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THE EMERALD HANDBOOK OF CHALLENGE BASED LEARNING

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Chapter 2

Challenge-Based Learning in Engineering Education: Toward Mapping the Landscape and Guiding Educational Practice

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Abstract

Challenge-based learning (CBL) is a trending educational concept in engineering education. The literature suggests that there is a growing variety in CBL implementations, stemming from the flexible and abstract definition of CBL that is shaped by teachers' perceptions. The chapter discusses how the CBL concept has been developed at Eindhoven University of Technology and describes the development and use of two educational resources aimed to facilitate conceptualization, design, and research of CBL for curriculum designers and teachers. The first resource is a set of CBL design principles for framing the variety of CBL and providing teachers with advice about how to develop CBL courses within an overall CBL curriculum. The second resource is a curriculum-mapping instrument called the CBL compass, which aims at mapping CBL initiatives and identifying gaps, overlaps, and misalignments in CBL implementation at a curriculum level. Both CBL design principles and the CBL compass have been developed by combining insights from theory and practical examples of CBL at TU/e into a higher order model of vision, teaching and learning, and support. We discuss the two educational instruments and showcase their application in the Eindhoven Engineering Education (E^3) program, and we discuss preliminary findings and insights. The chapter concludes with recommendations for future practice and research.

Keywords: Design principles; CBL compass; curriculum design; Eindhoven University of Technology; conceptual framework; research-informed educational innovation

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Introduction

Current societal problems ask for a new type of engineers who can work both within and outside the boundaries of their own discipline and consider environmental and social factors when approaching contemporary challenges (Barut, Yildirim, & Kilic, 2006; Kohn-Rådberg, Lundqvist, Malmqvist, & Svensson, 2020). In response, many universities of technology are shifting toward challenge-based learning (CBL) as a concept for educating engineers of the future and strengthening on-campus education (Gallagher & Savage, 2020; Malmqvist, Rådberg, & Lundqvist, 2015).

Empirical work on CBL is focusing on describing single learning environments or comparing small-scale CBL interventions with traditional teaching and learning approaches (Gallagher & Savage, 2020; Malmqvist, Rådberg, & Lundqvist, 2015; O'Mahony et al., 2012). While these case studies can be helpful, their implementation is context-related and not easily generalizable across different learning environments or disciplines. To achieve the desired outcomes of CBL, education needs well-designed and consistent learning environments. Curriculum and course developers need an understanding of the typical conditions that facilitate students' learning in a CBL environment (Doulougeri, Vermunt, Bombaerts, & Bots, Manuscript submitted for publication, Eindhoven University of Technology). Thus, at a pedagogical level, there is a need for a framework to visualize CBL implementations and principles to design CBL experiences.

This chapter discusses the efforts of Eindhoven University of Technology (TU/e) toward a curriculum-wide adoption and implementation of CBL (Rijk, 2019). This process toward CBL is spiral, starting from an educational vision, which inspires educational experiments, whose findings inform theory and research, which in their turn inform educational practice.

The objective of the chapter is twofold: firstly, we synthesize insights from theory and practice into a conceptual framework of CBL that includes three levels: vision, teaching and learning, and support (Van den Akker, 2003; Van den Beemt et al., 2020). This framework facilitates thinking about CBL and provides the conceptual basis for designing new experiments in a CBL curriculum via a set of design principles. The framework also facilitates mapping of CBL characteristics in current CBL experiments via the use of an instrument labeled *CBL compass* (Van den Beemt, Van de Watering, & Bots, 2021). Secondly, we provide an overview of the developed design principles and CBL compass, and we showcase their use in the context of Eindhoven Engineering Education (E^3). The E^3 program consists of two challenges for first year students, aimed at reimagining engineering education by adopting CBL.

Background

CBL in our perception is an educational concept, rather than a teaching method (see also Johnson, Smith, Smythe, & Varon, 2009). Educational concepts can be defined as views on what is worth learning and how students should acquire that learning (Thomas, 2001). Educational concepts underscore a complex set of educational practices that ask for a specific organization. These practices include vision and support, but above all, teaching methods, which in turn can be defined as the principles and activities used by teachers to enable student learning.

CBL as an educational concept allows for flexibility in and experimenting with effective teaching and learning activities, rather than predefining them. The aim of these experiments is to translate the concept CBL into practice, thus helping curriculum designers and teachers in developing their courses and teaching, and in formulating support requirements. Also, because it builds on for instance approaches such as Problem-based learning (PBL), Project-based learning (PjBL), and Conceiving-Designing-Implementing-Operating (CDIO) (Kohn-Rådberg et al., 2020), CBL can be considered an educational evolution, rather than a revolution.

Currently, over 40 CBL experiments are being conducted at TU/e, at both Bachelor and Masters' level, in various departments (e.g., Applied Physics, Industrial Design) and in inter- and transdisciplinary institutes (e.g., Innovation Space; Reymen et al., 2022) and programs (e.g., USE learning lines; Martin, Herzog, Papageorgiou, & Bombaerts, 2022). These experiments show a variety of CBL characteristics and implementations, ranging from small-scale assignments to curriculum-wide initiatives consisting of open-ended, complex challenges, presented by stakeholders and focusing on self-directed learning and interdisciplinary skills. In those CBL experiments, teachers tailor CBL according to different contexts and subject areas, using their own perceptions and operationalization of CBL, which leads to a variety in implementation.

In this chapter we present E^3 as an illustrative example of CBL for TU/e. The basic premise of E^3 would be to reimagine engineering education by adopting CBL as an educational concept at a curriculum level. The E^3 program was developed by staff members building on their experience with project-based and design-based learning. It followed a bottom-up approach and aimed to create a new educational experience for engineering students.

The development of CBL at our university is based on a program that combines implementation of bottom-up educational initiatives with research: in an evidence-informed setup, the effects of teacher-led CBL experiments on student learning behavior and learning outcomes are carefully studied. These studies aim to answer questions about principles of CBL (vision), learning behavior, learning outcomes, and didactical/pedagogical aspects of CBL, such as coaching and self-directed learning, assessment, pedagogies, design of challenges (teaching and learning), and facilitating structures (support). The findings of this research program thus guide the design of CBL. Existing literature shows that CBL most often is perceived as an added pedagogical approach to existing structures (Gallagher & Savage, 2020). In contrast, our university aims at CBL as embedded curriculum practice. This large-scale curriculum approach, in combination with research, intends to contribute to increasing the current limited body of evidence for mechanisms that cause CBL interventions to be effective.

Development of a Conceptual Framework for CBL

CBL has been mostly developed in engineering education from the ground up (Membrillo-Hernández et al., 2019). Such a practice-driven approach could easily confirm existing practices, rather than offering a good basis to develop new ideas. Yet, a theory-driven approach, which aims to implement existing ideas in a new context may lack sensitivity and flexibility and might stumble in translating theoretical ideas to practical implementations (Plomp & Nieveen, 2013). As Fig. 2.1 shows, both top-down and bottom-up processes are important for the development of sound research-informed educational innovations.

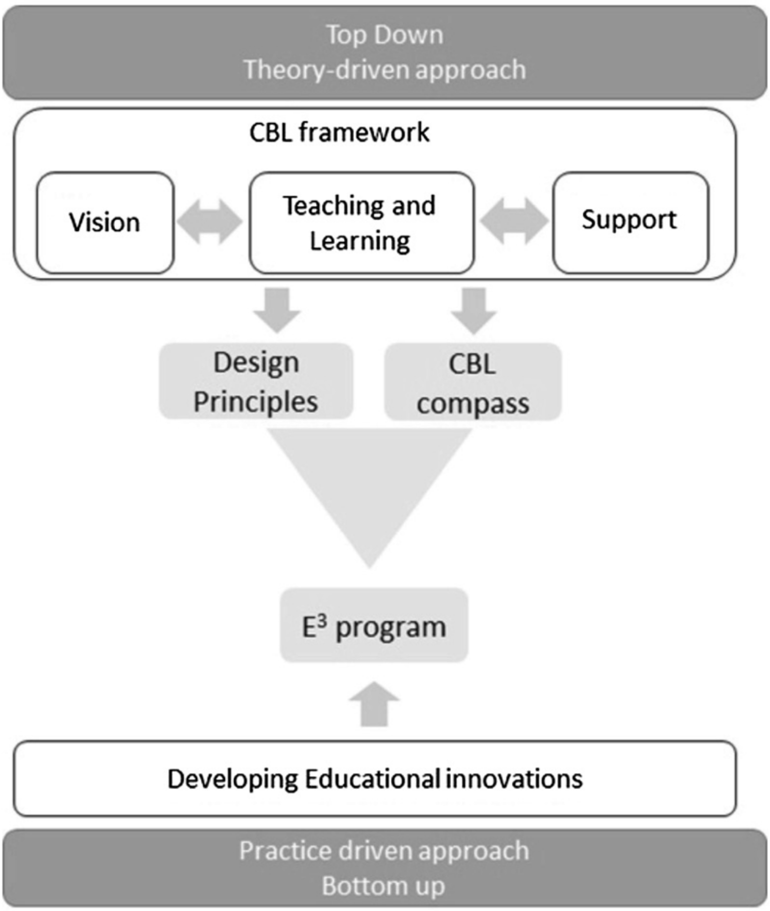

Fig. 2.1. Top-Down and Bottom-Up Approaches for the Development of Educational Instruments and Educational Innovations That Complement Each Other.

To guide the bottom-up design and analysis of CBL educational innovations, we propose a high-level conceptual framework, which builds on a basic why-how-what approach (Sinek, 2009) and that supports thinking about educational strategies from the ground-up. The high-level concepts allow to identify educational processes at the three levels of vision, teaching and learning, and support (Van den Akker, 2003; see also; Van den Beemt et al., 2020).

The conceptual framework aims to guide both teachers and curriculum developers in the CBL design, for example, in selecting efficient teaching and learning methods, tasks, and activity types. This includes the vision behind the educational innovation (why), ways of teaching and learning (how), of teaching and learning contents (what), particularly in the context of engineering subjects, cross-curricular key competences for lifelong learning, and ICT-enhanced teaching. We discuss the three concepts and their most relevant dimensions as found in the literature, and in experiments and research initiatives at our own institution. The three concepts, vision, teaching and learning, and support, provide the basis for the development of both CBL design principles and an instrument to visualize variety in CBL, labeled *CBL compass* (Van den Beemt et al., 2021). The higher-order framework, CBL design principles, and CBL compass are the result of efforts consisting of a literature review, discussions with experts and thought leaders at our own University and preliminary studies with teachers and students on their experience with CBL, their perceptions of teaching, learning, and assessment, and collaborative work among educational researchers and teachers.

Guiding Educational Practice: CBL Design Principles

CBL design principles aim to help teachers in (re)designing and aligning their courses within a CBL curriculum. By taking into consideration student characteristics and course objectives, we provide recommendations about how to develop powerful learning experiences for students. The design principles allow teachers to flexibly adapt them to specific course or curriculum contexts.

CBL design principles have been developed using a deductive approach, starting from theory and followed by a systematic review of the literature on CBL in engineering education (Doulougeri et al., Manuscript submitted for publication, Eindhoven University of Technology). In our systematic review, the CBL implementation at course level, as well as the outcomes and lessons learned reported by 40 empirical studies were analyzed. Furthermore, we used the higher-order conceptual framework (Van den Beemt et al., 2020), to develop design principles of CBL at the levels of vision, teaching and learning, and support. After developing the initial set of design principles, consultations with practitioners, and practical insights from earlier research conducted at TU/e (such as CBL pilot studies), it resulted in a final set of design principles discussed in this chapter. The development of design principles builds upon a systematic review of CBL implementation in engineering education conducted by the authors of the chapter. This set of design principles was developed and further reviewed by educational experts, researchers, and practitioners in the field of engineering education.

Mapping the Landscape: CBL Compass

The CBL compass supports teachers to identify which CBL indicators are currently addressed in their courses. It helps to make well-considered choices about the extent to which other CBL indicators should be addressed, considering learning goals and intended target group. The CBL compass also allows curriculum designers to map CBL experiments at a curriculum level, creating an overview of how CBL is operationalized and implemented in different experiments. When taking all CBL experiments together, the compass instrument helps curriculum designers to define the local color of CBL at faculty or institution level. The complete CBL compass consists of 12 dimensions, each counting multiple indicators. To distinguish CBL from other educational concepts, this description does not include general engineering learning activities such as modeling, arguing, and explaining, nor does it include domain-specific practices. Instead, this description focuses on core elements such as challenge characteristics, teaching and learning elements, and support for teachers.

All dimensions and indicators can be viewed from both the perspective of curriculum, and the perspective of individual study components. The (intended or observed) presence of individual indicators in experiments can be set on a four-point scale representing the extent of their presence. The approach of measuring the level of implementation implies a variety of CBL within a curriculum.

The CBL compass sets a minimum requirement needed for study components to be called “CBL”. This minimum requirement includes the smallest number of “must have” indicators and the smallest score on certain indicators, before we can speak of CBL as an educational concept. The CBL compass starts from three must-have indicators for CBL: a) the challenge is real-life and authentic, b) the learning activities in the challenge create a rigorous treatment of fundamental engineering knowledge and skills, and c) the challenge stimulates a combination of deep understanding and broader view of engineering. All three should have minimum score of three to fulfill the minimum requirement. Moreover, the situation might occur that other indicators are only implemented with low scores, and yet the course or curriculum is still characterized as CBL.

The rest of this section is structured in the following manner: first we discuss CBL in terms of vision, teaching and learning, and support, using existing literature. At the end of every section, we present a table with the developed CBL design principles and CBL compass indicators.

Design Principles and Compass Indicators

Vision of CBL

Vision addresses the question: *why students learn?* The overall aim of CBL is to educate engineering students in a context-rich environment about how to define and address the problem and to learn what it takes to work toward a solution, rather than to solve the problem itself (Membrillo-Hernández & García-García, 2020). Below we discuss the key aspects of vision for teachers to consider when (re)designing their courses, including challenge characteristics such as real-life, authenticity and open-endedness, the impact of challenges, and external stakeholders' involvement. Table 2.1 shows an overview of design principles and CBL compass at the vision level.

Table 2.1. Overview of Design Principles and CBL Compass Indicators at the Level of CBL Vision.

Dimensions	**Design Principles**	**Compass indicators**
1. Real-life, open-ended challenges	Put central in CBL a real-life challenge that needs an interdisciplinary perspective and requires the development of a concrete solution that students need to produce as the starting point of CBL. The challenge needs to present a certain level of ambiguity and avoid a predefined solution.	(1) The extent to which challenges are real-life and authentic (scale: theoretical/abstract to real-life) (2) The extent to which challenges are open-ended (scale: pre-defined to open-ended) (3) The extent to which challenges are complex (scale: one-dimensional to complex) (4) The extent to which challenges are interdisciplinary (scale: mono-, multi-, interdisciplinary)
2. Global themes	Connect the challenge to an outcome such as transforming a business or creating an impact at a local or global scale.	(1) The extent to which challenges focus on transforming business-as-usual practices and raising awareness and trust among actors (scale: no focus to full focus) (2) The extent to which challenges focus on short-term societal impact or long-term societal impact (scale: no focus to full focus)

Table 2.1. *(Continued)*

Dimensions	Design Principles	Compass indicators
3. Involvement of stakeholders	Develop a challenge with the collaboration of external stakeholders from academic or local communities (stakeholders as cocreators of the challenge). The addition of stakeholders will make the project more real-life, and it will increase the uncertainty of solving the challenge for the students.	(1) The extent to which challenges have a challenge owner from 1) academia, or from 2) industry, government, or culture (scale: internal to external) (2) The extent to which challenges require collaboration with external stakeholders (scale: no collaboration to full collaboration)

Real-Life and Open-Ended Challenges

CBL triggers student learning by engaging them in relevant, real-life, authentic, open-ended challenges. These challenges can be mono-, multi-, and interdisciplinary, originating from various sources (problems/challenges trigger learning) (Malmqvist et al., 2015). Challenges are authentic because they resemble or are derived from activities of real-world professionals (see also Baloian, Hoeksema, Hoppe, & Milrad, 2006). Open-ended assignments are common in engineering education because engineering design is open-ended with respect to both the solution and the process (Lammi, Denson, & Asunda, 2018); however, examples are also found in medicine (Brauner, Carey, Henriksson, Sunnerhagen, & Ehrenborg, 2007), literature (Coby, 2016, p. 1), and language studies (Egbert, Herman, & Lee, 2015). Open-ended challenges allow students to discover both a problem and a solution, allowing varying solution paths (Brophy, Klein, Portsmore, & Rogers, 2008).

The challenge should derive from practice and stakeholders' questions and urge students to acquire new knowledge or apply knowledge of their own and other disciplines for the development of a concrete solution (Kohn-Rådberg et al., 2020). When starting from an open challenge without a predefined solution, students are given the opportunity to define their own specific questions, decide which knowledge is relevant for answering this question and developing a solution. Content in CBL is partially open and allows for students' autonomy to focus on a specific aspect of the challenge, pursuing their own interests within a broader topic. Teachers should set some boundaries as to what is possible. Within those boundaries, students should feel free to focus on what they are interested in. The outcome of students' work should be the development of a solution or the suggestion of a solution for the given challenge depending on the time constraints and the educational level of students.

Focus on Global Themes

Thematic content areas addressed in CBL are predominantly rooted in themes of global importance, such as sustainability (Gallagher & Savage, 2020). In that respect, CBL is value-driven, with a focus on transformative value and integrative value (Larsson & Holmberg, 2018; see also; Kohn-Rådberg et al., 2020). Transformative value is perceived as outcomes that challenge business-as-usual practices understood as unsustainable. Integrative value can be described as awareness raised and trust built when a diverse group of actors, disciplines, and perspectives are brought together in dialogue to explore a common issue. Both types of value can have either a short-term or long-term societal impact, of which students need to be aware (Larsson & Holmberg, 2018). Students learn via working on challenges that require a real solution that should bring benefit at an individual, community, or society level.

Involvement of Stakeholders

CBL engages students by involving stakeholders from science, industry, or the societal context (Kohn-Rådberg et al., 2020). A distinction can be made between 1) university-developed challenges, reflecting little collaboration with external stakeholders, and 2) challenges brought and actively supported by stakeholders (Membrillo-Hernández et al., 2019).

Depending on the level of implementation (course or curriculum level), it is important that the relevant parties are included in the decision. For example, at a course level, it is important when a teacher decides on the rationale of a CBL course to consult with stakeholders who are going to be part of it. Similarly, at a curriculum level, the university ecosystem including companies and societal actors should also be included to reach a coherent rationale. The involvement of stakeholders as challenge owners can make the challenge more realistic and increase the engagement of students (Rodríguez-Chueca, Molina-García, García-Aranda, Pérez, & Rodríguez, 2020). In addition, having an industry partner and external stakeholder as challenge owners can be related to increase perceived complexity and uncertainty of the challenge. (e.g., Félix-Herrán, Rendon-Nava, & Nieto Jalil, 2019; Gonzalez-Hernandez, Cantu-Gonzalez, Mora-Salinas, & Reyes-Avendaño, 2020; Martínez & Crusat, 2017). Having an industrial partner in CBL is important to increase the complexity of the challenge and the levels of uncertainty and expose students to real-life problems that need to be solved (Membrillo-Hernández et al., 2019). The stakeholders will evaluate at the end whether the suggested or developed solution is answering the initial challenge (see also "assessment" below).

CBL Teaching and Learning

This level of the conceptual framework answers the question: *How do students learn?* Below we discuss important goals of CBL as identified in literature and research at our own institution. Learning goals need to be defined at various levels (individual, group, stakeholders) and in relation to expected learning outcomes.

The central question for course designers and teachers includes: "what knowledge, skills and attitudes should engineering students have developed at completing a CBL course?" The existing literature suggests CBL to be a chosen approach to enhance students' problem-solving and disciplinary and interdisciplinary knowledge acquisition and application as well as the development of transversal attitudes and skills. It is important that learning activities are aligned with decided learning objectives. Table 2.2 gives an overview of design principles and CBL compass at the level of teaching and learning.

Table 2.2. Overview of Design Principles and CBL Compass Indicators at the Level of Teaching and Learning.

Dimensions	Design principles	CBL compass indicators
4. T-shaped Engineers	Define as precisely as possible learning goals, both easy and difficult to measure including knowledge acquisition and application, transversal skills, (social) attitudes.	(1) The extent to which learning activities create a rigorous treatment of fundamental engineering knowledge and skills (scale: not implemented to fully implemented) (2) The extent to which challenges stimulate the combination of deep understanding and broader view (scale: not implemented to fully implemented) (3) The extent to which learning activities enable critical thinking (including validating statements) (scale: not implemented to fully implemented) (4) The extent to which learning activities enable creative thinking (scale: not implemented to fully implemented) (5) The extent to which learning activities allow problem formulating and designing (scale: not implemented to fully implemented)

Table 2.2. *(Continued)*

Dimensions	Design principles	CBL compass indicators
	Challenges should define the content to be learned by the student. Develop learning material that is suitable to the cognitive level of students and is content specific for the challenge.	(6) The extent to which materials and learning activities support contextualized acquisition and application of knowledge and skills (scale: not implemented to fully implemented)
5. Self-directed Learning	Develop learning activities that promote self-directed learning.	(1) The extent to which materials and learning activities support contextualized acquisition and application of knowledge and skills (2) The extent to which learning activities support the development of metacognitive skills and self-regulatory abilities (learning to learn) (scale: not implemented to fully implemented) (3) The extent to which learning activities encourage ownership and Self-directed learning (scale: not implemented to fully implemented) (4) The extent to which learning activities enable dealing with uncertainty (scale: not implemented to fully implemented)

Table 2.2. *(Continued)*

Dimensions	Design principles	CBL compass indicators
6. Collaborative Learning	Develop learning activities that foster collaborative learning.	(1) The extent to which challenges enable cycles of divergent and convergent reasoning (scale: not implemented to fully implemented) (2) The extent to which learning activities enable peer learning (scale: not implemented to fully implemented)
7. Interdisciplinarity	Develop learning activities that require interdisciplinary perspectives. Define whether and how students can solve a challenge using a multidisciplinary approach.	(1) The extent to which challenges require interdisciplinary teamwork (scale: not implemented to fully implemented) (2) The extent to which challenges support combinations of individual and teamwork (scale: not implemented to fully implemented) (3) The extent to which learning activities support development of interdisciplinary professional skills (teamwork, project management, etc.) (scale: not implemented to fully implemented)
8. Teaching	Teachers should act as coaches and strive for balance between openness and scaffolding.	(1) The extent to which coaching supports scaffolding of students' learning (scale: not implemented to fully implemented) (2) The extent to which teachers find a balance between openness and scaffolding (scale: not implemented to fully implemented)

Table 2.2. *(Continued)*

Dimensions	Design principles	CBL compass indicators
	Teachers should act as cocreators of the challenge solution.	(3) The extent to which teachers can act as coaches and colearners and cocreators (scale: not implemented to fully implemented)
9. Assessment	Develop assessment methods that assess both individual and group learning	(1) The extent to which assessment is balanced between focus on individual learning and on team learning (scale: not implemented to fully implemented)
	Develop assessment methods that assess both process and product.	(2) The extent to which assessment is balanced between focus on product and on process (scale: not implemented to fully implemented)
	Develop formative and summative assessment methods.	(3) The extent to which assessment is balanced between focus on (in) formative and summative assessment (scale: not implemented to fully implemented)
10. Use of Learning Technology	Make use of the learning technologies to foster teaching and learning.	(1) The extent to which learning activities imply innovative use of educational technologies (scale: not implemented to fully implemented) (2) The extent to which learning analytics are used to improve teaching and learning (scale: not implemented to fully implemented)

Learning Goal: Development of T-Shaped Professionals

Engineering education has long emphasized metacognitive abilities such as systems thinking, and T-shape competencies, in which an in-depth disciplinary expertise is coupled with the ability to work with a broad range of people and situations (Gero, 2014; Van den Beemt et al., 2020). CBL challenges teachers to present learning activities that contribute to an in-depth disciplinary expertise, by creating a rigorous treatment of engineering fundamentals (Kohn-Rådberg et al., 2020). Furthermore, innovation and creativity are considered important aspects in many CBL cases (Gallagher & Savage, 2020). This can be operationalized in critical thinking (see also Crawley, 2001; Rieckmann, 2012) and creative thinking (Bocconi, Kampylis, & Punie, 2012). Finally, CBL is characterized by a combination of problem formulating and designing, which implies working in an iterative cyclical way, involving both analysis and synthesis (Malmqvist et al., 2015). For the development of CBL design principles and CBL compass, we consider critical thinking, creativity, analysis, and synthesis as important learning goals in the development of T-shaped engineers.

Learning Goal: Self-Directed Learning

CBL creates a learning urgency, by encouraging students to both acquire and apply knowledge and skills that are needed to work on a specific challenge, which makes their learning contextualized (e.g., Edson, 2017). The CBL case should enhance student participation in conceiving and defining their own pathway in learning, also known as "learning trajectories" (Pepin & Kock, 2019). The involvement of students in the creation of knowledge, both individually and in groups, is considered an essential characteristic of CBL. Learning activities should encourage students take the initiative for their own learning, diagnose their learning needs, formulate goals they want to pursue within the course, identify resources, implement appropriate activities, and evaluate the outcome of their work (Doulougeri, Vermunt, Bombaerts, Bots, & de Lange, 2021). CBL fosters deep learning by supporting the development of metacognitive skills (cf. Novak, 2002). CBL is also active learning that allows students to construct a network of knowledge and take ownership (agency) of their own learning process (self-directed learning), including the freedom to choose within a broader challenge the specific problem they want to focus on (Hernández-de-Menéndez, Vallejo Guevara, Tudón Martínez, Hernández Alcántara, & Morales-Menendez, 2019). Active learning is perceived as an approach that creates student engagement with learning materials through interactions such as reading, watching, listening, writing, analyzing, experimenting, and thinking (Kalinga & Tenhunen, 2018; Nascimento, Santos, Sales, & Chanin, 2019). Agency and self-directed learning also include an entrepreneurial mindset, which finds ways to deal with uncertainty (Maya, Garcia, Britton, & Acuña, 2017) and open-endedness.

Learning Goal: Collaborative Learning

Working as a group is preparing engineers for their future career. The opportunity to collaborate is an important element of CBL. Consequently, tasks need to be designed and addressed to the group rather than the individual, and appropriate means of communication need to be established. Depending on the specific objectives of the course, the team can be comprised by students of the same or different disciplines. The group size should be large enough for students to be exposed in different perspectives and assume different tasks and roles.

CBL means working in an iterative cyclical way in teams (Baloian et al., 2006; Jensen, Utriainen, & Steinert, 2018). These cycles consist of divergent and convergent reasoning bringing students closer to possible solutions to the challenge. Divergent reasoning includes a variety of perspectives and solutions, while convergent reasoning brings focus and priority to this variety. Ideally these cycles are discussed and evaluated in groups, which in turn enables room for peer feedback and support.

Learning Goal: Interdisciplinary Learning

Interdisciplinarity requires some level of integration between fields of expertise (Huutoniemi, Klein, Bruun, & Hukkinen, 2010; Klein, 2010). Individuals in interdisciplinary teams learn from others' perspectives and produce work in an integrative process that would not have been possible in a monodisciplinary setting (McNair, Newswander, Boden, & Borrego, 2011). The result, at least in theory, is that participants emerge from such interactions speaking "one language" (Van den Beemt et al., 2020).

Regarding student teams, teams can be mono-, ulti-, or interdisciplinary depending on the design of the course. In the CBL studies that used interdisciplinarity as a design principle, the designers considered such a competence important and relevant for future engineers (Maya et al., 2017). Interdisciplinary CBL facilitates students from different (sub-) disciplines to learn to work in a team. Their interdisciplinary interactions can be seen as attempts to integrate heterogeneous knowledge bases and knowledge-making practices (Krohn, 2010). Working in an interdisciplinary group can encourage students to explore the task from different perspectives, considering various points of view and help them collaboratively effectively with people from divergent backgrounds (Van den Beemt & MacLeod, 2021).

Learning Activities

Learning activities play an important role in CBL. Authentic learning activities are tasks given to students in the real world where they can apply what they learned in class and continue to learn more in a setting that is relevant to them. To enable these activities, students need to be offered ill-defined tasks with real-world relevance, and which present a complex task to be completed over a sustained period (Herrington, Reeves, & Oliver, 2014). By providing students with tasks that are ill-defined, students need to direct their own learning, and move from a broad challenge to the definition of a concrete problem for which they would like to develop a solution. Students can find it challenging to go from a topic to a specific one, and learning activities should stimulate them to examine their current knowledge, identify gaps in it, and search for resources. In accordance with the learning goals described above, learning activities should aim to foster knowledge acquisition, knowledge transfer and application, and self-directed, interdisciplinary, and collaborative learning.

Teaching

CBL involves adaptive teacher and expert guidance of construction of knowledge by students. Students need scaffolding toward content (also known as clear signposting) and toward active learning (Binder, Nichols, Reinehr, & Malucelli, 2017; Johnson et al., 2009; Piironen, Ikonen, Saurén, & Lankinen, 2009). Yet, given the level of open-endedness and complexity of challenges, teachers are suggested to find a balance between openness and scaffolding. It appears that this balance is easier to be found when teachers act as coaches and colearners and cocreators (cf., Balasubramanian & Wilson, 2007; Botha & Herselman, 2016).

Often in open-ended challenges, teachers do not have beforehand an idea of the possible solutions, so they also work under a certain level of uncertainty. Thus, teachers should act as colearners in the CBL process. In addition, they should be the link between stakeholders and students in terms of communication and translating stakeholders' needs to meaningful tasks that support students' learning.

Students should not be left alone in a CBL context. Even though self-directed learning is one of CBL's central characteristics, learning is best facilitated by the inclusion of coaching and scaffolding supports provided principally by the teacher but also by other involved parties, such as the stakeholders. Depending on students' educational level, teachers should set clear boundaries in the project and within those boundaries adapt the amount of support and scaffolding they provide to students.

Assessment

Case studies on educational innovations in domains including STEM show relatively infrequent attention to assessment (Richter & Paretti, 2009; Van den Beemt et al., 2020). However, generating constructive alignment between learning goals and assessment procedures raises significant challenges, especially when students from different disciplines collaborate (Borrego & Cutler, 2010; Valencia, Bruns, Reymen, & Pepin, 2020). Gallagher and Savage (2020) show how CBL research that follows a framework approach generally uses both summative and formative assessments and assessment of individual and team involvement. We perceive this as that CBL assessment can be characterized by a balance between traditionally separated forms of assessment, which fits trends toward a holistic view on assessment that combines assessment strategies (see also Van der Vleuten, Heeneman, & Schuwirth, 2017).

Because CBL evenly values the process of working toward a solution, it should stimulate forms of assessment balanced between product-focused assessment and process-focused assessment. In product-focused assessment, the deliverable represents what is learned in terms of content knowledge and understanding, and the mastery of real-world skills (Nichols, Cator, & Torres, 2016). Process-focused assessment evaluates whether the knowledge and skills have been obtained, also known as assessment for learning, which includes feedback loops and metacognition (William, 2011). The balance between these two stands for the extent to which intended learning behavior becomes visible in both product and process (Magnell & Högfeldt, 2015), known as "assessment as learning" (Van der Vleuten, Sluijsmans, & Joosten-ten Brinke, 2017). Focusing on the balance between forms of assessment allows for research on efficacy of CBL aspects such as team progress, interdisciplinarity, and advanced knowledge and skills, which can be evaluated during regular checkpoints with teams, individuals, and indeed external stakeholders (Nichols et al., 2016).

Use of Technology

Because the nature of CBL presumes extensive access to technology (Johnson, Adams, & Haywood, 2011), technology-rich learning environments lend themselves to support learning aspects of CBL such as active learning, deep learning, social learning, and learning analytics (Gallagher & Savage, 2020; Johnson et al., 2009). Especially for engineering education, learning technology plays a key role in learning processes, for example, with simulators and virtual labs, and is also often a product of this learning (Martín, Lopez-Martin, Moreno-Pulido, Meier, & Castro, 2019).

CBL Support

Resources and Space

Teachers need to be realistic about resources offered by stakeholders (e.g., time for onsite visits by the students, time for feedback) and by the university (e.g., availability of makers space) when developing a CBL course. Clear arrangement with stakeholders and the university are required in terms of time investment, intellectual property rights, and financial input. The location, where learning takes places, is an added resource that can facilitate learning in CBL. It is important that teachers adapt the challenge to possibilities offered by the university in terms of space and encourage students to pursue knowledge outside the university, for example, by visiting stakeholders' sites.

CBL involves facilitation of learning and teaching in terms of required materials, spaces such as classrooms or laboratories, and tools including ICT (Gardner, Jansujwicz, Hutchins, Cline, & Levesque, 2014; Lantada, Bayo, & Sevillano, 2014; Rashid, 2015). Especially the combination and alignment of physical and online facilities is reported as important by stakeholders (Mielikäinen, 2021). Table 2.3 shows an overview of design principles and the CBL compass at the teacher support level.

Table 2.3. Overview of CBL Design Principles and CBL Compass Indicators at the Level of Teacher Support.

Dimensions	Design principles	CBL compass indicators
11. Facilities/ Resources	Adapt the challenge according to the possibilities/ resources offered by the stakeholders and by the university. Use a learning space (physical or online) that allows students to work as a group. Encourage students to use stakeholders and university facilities for CBL.	(1) The extent to which facilities offer required materials (scale: not available to fully available) (2) The extent to which facilities offer required spaces if necessary (scale: not available to fully available) (3) The extent to which facilities offer required tools, including ICT (scale: not available to fully available)
12. Teacher support	Develop teaching team and ensure appropriate training and alignment of all teaching staff. During the course, create peer feedback sessions of more and less experienced teachers to support each other.	(1) The extent to which support structures offer course design and pedagogical support for teachers (scale: not available to fully available) (2) The extent to which support structures guide teachers in developing coaching skills, and other teaching skills required in a CBL context (scale: not available to fully available)

Teacher Support

CBL involves support for teachers and tutors, not only on the design of challenges and related learning activities but also in dealing with uncertainty and in their shift from content expert to being both expert and coach (Membrillo-Hernández & García-García, 2020). Additional training before and peer feedback during the course are considered important support for teachers to adapt in their new role.

Implementing CBL: The Case of E^3

In 2018–2019, 13 staff members of TU/e participated in the course the "Professional Leadership in Education." After 15 months of learning and working together, a new educational innovation had been conceived. The educational innovation was called Eindhoven Engineering Education or E^3. The basic premise of the program would be to reimagine engineering education by adopting CBL as an educational concept. The E^3 program was launched in November 2020. Some of the characteristics of E^3 include self-directed learning of basic engineering knowledge, deepening of knowledge through research, multidisciplinary teamwork, working on real-life challenges, application of knowledge and creativity, providing online support and offline seminars, and coaching on expertise and teamwork. In this chapter, we use E^3 as an example of a CBL course in TU/e where CBL design principles and CBL compass could be used for its redesign by bridging theory-driven insights with the practical experience gained by conducting a CBL course for the first time.

The E^3 program has been developed independently of the CBL design principles and the CBL compass. In this chapter, we present it as an example of CBL implementation in our university, and we use it to showcase the use of the two developed instruments. More specifically, we explored how the CBL compass can facilitate reflection about the implementation of CBL and identify aspects for redesign. Subsequently, we provided the E^3 course coordinators with the CBL design principles and asked them to assess whether these provide a helpful instrument for the redesign of a CBL program, such as E^3.

Table 2.4 presents an overview of the two E^3 challenges. Both challenges included only a small number of first year students from various disciplines that worked together for 11 weeks.

Table 2.4. Overview of E^3.

Characteristics	**Challenge 1**	**Challenge 2**
Students (*N*)	30 students	43 students
Level	1st year bachelor	1st year bachelor
Ects	5	10
Duration	11 weeks	11 weeks
Cases	Pulsar navigation Healthy soundscapes Wind energy storage The living cell as material	Health: DIAGAME Mobility: 5G-mobix Energy: RED
Course Content	Applied Natural Sciences	Data analytics and ethics
Real-life, open-ended challenges	Open-ended	Real-life and open-ended

Table 2.4. *(Continued)*

Characteristics	**Challenge 1**	**Challenge 2**
Global themes	No direct link	Transform business practice
Involvement of stakeholders	Academics from TU/e	Student teams from TU/e
T-shaped Engineers	Students were encouraged to set their own specific content-related and professional goals.	*(For the full list of learning objectives see Martin et al., 2022)* *Ethics* Demonstrate a basic ability to reflect on engineering in a temporal and societal context. *Data analytics* Select and apply established suitable data analysis methods for solving the defined problem using the collected data.
Learning Activities	Online modules on Applied Natural Sciences Weekly meetings with teaching assistants that provide coaching on group process Weekly meetings with stakeholders that provided coaching on content matters	*(For detailed description of learning activities see Martin et al., 2022)* Flipped classroom-online material for ethics Weekly online discussion sessions with ethics teacher Weekly meetings with teaching assistants Weekly (optional meetings) with experts Meetings with stakeholders (three times throughout the course)

Table 2.4. *(Continued)*

Characteristics	**Challenge 1**	**Challenge 2**
Self-directed Learning	Personal Learning portfolio. Students were encouraged to set their own learning objectives and reflect on their progress at two points during the course Teaching assistants provided written feedback on personal portfolio	Weekly individual reflection. Coaches provided short-written feedback on a weekly basis to students' reflections Weekly group coaching sessions, where students reflected on their individual development and learning progress
Collaborative Learning	Weekly SCRUM meeting, supported by a teaching assistant to support students on group processes Peer feedback among group members for group processes	Weekly meetings with teaching assistants. Use of Miro board for brainstorming Weekly group coaching sessions, where students reflected on their group processes
Interdisciplinarity	Not focus of the course	Weekly teaching session with three teaching assistants representing ethics, data analytics, and stakeholders' perspective on the challenge Integration of ethics and data analytics for the development of a solution
Teaching	Teachers (experts and teaching assistants) acted as coaches and strived for balance between openness and scaffolding	Teachers (experts and teaching assistants) acted as coaches and strived for balance between openness and scaffolding

Table 2.4. *(Continued)*

Characteristics	Challenge 1	Challenge 2
Assessment	*Product – group* Students had to produce a group report and final presentation presented to the challenge owners *Process – individual* Student process was assessed by Personal Learning portfolio *Process – group* Peer feedback session	*Product – group* Students had to submit a report as a group and final presentation to the stakeholders *Product – individual* Each student individually had to write a final report elaborating on one aspect of ethics and data analytics that he/she particularly focused during the project *Process – individual* Student processes were assessed by individual weekly reflections and a final individual overall reflection report.
Use of Learning Technology	Use of different platforms such as CANVAS and TEAMS to support collaboration and communication	Use of different platforms such as CANVAS, TEAMS, WONDER, and MIRO to support collaboration and communication
Facilities/ Resources	Online course due to COVID-19	Online course due to COVID-19
Teacher support	Course coordinator had frequent meetings with teaching assistants and experts to discuss any experienced problem, clarify ambiguities, and provide support	Teaching assistants attending a workshop about CBL Weekly peer feedback sessions for all teaching staff to support less experienced teaching assistants and reflect on next steps, how to deal with different challenges and make sure that everyone was on the same page

The detailed description of the two challenges is beyond the scope of this chapter; however, a more detailed overview of E^3 Challenge 2 is provided in the chapter by Martin et al. (2022). Instead, we focus on how the CBL compass was used to map differences and similarities in key components of the two E^3 challenges and discuss how this instrument can be used at a course and curriculum level.

Mapping of E^3 Using the CBL Compass

Fig. 2.2 shows the differences and similarities of the two courses in terms of challenge characteristics, teaching and learning, and support. Noteworthy is that both challenges took place online due to COVID-19. Thus, certain aspects of support, such as materials and spaces were not applicable.

Below we provide some examples of insights resulted from the analysis of the CBL compass and discussions we had with course coordinators after the end of both challenges. We elaborate on three examples at the level of vision, teaching and learning, and support, where we compare the two challenges.

At the level of vision and challenge characteristics, we see that the two courses offered cases, which were open ended but differed in the aspect of real-life and interdisciplinarity. For E^3 Challenge 1, it was a design choice to gradually introduce students to the open-endedness of CBL but without an explicit link to real life. The cases of E^3 Challenge 1 were provided by the challenge owners, who were all researchers in TU/e. Still, problems remained open-ended, and students were able to decide their particular focus and approach to solve the problem depending on their own interests. However, there was also variety among the offered cases. One of the discussion points was how open a challenge offered in this course should be, especially if a link with other basic courses like calculus and applied natural sciences is desired and students need to apply content knowledge in the development of a solution.

On the other hand, E^3 Challenge 2 included real-life components, such as external stakeholders with a problem requiring a practical solution. That made the cases more relevant and appealing to students because they resembled real-life practice. At the same time, the real-life aspects of the cases created a higher degree of uncertainty and ambiguity for the cases.

In terms of teaching and learning, we see that both challenges stressed the importance of self-directed learning. Students were given freedom and autonomy, and they were expected to show initiative and proactivity in their learning. Teaching and learning activities to support self-directed learning included weekly coaching session focusing on team processes, meeting with stakeholders and experts for feedback and asking questions. Both challenges supported students in self-directed learning by introducing reflection activities such as the personal learning portfolio in Challenge 1 and individual weekly reflection reports in Challenge 2.

At the level of support, a difference between the two challenges was highlighted by the CBL compass. E^3 Challenge 1 revealed that the transition to CBL

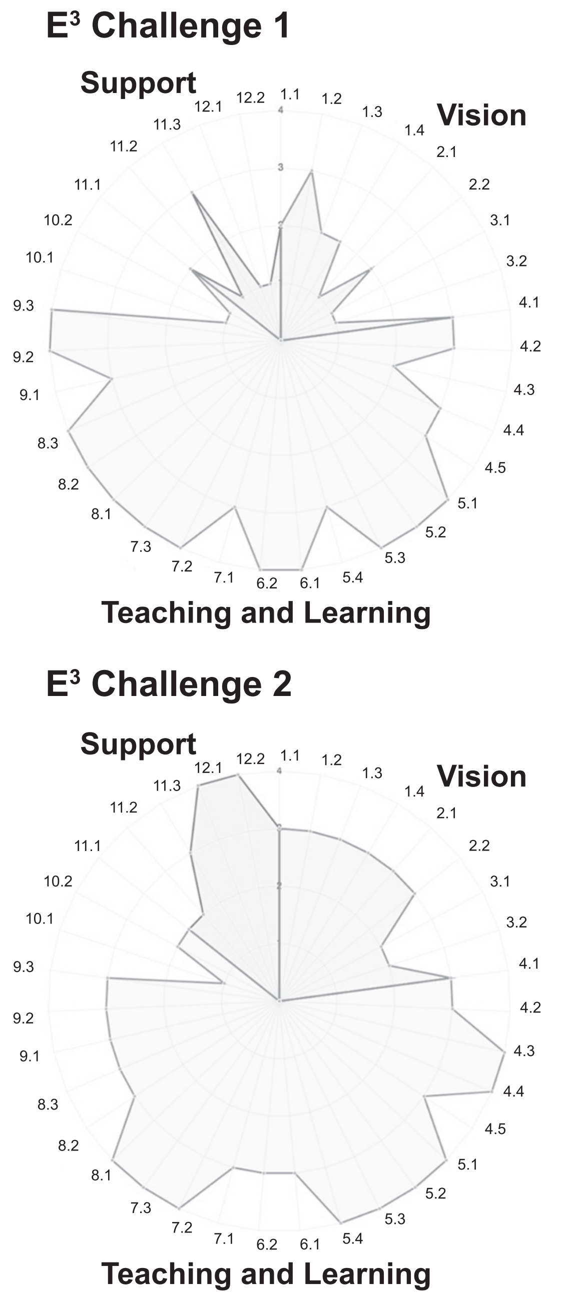

Fig. 2.2. Mapping E³ Challenge 1 and Challenge 2 Using the CBL Compass.

was new for both students and teachers. Students experiencing CBL for the first time need scaffolding, especially at the initial stages of the challenge, and they need to adopt an active learning attitude to navigate complex and open-ended problems. This influences teaching in CBL, where teachers need to adopt the role of a coach. Teachers struggled to achieve an optimal balance between scaffolding and guidance, and they also expressed their need for additional support and sharing of good practices. This insight was considered in the development of E^3 Challenge 2, where attention was paid to the preparation and support of teachers to their new role as coaches in CBL. E^3 Challenge 2 emphasized teacher development and support, by offering training to teaching assistants, as well as weekly peer feedback sessions, where all teaching staff of E^3 Challenge 2 met and shared good practices and supported each other.

Overall, the CBL compass was useful to identify commonalities and discrepancies between the two challenges. This is particularly important for the redesign of the two challenges as a continuous curriculum but also as independent courses.

To sum up, at a course level, the compass allowed the coordinators to assess what was achieved and how. Thus, completing the CBL compass created an awareness between what was the intended and implemented curriculum (Van den Akker, 2003). At a curriculum level, the compass showed how the two challenges build on each other and facilitated the identification of overlaps or discrepancies that both fostered the dialogue about redesign. At the end of both challenges, some common questions relevant for the redesign were reported:

- What are the characteristics of a good challenge for first year engineer students?
- How to prepare teaching assistants for their role as CBL coaches?
- How to encourage students to be in charge of their learning (self-directed learning)?
- How to develop good assessment practices in CBL at an individual and group level, for products and processes?

The Use of CBL Design Principles to Guide Redesign of E^3

The questions posed above by the E^3 coordinators highlight the need for teachers to use theory-driven insights before (re)designing a CBL course. One way to address this need is by using the CBL design principles as a starting point for discussion among all involved parties in the development of a CBL course.

In the case of E^3, the challenge coordinators reviewed the design principles and discussed how they could be used in the next steps of redesigning E^3. The coordinators suggested that implicitly many of the design principles were already used. However, the full list of design principles and the distinction in the three levels of vision, teaching and learning, and support provided a good overview of all relevant aspects that need to be addressed and aligned with each other when designing a CBL course. For example, the need for alignment was considered essential between learning objectives and assessment practices. For instance, for

E^3 – Challenge 1, at the level of vision, deep learning of course content was a central objective, but this learning goal was not aligned with the assessment practices. At an individual level, there was no assessment of whether students reached a deeper understanding of Applied Natural Science concepts.

Similar, in E^3 Challenge 2, even though collaborative learning was a key component of the course, there was no assessment of students' contribution to the group processes. Regarding assessment, a balance in assessment of individual and group contributions, products, and processes was also considered important by the E^3 coordinators.

According to the E^3 coordinators, the CBL design principles were useful as a starting point for discussing the next steps in redesign of E^3. In combination with the CBL compass which helped them to map the current situation, CBL design principles encouraged a dialogue about how to move forward, putting emphasis on the alignment among different components at the level of vision, teaching and learning, and support. However, it was also pointed out by E^3 coordinators that translating the design principles into concrete learning material, resources, and learning activities requires the collaboration of a multidisciplinary group of professionals.

Discussion

This chapter described efforts at TU/e to adopt CBL as a central thread of learning, educational innovation, and practice-based research. We aimed to highlight that the transition to a CBL curriculum can be supported by design principles and an instrument to map existing practices. In the discussion and conclusion section, we reflect on the use of the two instruments for CBL at our institution and discuss future developments and recommendations for educational practice and research.

The CBL design principles presented here establish a common ground among all CBL experiments without being too restrictive and inhibiting creativity of teachers. These design principles offer a useful framework for teachers to identify what is important in their course (vision) and help them to redesign their teaching and learning approach and identify what sources of support are needed. Discussions with the E^3 coordinators revealed that the design principles also provide a good starting point for redesigning courses or indeed a complete program. We could say that CBL design principles help teachers define the intended CBL curriculum (Van den Akker, 2003). However, it is important to note that design principles are not "recipes for success" but are intended "to help others select and apply the most appropriate substantive and procedural knowledge for specific design and development tasks in their own settings" (McKenney, Nieveen, & van den Akker, 2006, p. 73).

At the same time, the CBL compass can be used both at a course level as a reflective instrument for teachers, and as a managerial instrument to evaluate and map implementation of CBL at a curriculum level. In this sense, the CBL compass provides a useful instrument to assess the implemented CBL curriculum

(Van den Akker, 2003). Both instruments introduce a shared language and can foster dialogue among various parties involved, such as teachers, researchers, and policy-makers.

Regarding implementation of CBL in our university, there are a lot of interesting initiatives (see also chapter by Reymen et al., 2022). E^3 is one of the promising CBL experiments at TU/e. Although our chapter focuses on the local TU/e experience, it is important to stress that no single CBL approach works optimally under all conditions. In our view, variety in CBL within an institution is not only unavoidable but also desirable. The context and content of studies and student characteristics should be taken into consideration when designing a CBL experience (Bombaerts et al., 2021). Challenge characteristics and the development of specific learning goals can differ significantly depending on the educational context (Doulougeri et al., Manuscript submitted for publication, Eindhoven University of Technology). The CBL design principles and the CBL compass presented in this chapter aim to create a common framework for researchers and teachers, yet also provide enough flexibility for customization to be transferred to other contexts outside engineering education.

We also suggest that CBL implementations should be accompanied by research. Guiding research may explain why certain characteristics of CBL, preferably based on theory, might work in a specific context with specific goals in mind. The theory can help us explain how complex phenomena in CBL interact and thereby add to our understanding. Current and newly emerging theories should inform redesigns of CBL. CBL is very context-specific, and its context changes continually, thus, policy-makers, program directors, and teachers also need to be able to adapt.

Solutions and Recommendations

Our chapter highlights the importance of combining theory- and practice-driven insights when designing CBL. For effective CBL interventions, it is important that teachers reflect together with their team on the overall vision, teaching and learning, and look for adequate support well in advance.

When designing a CBL course, contextual and student characteristics should also be considered. Contextual factors that can influence students' learning include opportunities for agency, autonomy provided by the learning environment, meaning associated with learning activities, available time and availability of learning resources and materials.

At an interpersonal level, students in CBL are invited to actively monitor and regulate their own learning in interaction with teachers, experts, and external stakeholders, and with a group of peers to collaboratively coconstruct a solution to a challenge. Social support, coaching, and scaffolding practices as well as feedback are essential in such a context (Jääskelä, Poikkeus, Vasalampi, Valleala, & Rasku-Puttonen, 2017; Sitzmann & Ely, 2011; van Diggelen et al., 2019).

At a personal level, CBL gives students the responsibility to direct their learning. Personal characteristics that influence self-directed learning in an educational setting include the students' skills in regulatory mechanisms such as: planning, monitoring, metacognition, attention focusing, employing various learning strategies, persistence, time management, environment structuring, help seeking, emotion control, and effort control (Doulougeri et al., 2021; Jääskelä et al., 2017; Sitzmann & Ely, 2011).

When designing an educational innovation, very often it is difficult to translate theoretical concepts into educational practice. We recommend teachers to combine top-down and bottom-up approaches to guide educational practice adapted for their specific contexts.

Our chapter also highlights the importance of communication and dialogue among different professionals involved in CBL such as researchers, teachers, developers, and policy-makers. It is reasonable that every change might be encountered with resistance. It is thus important to provide teachers with time and resources to adjust. Additional teachers' support to help teachers to transition to CBL is necessary. Creating alliances and working groups including teachers, policy-makers, researchers, and developers is essential.

We recommend teachers to start early discussing with their team the aspects of vision, teaching and learning, and support. We also recommend using the CBL compass as a reflection instrument to assess which of their objectives were completed in implementations. We also encourage a strong collaboration between teachers and researchers.

The design principles can help teachers to operationalize all desired elements that a CBL experience should contain to achieve the desired outcomes and accordingly develop all relevant learning materials and activities. The CBL compass can act at this level as a mapping and reflection instrument to see if and how all necessary elements are addressed (Van den Beemt et al., 2021).

To improve chances on successful CBL implementation at a wider level, an integration of curriculum change and professional learning and development of all individuals and organizations involved is recommended. The professional community of CBL educators would be helped by a growing body of knowledge of theoretically underpinned and empirically tested design principles and methods about CBL. CBL design principles can be further refined by sharing them with other researchers and practitioners, through dissemination. Peer review of design principles is essential for the overall improvement of professional practice and related student outcomes, such as increased student engagement. CBL design principles, through dissemination, provide the means to communicate the results of research beyond the local context to teachers and researchers in similar and parallel contexts worldwide.

Future Directions

CBL is an emerging concept for engineering education. It is important that such educational innovation is grounded in sound research. Research-informed educational innovation should fulfill a double objective: advancement of knowledge and theory as well as enhancement of educational practice (Vermunt, 2021). We recommend the collaboration of an interdisciplinary team of visionaries, policy-makers, teachers, teacher-researchers, and researchers for the development of CBL educational innovations that are also accompanied by sound educational research to produce not only good practices but also advance our knowledge about which aspects of CBL work and why.

In this chapter, we described the development of the CBL compass and a set of CBL design principles that could be used in designing learning environments that engage students in active and self-directed learning, make use of new learning technologies, and promote student motivation and engagement. We provided preliminary findings of the use of the CBL compass as a reflective instrument used by only two teachers in two CBL courses. Future work should aim to explore the perceived benefits, limitations, and difficulties that teachers experience when they use the CBL compass to (re) design a CBL course.

In addition, although the design principles can help teachers to develop engaging learning materials and activities, we can do more in articulating them and link them to practice. In addition, future work should aim at creating a model that describes how the principles interact to promote students' learning.

Assisting teachers to develop suitable learning materials presents only one necessary element to promote reform. We also face challenges to support teachers in their new role within CBL. Professional development of teachers represents a critical component in scaling up CBL across the curriculum, especially regarding scaffolding of student learning, finding a balance between openness, and giving students structure in their learning process and finally assessment of interdisciplinary group work. Thus, future research should explore the competencies teachers need to develop to fulfill their role within CBL and how to develop these competencies.

Conclusion

The landscape in engineering education is changing and is putting students in the lead of their education. This means that teachers and curricula need to adapt in this new era. This chapter discussed CBL in the context of engineering education and the need to support educational innovation with instruments aimed to facilitate designing and mapping CBL experiences. Our work, although preliminary, shows the need not only to conduct educational innovation in standalone courses but the need for theory-driven, research-informed education innovation. In the future, we aim to use the CBL design principles and CBL compass in more cases and evaluate their usefulness for (re)designing CBL courses.

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