their education and knowledge to real life local situations and challenges stemming from the locations of the participating universities (knowledge and comprehension);
2. is able to analyse and critically assess societal challenges in the framework of the UN SDG 11, "Mak[ing] cities and human settlements inclusive, safe, resilient and sustainable" (analysis);
3. can co-design and conceptualise solutions for [given] societal challenges (synthesis);
4. can present these solutions in a suitable format, taking into account their skillset, innovation and the various stakeholders dynamics (societal leadership);
5. has acquired knowledge of different disciplines around the main thematic;
6. has developed intercultural competences through communicating and functioning effectively in a multicultural team

APPENDIX B
Assessement rubric

Criteria	Pass			Fail	Assessment	Feedback (motivation for the given assessment score)
	Excellent	**Good**	**Satisfactory**			
Interdisciplinary collaboration	Reflects on every important aspect of how differences in disciplines affected (positively and/or negatively) the team collaboration. Provides many specific examples on how the team dealt with them.	Reflects on the most important aspects of how differences in disciplines affected (positively and/or negatively) the team collaboration. Provides some specific examples on how the team dealt with them.	Reflects on some aspects of how differences in disciplines affected (positively and/or negatively) the team collaboration. Provides a few not very specific examples on how the team dealt with them.	*Absent or very limited reflection on how differences in disciplines affected (positively and/or negatively) the team collaboration (No examples how the team dealt with them are provided)*		
Multicultural collaboration	Reflects on every important aspect of how multicultural differences affected (positively and/or negatively) the team collaboration. Provides all the necessary examples on how the team dealt with them.	Reflects on the most important aspects of how multicultural differences affected (positively and/or negatively) the team collaboration. Provides some examples on how the team dealt with them.	Reflects on some aspects of how multicultural differences affected (positively and/or negatively) the team collaboration. Provides a few examples how the team dealt with them.	*Absent or very limited reflection on how multicultural differences affected (positively and/or negatively) the team collaboration.*		
Team Decision Making	Reflects extensively on the team decision-making process (how, as a team, they applied each team members competences in the work). No additional explanation is needed to understand team decision-making process.	Reflects not extensively on the team decision-making process (how, as a team, they applied each team members competences in the work). Some additional explanation would be needed to understand team decision-making process.	Reflects loosely on the team decision-making process (how, as a team, they applied each team members competences in the work). Substantial additional explanation is needed to understand team decision-making process.	*Absent or very limited reflection on the team decision-making process.*		
Communication and contribution	Reflects extensively on the effective exchange of ideas among team members. It helps to understand the full extent of	Reflects not extensively on the effective exchange of ideas among team members. It helps to understand to some extent	Reflects loosely on the effective exchange of ideas among team members. It helps to sufficiently understand	*Absent or very limited reflection on the exchange of ideas among team members.*		

	their communication.	their communication.	their communication.			
	Reflects on a workload distribution that was extensively based on the disciplinary and cultural background of the various team members.	Reflects on a workload distribution that was not extensively based on the disciplinary and cultural background of the various team members.	Reflects on a workload distribution that was loosely based on the disciplinary and cultural background of the various team members.	The workload distribution was not based at all on the disciplinary and cultural background of the various team members.		
Interpersonal relationships	Reflects on every important aspect of the interpersonal team engagement. Provides all the necessary examples of positive situations (e.g., everybody feels respectful) and/or conflicts that were resolved (e.g. a compromise between opposing views).	Reflects on the most important aspects of the interpersonal team engagement. Provides some examples of positive situations (e.g., everybody feels respectful) and/or conflicts that were resolved (e.g. a compromise between opposing views).	Reflects on some important aspects of the interpersonal team engagement. Provides a few examples of positive situations (e.g., everybody feels respectful) and/or conflicts that were resolved (e.g. a compromise between opposing views).	*Absent or very limited reflection on the interpersonal team engagement. Only negative examples (e.g., competitive and individual atmosphere) are provided and/or conflicts has been left unresolved.*		
	Reflects extensively on how individual strengths and weaknesses of the team members affected team collaboration.	Reflects not extensively on how individual strengths and weaknesses of the team members affected team collaboration.	Reflects loosely on how individual strengths and weaknesses of the team members affected team collaboration.	*Absent or very limited reflection on how individual strengths and weaknesses of the team members affected team collaboration.*		
Report length	The report length is within the given word count (1250-1500 words, excluding references)	The report length slightly violates the given word count (by <150 words, excluding references)	The report length violates the given word counts (by >150 but <300 words, excluding references)	The report length is largely outside the given word count (by >300 words, excluding references)		