Chapter 1

Creating a Learning Ecosystem for Developing, Sustaining, and Disseminating CBL the Case of TU/e Innovation Space

Isabelle Reymen, Miguel Bruns, Jasmina Lazendic-Galloway[*], *Kerstin Helker, Ana Valencia Cardona and Jan D. Vermunt*

Abstract

This chapter presents a case study of building TU/e innovation Space, a unique learning hub for developing, sustaining, and disseminating research-informed challenge-based learning (CBL) practices at the Eindhoven University of Technology (TU/e). This learning hub for education innovation fosters the collaboration between students, industry, research, and societal organizations and drives the continued development of the CBL approach at TU/e. The chapter presents insights from the development of CBL at TU/e innovation Space, drawn from postcourse evaluation surveys of two flagship courses, the innovation Space Bachelor End Project (ISBEP; third year bachelor level) and the innovation Space Project (ISP; master's course level). Analysis of the data shows that students generally rated the courses highly. As the main motivation to choose these courses, students cited the desire to do something else than their own major, aiming for interdisciplinarity and breadth of knowledge, and wanting to do something real-life or business-like. Students also liked the ability to choose their own project, but in some cases, struggled with the structure of the assessment. We also briefly describe academics' perspective on running CBL courses at the hub and present additional activities related to the full learning ecosystem of the hub. Finally, we describe some of the future directions in terms of CBL research and educational developments at the hub.

[*]Corresponding author

The Emerald Handbook of Challenge Based Learning, 13–33

doi:10.1108/978-1-80117-490-920221002

Keywords: Challenge-based learning; learning ecosystems; engineering education; interdisciplinary education; entrepreneurial education; open-ended projects

Introduction

Modern society is faced with a multitude of challenges that are complex, open-ended, and not easy to define (e.g., Gómez Puente, Van Eijck, & Jochems, 2013). Traditional teaching approaches that focus on the transmission of knowledge are therefore starting to lose their functionality (Vermunt & Verloop, 1999). Motivated by the United Nations' 17 Sustainability Goals and Grand Challenges, engineering programs are increasingly starting to embrace more authentic and active learning such as Challenge-Based Learning (CBL; e.g., Kohn Rådberg, Lundqvist, Malmqvist, & Hagvall Svens, 2020). These teaching practices are focused on offering choice in problem-solving and enabling training in interdisciplinary teamwork and decision-making, where "learning takes place through the identification, analysis and design of a solution to a sociotechnical problem." (Malmqvist, Kohn Rådberg, & Lundqvist, 2015). Challenges are usually open-ended and require interdisciplinary work while aiming to develop "21st century skills such as self-awareness, self-leadership, teamwork, and an entrepreneurial mindset." (Van den Beemt, MacLeod & Van der Veen, 2020, p. 2).

CBL is at the core of the educational vision for 2030 at Eindhoven University of Technology (Technische Universiteit Eindhoven, TU/e). TU/e has made an important educational transition with a perspective on creating engineers of the future (i.e., self-directed, self-aware, life-long learners) by introducing the Bachelor College in 2012, and followed by the set-up of the graduate school. Changes were introduced to allow students to tailor their degree toward their own interests and goals while still ensuring the broad attitude, knowledge, and skills required of all TU/e engineers. These structural changes made considerable room for elective courses and sparked educational experiments focused on finding new educational models linked to solving societal challenges, such as CBL. Furthermore, this development enabled a group of innovative academics to forge ahead with experimentation and creation of new courses, which also led to creation of a unique learning hub, TU/e innovation Space.

This chapter presents a case study of CBL courses set up in TU/e innovation Space. The learning hub was born as a concept at the end of 2015, with the initial idea to create courses which focus on interdisciplinary teaching and learning, the integration of theory and practice, entrepreneurship, and design thinking. Today, the hub is a learning ecosystem for developing, sustaining, and disseminating research-informed CBL practices for curricular and extracurricular activities. We describe different elements of this learning ecosystem and use a survey instrument to investigate how students have perceived the key CBL characteristics of the two flagship courses in the first two years of implementation. This study can provide useful information to other institutions in establishing similar full or partial learning ecosystems related to CBL. The chapter starts with the background information on TU/e innovation Space, including a description of the adopted key CBL characteristics. This is followed by a brief description of the two flagship courses and the lessons learned from student and teaching staff experiences in these courses. We also briefly present elements of the wider learning ecosystem and conclude the chapter by discussing our future research plans based on the current insights.

Background

Situated within a technological hotspot of Europe, the Brainport Eindhoven region, TU/e collaborates with major innovative companies. Industry indicates that future engineers need a new set of skills – engineers today need to be able to collaborate in interdisciplinary teams, have an entrepreneurial mindset, and think on a systems level (QS, 2019). The well-known interdisciplinary student teams, such as Solar Team Eindhoven (https://solarteameindhoven.nl), demonstrate what kind of learning is needed to achieve this – students work with passion on open challenges with a competitive edge, collaborate with companies and society, experiment with users, and embody entrepreneurial behavior. In this way, the students develop both their professional skills and learn to apply their disciplinary skills in context, deepening their disciplinary knowledge. TU/e embraces these skills and behaviors, and through TU/e innovation Space, aims to facilitate this approach to learning for all students.

The hub provides an innovative and flexible learning environment in which staff can experiment with CBL. Through these experiments, which are monitored in collaboration with experts from TU/e Education and Student Affairs (ESA) and Eindhoven School of Education (ESoE), the hub is working on building up experience with interdisciplinary CBL on a micro level, in individual courses and projects, and at the macro level of the whole University, with included support structures (physical and digital facilities, technical, administrative and educational support, student assistants, etc.). The University has chosen a bottom-up approach for CBL, with strong top-down support. In that respect, TU/e innovation Space can be classified as "an (open) innovation lab" which is defined as a "semi-autonomous organization that engages diverse participants – on a long-term basis – in open collaboration for the purpose of creating, elaborating, and prototyping radical solutions to open-ended systemic challenges" (Gryszkiewicz, Lykourentzou, & Toivonen, 2016, p. 84).

In the courses supported by the hub, students have the opportunity to work on open-ended, interdisciplinary challenges and cooperate with different stakeholders, such as industry partners, research institutions, and societal and government organizations. In some courses, the challenges are chosen by the lecturers (often in line with knowledge-focused learning outcomes), and in others, students can choose challenges from a range of topics (often in line with skill-focused learning outcomes). Therefore, students can choose CBL course(s) which match their personal interest, stimulate their personal and professional development, and enable peer learning through collaboration with students from other disciplines.

Since CBL is still relatively new concept and has variety of forms and characteristics (e.g., Gallagher & Savage, 2020; Malmqvist et al., 2015), the education team has come to a working definition which describes the key characteristics of CBL at TU/e (Reymen et al., 2020):

> CBL focuses on complex, real-life open-ended challenges derived from different sources (research, industry, society). The challenges have in common that they are able to engage the students by being societally relevant, technically challenging and relevant for the engineering profession. In order to solve real-life challenges, often an interdisciplinary approach is needed, where all team members contribute from their own expertise and skills, and students learn to work together to achieve the desired result. CBL at TU/e also requires systems thinking, a holistic approach that focuses on how system's constituent parts interrelate and how systems work in the context of larger systems. Furthermore, CBL combines a deep understanding of the field in which students are specializing with the ability to take a broader view so they appreciate and value ways of thinking different from their own. CBL is active learning that allows students to construct a coherent network of knowledge and take ownership of their own learning process. This action orientation is also stimulated via entrepreneurial thinking. CBL also means working in an iterative cyclical way, involving both analysis and synthesis; divergent reasoning to develop creative and innovative solutions, and convergent reasoning to analyze these options and assess which one is most desirable, feasible, and viable. CBL should create a learning urgency that encourages the acquisition and application of new knowledge and skills. Learning these "just-in-time" implicates that the knowledge and skills gained are applied in context. Because the challenges are based on real questions from (fundamental and applied) research, industry and society, contextual learning is stimulated and retention of information is optimized. Finally, CBL fosters deep learning by having students reflect on their learning process and development, in order to develop meta-cognitive skills and self-regulatory abilities.

Creating a Full Learning Ecosystem

Two Flagship CBL Courses

Since the start, TU/e innovation Space has placed great emphasis on an evidence-based way of working. This started by visiting existing international initiatives, such as those at Aalto University, for example, as well as similar initiatives in the Netherlands (in Delft, Utrecht, Wageningen, and Amsterdam). Learning approaches evident in extracurricular student teams, where students develop their professional skills but also learn to learn and apply their disciplinary skills in context, have also provided inspiration. All these examples helped to shape the first iterations of CBL courses and projects in innovation Space. Students also investigated and designed solutions for parts of the hub under the supervision of the leading academics (the first and second author). The two flagship CBL courses initiated by the founders of the hub, the innovation Space Bachelor End Project (ISBEP; third year bachelor course) and the innovation Space Project (ISP; master's course), continue to be a "playground" for educational innovation (Tables 1.1a and 1.1b).

The ISP was the first CBL master's course at TU/e (initiated by the first author). In this course, students work in interdisciplinary teams on real-life challenges, with a focus on developing minimal viable products. The course focuses on developing a mindset for dealing with uncertainty by combining design thinking with entrepreneurial thinking. The course has no lectures but extensive coaching by lecturers and peers. Students are explicitly asked to reflect on their personal and team development as part of the course assessment.

Table 1.1a. Short Overview of ISP Course.

Start	**September and February**
Duration	One semester
Group formation	Interdisciplinary teams (3–6 students)
Challenges	open-ended interdisciplinary challenges
Challenge owners	TU/e startups, student teams, researchers, societal organizations, and industry
Involvement Challenge owners	regular meetings and "key moments" presentations, two times in the semester
Programs involved	Students from all master programs are able to join
Learning goals	being able to select and apply appropriate design, engineering, and business approaches and tools; to perform an analysis of a complex real-life problem, to perform a synthesis resulting in a design that balances desirability, feasibility, and viability perspective; to contribute to interdisciplinarity by being able to identifying, envisioning, and promoting the role and contributions of the different disciplines involved and integrating the different contributions; to develop leadership and communication skills and behavior and develop an entrepreneurial mindset; define and regularly reflect on personal and team development.
Coaching from hybrid teacher	on entrepreneurial behavior
Peer learning	during weekly meetings
Rules and regulations	elective master course

Table 1.1b. Short Overview of ISBEP Course.

Start	September and February
Duration	One semester
Group formation	interdisciplinary teams (3–6 students)
Challenges	open-ended interdisciplinary challenges
Challenge owners	TU/e startups, student teams, researchers, societal organizations, and industry
Involvement Challenge owners	regular meetings and “key moments” presentations, four times in the semester
Programs involved	Students from all bachelor programs are able to join
Learning outcomes	competence-based and focused on broader professional skills, such as interdisciplinary communication, reflection, systems thinking, as well as the domain of (disciplinary) content knowledge
Coaching from innovation Space	on competence development and team process: weekly
Coaching from academics in other faculties	on disciplinary knowledge and skills: academic staff from the department when needed
Peer learning	during weekly meetings
Rules and regulations	interprogram: regulations of the individual programs for final bachelor projects apply

The ISBEP (initiated by the second author) is offered to students from *all bachelor programs/majors*, where they can work in an interdisciplinary team toward creating solutions to real-life challenges while finishing their Bachelor End Project (BEP). Consequently, ISBEP is high stakes because students are awarded their engineering diploma upon successful completion of the project. In this unique course, some aspects of learning outcomes are supported by the academics from the disciplinary programs and other aspects are supported by the coaches from innovation Space.

Lesson Learned – Students' Perspective

To gather feedback on students' experiences with CBL learning, the education team at the hub uses a custom-made course evaluation survey each quarter (or semester) containing both closed and open-ended questions. In this chapter, we present evaluations from the student perspective of the two flagship CBL courses from the first two years of implementation; the overview of the evaluation ranging across all the courses in the hub has been presented in Lazendic-Galloway, Reymen, Bruns, Helker, & Vermunt, (2021).

The survey was carried out by adding the custom-made questions to the regular end-of-the-course student evaluation survey. Ethics approval was obtained for use of these data (ERB2021ESOE8). Over the period of two years, the evaluation for the two flagship courses has been completed by 124 students from the four semesters (with 55 participants in the first year and 69 in the second year), roughly 50% of the students who have taken these courses. The five closed questions, with five-point Likert scales from "1 = No, definitely not" to "5 = Yes, definitely," are designed to collect feedback from the students on what is the (perceived) level attained for the five key CBL characteristics (KCs) and are shown in Table 1.2.

1. Was there any significant variation between different CBL characteristics? Data show that students generally rated the ISP and ISBEP courses highly on the five key CBL characteristics (KCs). In Fig. 1.1 we present aggregated results from data analysis of the quantitative data from the survey instrument. In the first year (2018–2019) that courses have been run, the median values are 4.0 and above,

Table 1.2. The Closed and Open-Ended Survey Questions Used in This Study Related to the Five Key CBL Characteristics and Collecting Other General Feedback Regarding Motivation to Engage in a CBL Course.

Closed Questions (scales from "1 = No, definitely not" to "5 = Yes, definitely")

Q. To what extent do you think this course:

(KC1) was interdisciplinary? (cooperating with students from different study programs, applying/integrating knowledge from different disciplines for the end result)

(KC2) was challenge based? (challenging question at the start of the project, real-life problem)

(KC3) was hands-on? (learning by doing; developing a prototype or minimal viable product)

(KC4) had an entrepreneurial mindset? (have to deal with uncertainty, take entrepreneurial aspects into account)

(KC5) contributed to personal and team development? (in terms of professional skills, like collaborating, presenting, coaching, creativity)

Open-ended Questions

Q1. Why did you choose this course?

Q2. Would you recommend this course to a fellow student, and why?

Q3. What is, in your opinion, the added value of taking a course in TU/e innovation Space?

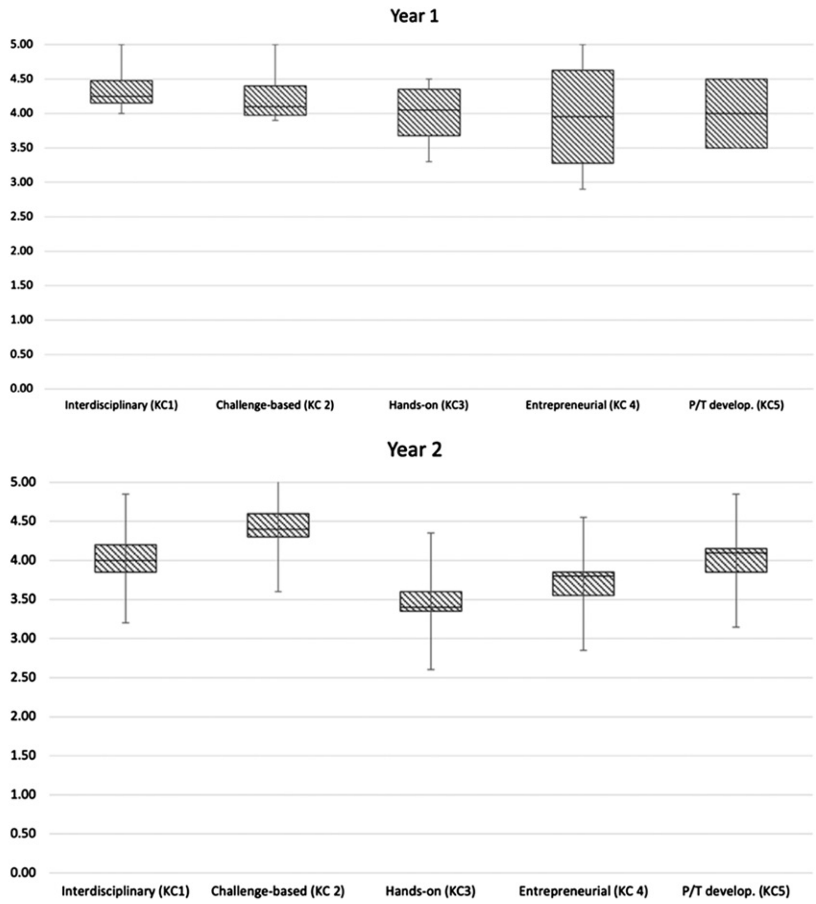

Fig. 1.1. Student Ratings of the Five Key Characteristics (KCs) of CBL. The two boxplots represent the median values, where 50% of the scores sit (the interquartile range), as well as the minimum and maximum score for each of the closed survey items (see Table 1.2) across the first and second academic year that the ISP and ISBEP courses have run at the TU/e innovation Space.

with the entrepreneurship aspect having the widest range of values (from 2.9 to 5.0). In the second year (2019–2020), there was more agreement between the students on the level achieved for each characteristic. The second iteration of the courses and the feedback provided in the first year would have helped streamline some aspects of the courses. The hands-on aspect of the courses has the lowest median, which is not surprising since this academic year got disrupted by the global pandemic, so there was a reduced amount of face-to-face and hands-on sessions.

2. Why do students choose CBL courses? To explore in more detail how students experienced CBL learning in the first two years of implementation of ISP and ISBEP courses, we analyzed the answers to the open-ended survey questions. We used exploratory thematic analysis to identify any interesting insights from the students and performed inductive coding using participants' own words to identify metathemes. The final analysis was then performed by combining metathemes into overarching main themes, which are listed in Table 1.3. There were fewer participants filling out the open-ended questions: 53 students filled Q1, 49 filled Q2, and 30 filled Q3. Some of the themes match some of the KCs identified as important by the education staff, as indicated in Table 1.3.

As the main motivation to choose one of these two courses, students cited mainly the desire to do something different than their own discipline. The second most frequently mentioned reason was that students wanted to do something real-life or business-like (i.e., not related to research). The last statement is important in terms of making students aware of diverse career pathways, rather than just the academic ones (Roach & Sauermann, 2017). Almost as frequently mentioned by the students was the desire to do something interdisciplinary or multidisciplinary (these two terms are often used interchangeably by the students). Another important reason mentioned was the desire to do a group work (project), in contrast to discipline-based master or BEP projects that are usually done individually. The students also listed a desire to learn from other students, and work with like-minded people.

3. Why do students recommend CBL courses? When asked if they would recommend these courses to other students and why, the students expressed

Table 1.3. Metathemes and Main Themes Identified From the Open-Ended Question "Why did you choose this course?" (Q1).

Main Themes (T)	**Metathemes**	**No.**	**%**
T1: Breadth of knowledge and skills	something different, not research, other than major, wanted breath of knowledge and skills, more interesting than their major	20/53	38%
T2: Real-life, challenge-based (KC2)	work with companies, real-life, business oriented, responsible innovation	11/53	21%
T3: Interdisciplinary (KC1)	Interdisciplinary (multidisciplinary)	10/53	19%
T4: Personal and team development (KC5)	group work, learn from other students, work with similar-minded people	6/53	11%
T5: General interest	Interesting, fun, curious about, seems challenging	6/53	11%

diverse opinions. Furthermore, because the students expressed emotions in their answers to this question, we separated their answers into positive, neutral, and negative. There were 49 answers provided, with 35 comments related to positive experience, 24 related to negative experience, and nine related to neutral experience (with four students expressing both positive and neutral experience for different aspects of the course). Therefore, at least 70% of the students would recommend these courses. We list the identified themes and metathemes in Table 1.4.

The students recommend the CBL courses to those interested in developing their career skills related to interdisciplinary collaboration, working on self-growth, and getting opportunities to work with companies. The learning experience is an important factor for successful learning, and the students felt they learned a lot, had fun in the process, and had learned a lot in an exciting or different way. They enjoyed working in diverse teams or on more practical or interesting projects. They felt they were given more freedom of choice and were able to be more creative. The students felt they received more feedback and had more interactions with teaching staff and students. This is indeed one of the strengths of CBL approaches to instruction compared to more traditional approaches. The full community of the hub includes academic and technical staff, coaches, challenge owners, student assistants, student teams, and all the students, which enables frequent interactions and opportunities for learning and seeking feedback.

As with any innovative educational concept, there are always some challenges that need to be overcome. The neutral and negative metathemes identified from the open-ended question in the survey question provide us with some insights into what are elements to be aware of when implementing CBL in courses.

Some students mentioned that this is an interesting learning approach but that they would prefer a more technical direction or a more theoretical or predefined problem to solve. While we know that learners have a preferred way of learning, they also need to be given a variety of learning opportunities to grow. A few students mentioned that they would have preferred more directions given in their projects. This is a critical balance that academic staff and coaches have to negotiate in CBL courses (similar to other project-based courses), that is, providing enough freedom for students to take full ownership of their learning, as too many directions will then feel just like any other assignment students have to do. At the same time, it is important for instructors to step in if the students are having trouble finding a direction in their projects and coach students through guided reflection to come up with their own solutions (constructive friction: Vermunt & Verloop, 1999).

The negative experiences were mainly linked to cross-faculty communication or assessment compliance issues and the structure of the assessment. In particular, the students appeared to struggle to engage in the interdisciplinary project while fulfilling the BEP requirements of their specific programs. This and other issues in assessment have been explored in ISBEP by Valencia, Bruns, Reymen, and Pepin (2020). For example, while students join the challenges motivated by interdisciplinary learning in a team, summative assessment in the course is based on

Table 1.4. Themes and Metathemes Identified From the Open-Ended Question "Would you recommend this course to a fellow student and why?" (Q2).

Themes (positive)	*Metathemes (positive)*
Related to general learning experience (17)	Learned a lot (4) Having lots of fun (4) New exciting way to learn (3) Different learning process (3) Received more feedback (2) Having better interactions (1)
Related to projects (10)	More interesting projects (2) Doing something different (2) More practical (2) Leaving comfort zone (1) More freedom of choice (2) Allows creativity (1)
Related to career (8)	Interdisciplinary work or personal growth valuable for career (5) Getting career opportunities with companies (1) Working in diverse teams (2)
Themes (neutral)	*Metathemes (neutral)*
Related to general learning experience (5)	Room for improvement (4) Need more time for work (1)
Related to projects (4)	Prefer more technical or theoretical direction or to be given predefined questions, or clearer project direction (4)
Themes (negative)	*Metathemes (negative)*
Related to assessment (13)	Cross-faculty communication or compliance issues (8) Assessment issues (5)
Related to course set-up (6)	Organization or management of the course not satisfactory (3) Better communication in the course needed (1) Better structure needed (2)
Related to self-efficacy (5)	Feeling like giving up, disappointed (3) COVID-19 disruption (1) Uneven contribution from team members (1)

students' individual reports largely focused on discipline-specific (i.e., mechanical engineering, chemical engineering) learning goals. Therefore, this creates tension among students, who struggle to balance their personal development goals and those of their programs. These issues of discrepancy between the perceived learning outcomes by students and assessment criteria have been addressed by a research and design project, which focuses on cocreation approach (see Valencia, Bruns, Reymen, & Pepin, 2021). In particular, the project has led to the design of assessment tools, such as rubrics and self-assessment procedures, to support the learning of students.

A smaller number of comments from the students are less specific, referring to the need for more structure, organization, or communication in the course, which are common "teething" problems when starting new courses. Interestingly, there was only one mention of the disruption by COVID-19 pandemic as a negative experience. While TU/e stopped most of the face-to-face sessions like many other universities, some of the CBL courses were allowed to resume some of the more practical activities, under strict COVID prevention guidelines, of course.

4. Added value of course in innovation Space. The final question asked about the added value of the course being placed at the hub (as opposed to one of the departments). As explained above, the hub was set up to be a collaborative space, where all the stakeholders interact in formal and informal ways, enabling collaborative, interdisciplinary, and hands-on work with the relevant tools and technical support available. It was important to get feedback on whether students make use of all these components. As before, we coded the answers to identify the metathemes first, which we then grouped under overarching themes. Table 1.5 lists themes and metathemes for this question.

Table 1.5. MetaThemes and Main Themes Identified From the Open-Ended Question "What is in your opinion the added value of taking a course in TU/e innovation Space?" (Q3).

Main Themes (T)	Metathemes	No.	%
T1: Interdisciplinarity (KC1)	Interdisciplinary (multidisciplinary)	13/30	43%
T2: Personal and team development, teamwork (KC5)	Learning from others, working with others	12/30	40%
T3: Real-life (KC2)	working with companies, real-life, making business case	8/30	27%
T4: Practical (KC3)	practical, hands-on, learning by doing	8/30	27%
T5: General benefits	new perspective and possibilities, more freedom, developing research	6/30	20%

The most frequently mentioned value of the hub was in facilitating collaboration between students from different majors/programs, which students found to be a more authentic learning and working experience. The next important value was found to be in facilitating relationships with companies, which gives students "a better idea of what is possible" within their studies. A student also found that this provides strong motivation for succeeding in their studies.

Another important value of the space was the ability to do practical things with adequate support, such as all the tools needed to start an idea and develop it into a working product. In addition, the students mentioned that the staff are eager to help when needed. A small number of students also remarked on the fact that this space gave them more freedom in terms of research direction and development, noting that working together with other disciplines would not be possible in their own faculties.

As a learning hub, TU/e innovation Space reduces the burden on research groups and expensive research facilities (e.g., at the Biomedical Engineering department, lab facilities for graduation projects can amount up to 12k€ per student) by offering alternative BEPs that address interdisciplinary challenges. This is particularly beneficial in view of the increased number of students at TU/e in the last 10 years.

Lesson Learned – Academics' Perspective

The staff from TU/e innovation Space has invited academics involved in the CBL courses running at the hub to debrief sessions at the end of their courses, which they captured in yearly summaries. We performed document analysis of these summaries to investigate advantages and challenges of running CBL courses in general and at the hub:

- The lecturers liked the collaborative spaces and technical facilities offered by the hub, although for some courses, only some of the project teams needed to use the hub.
- The lecturers found that interacting with companies is more suitable in open collaborative spaces available at the hub, rather than in lecture theaters.
- The hub was seen by lecturers as an enabler of providing more materials and resources for their courses, or in terms of networking with people who can support their courses.
- Some lecturers stated that the hub enabled introduction of new topics from external stakeholders in their courses, which made their students a lot more motivated, because they are working on a "serious topic" and they see that their ideas could be applied in a real-life setting.
- The lecturers found the training and practice sessions for giving pitches that the hub organized for the students very helpful.
- In terms of challenges to overcome, some lecturers found that their courses that run only one quarter (eight weeks) were too short for the students to properly develop ideas and finish their prototype; they have considered expanding their

courses across two or three quarters in order to enhance the learning experience for their students.
- Others have mentioned that running a CBL course involves more coordination work, since there are more stakeholders to manage, but have not considered that too big of a problem.
- Some lecturers stated that the upscaling of their CBL courses would be a major challenge. For example, running a CBL course with 20–30 students seems straightforward, and some lecturers have managed up to 100 students, but numbers beyond that were seen as raising various logistical issues (needing more space or multiple sessions, needing more support staff, etc.).

These early courses have been useful experiments for the hub's staff to develop experience and expertise across a wide range of topics. The main aim of the hub's education team is to create and accelerate structural change in education. This requires upscaling of initiatives, so focus groups and debriefings with lecturers have proved crucial to this end. The hub works closely with lecturers, has set up a network of ambassadors from all the departments, and offers an intake process to support teachers in transforming their courses toward CBL approach, thereby also supporting the development of interdisciplinary courses. The hub facilitates the whole process from advertisement to student registration, alignment with departmental processes, team formation, project coaching, intermediary and final presentations, and support with additional course evaluations for quality insurance. The hub actively engages in discussions with program directors, study advisors, coordinators, and students and shares its knowledge and experience through seminars and inspirational sessions.

The hub offers physical facilities and spaces, and learning and training activities that complement those offered by the departments. Furthermore, some lecturers voiced the desire to have teaching spaces that resemble the hub in their own departments, where students can have all the spaces needed (small lecture rooms, collaborative spaces, and prototyping/lab spaces), rather than having to move between the buildings for different sections of the course.

Other Elements of the Learning Ecosystem

The hub collects challenges from within the University and from industry and society, and in collaboration with the lecturers, translates these into challenge descriptions for specific courses. It then arranges a kick-off session where all challenge owners can pitch their challenge for a specific course, and where the students can determine their preference. And at the end of the course, the hub organizes final presentations from the students with the challenge owners.

For all the students at TU/e, the hub offers voluntary workshops on relevant topics (e.g., getting to know your project team, project management, pitching, etc.). These workshops, called *innoApproach*, are organized per quarter and are planned in consultation with the lecturers offering courses at the hub, often matching the needs of students at given stages during the projects. Lecturers advertise and invite students to participate in these workshops during their courses.

Furthermore, some of the project teams from the CBL courses are translated each year into extracurricular startups and student teams then become the source of new challenges for new generations of students. The hub thereby facilitates the integration of *curricular* and *extracurricular* activities. Similarly, students who complete some of these courses become coaches for new cohorts, and thus students are the partners that actively contribute to the educational innovations at the hub. Indeed, the staff at the hub often talks about student teams and student assistants as a driving force and invaluable support for all the activities at the hub.

The hub currently hosts around 38 extracurricular student teams, which are supported by well equipped, generic prototyping facilities with technical support. Furthermore, the hub facilitates an entrepreneurship competition for all TU/e students, called *TU/e Contest*. The project teams can attend workshops, attend peer learning and community building events, present their idea or a prototype, and test their business model with a network of company experts, called Guru's. After the contest, some teams might get invited to work on a business case with a company, and all students benefit from the wide network opportunities.

The hub has also started new initiatives outside the university: (1) working on supporting entrepreneurial learning within 4TU federation, made up of four universities of technology in the Netherlands – TU Delft, Eindhoven University of Technology, the University of Twente, and Wageningen University and Research; and (2) facilitating challenges with other universities through a unique alliance with Utrecht University (UU), the Utrecht University Medical Centre (UMC), and Wageningen University and Research (WUR), on the basis of the complementarity of knowledge and talent. For example, in 2020, the hub set up the "TU/e against Covid 19" platform in only a few months, successfully matching students, researchers, and organizations that offered their help for 10 different challenges from industry, hospitals, and other organizations that requested help.

Impact of the Whole Learning Ecosystem

More than 2,200 students per year, from all majors and programs, take courses hosted by the hub, which has highly impacted their learning. Students were enabled to take more ownership of their learning and work on challenges that are close to their passion and directly impact the world.

The hub facilitated over 200 challenges over the last three years, working closely with the programs to have challenges that match their needs and facilitate relevant knowledge acquisition. The main benefit of facilitating the CBL experiments on this scale is that the staff has gained an insight into what types of challenges fit certain courses, what is realistic to aim for, and what are related needs of students and challenge owners. They have nurtured a network of enthusiastic challenge owners and developed a database of available and completed challenges. They have developed a procedure on how to involve lecturers in the challenge development process or involve existing student teams and university startups in CBL challenges.

There is high growth in the number of courses hosted at the hub. The hub started with the involvement of three leading academics (the first and the second author, and Professor Rick de Lange). By giving presentations in all the departments and leading by example, they attracted the participation of even more lecturers (currently 27 are involved), of which two were awarded as a teacher of the year at TU/e, and one of which was awarded as a national teacher of the year. Moreover, as an expertise center, the hub works closely together with educational researchers and translates research insights into practical tools/ insights to support the implementation of CBL across TU/e. TU/e innovation Space now reaches out to all lecturers interested in innovating education related to CBL and offers help via an Expert Pool, which also contributes to necessary teacher professionalization and support.

The hub as an initiative attracts many visitors from all over the world. The hub director (the first author) is a member of the Comenius Network (through the award of Comenius Leadership Fellowship), which ensures experiences are shared on national level and a lasting impact on higher education is achieved in the Netherlands, as well as the international level. Members of the hub's education team participate as advisors in regional and national education innovation initiatives and collaborate on challenges with other regional educational institutes such as Summa, Fontys, and Avans and on national and European level (https://eurotech-universities.eu/euroteq-european-engineering-education-of-the-future/).

The hub has an impact in the Brainport high-tech region and beyond by educating engineers of the future. Over 200 challenge owners are inspired by solutions developed by students in interdisciplinary courses facilitated by the hub. The ISP course has created at least three startups (Callisto, SpaceSea, and Aristotle Cognitive Training), illustrating that it really stimulates entrepreneurial behavior. Furthermore, the 38 extracurricular student teams currently hosted by the hub consist of more than 350 bachelor and master students who are active in the community. They work on solving grand societal challenges and create an ongoing impact in society, which is appreciated by the numerous partners they involve in their challenges. As already mentioned, the extracurricular teams also act as challenge owners in courses and contribute to the vibrant community. Also, several of these teams continued their journey beyond TU/e as startups (e.g., Taylor, Spike, and Ratio). This further provides input into research focused on how students' contributions translate into value for society (Velasco Montanez, Talmar, & Bruns, 2019).

Future Research Directions

For the CBL approach to truly have an impact, it needs to be implemented in the core of the university curricula and become the leading principle for education at a university level. Implementing such large-scale educational innovations can be difficult to achieve and requires special attention (e.g., Borrego, Froyd, & Hall, 2010). First of all, the educational concept requires strengthening of its conceptual basis, supported by evidence-based research, especially in terms of what "flavors" of CBL are possible and suitable for TU/e (see other chapters in this book: Doulougeri, Van den Beemt, Vermunt, Bots, and Bombaerts; Martin, Herzog, Papageorgiou, & Bombaerts). The next step is to develop guidelines for designing CBL, which can help academic and support staff effectively and successfully transit their courses to CBL or build a new CBL course from scratch. For this to happen, we need a deeper insight into the effects of implementing CBL for different kinds of students in different stages of the bachelor and master's programs. We are currently mapping the existing CBL experiments with a CBL "compass tool" (see Doulougeri et al. in this book) to provide such insights.

Maybe the biggest challenge in shifting to university-wide CBL delivery is convincing the teaching staff that change toward a shared vision is worth doing. While educational innovations are commonly driven by an enthusiastic group of innovators, getting a broader group of educators involved will mean change management of teaching practices on a large scale, ensuring that all teaching staff is sufficiently equipped and supported (e.g., Gast, 2018). The role of academic staff in CBL differs from the usual role in traditional lecture-based teaching. Rather than mainly transmitting and explaining their disciplinary knowledge, teaching staff might spend more time as coaches – helping students clarify their learning needs, define realistic boundaries for their challenges, and monitor their learning, design, and collaboration processes. While academics are familiar with some of these roles when supervising PhD students or postdoctoral associates, more work is required for having to adjust expectations for undergraduate students and for the uncertainty of open-ended challenges. Therefore, we are systematizing learning from the first generation of CBL coaches and academics about what expertise they needed/developed in their new roles (Pepin, 2018), how they acquired that expertise, and how other academics could be supported in developing such expertise. Since there are usually two or three academics involved in the same course, we are exploring the use of a team-based instructional change model (Olmstead, Beach, & Henderson, 2019) to help new academics develop expertise together and provide peer support when implementing, delivering, and sustaining their CBL courses. Our work also focuses on empirical studies about which CBL practices lead to enhanced student-learning gains (Vermunt, Ilie, & Vignoles, 2018), the retention of their learning, and impact on their learning and career progression.

These studies will lead to guidelines for designing successful CBL approaches and means for achieving teaching staff involvement and professionalization. The best practices regarding CBL and the support system that is created in this way can be used to scale up CBL at the departmental or institutional level. Another element that can help in upscaling CBL is integration of curricular and extracurricular activities via thematic student challenges (that can also significantly increase cross-disciplinary research on campuses), as seen with so-called "threads" in MIT NEET (New Engineering Education Transformation) program (Graham, 2018). Vertical learning in such thematic topics can increase efficiency, as students with experience in interdisciplinary CBL can support in coaching younger students. This will relieve the coaching role of academic staff and create more opportunities for them to take up the position of domain experts, which many of them feel more comfortable in. This also creates an educational model where students are partners through the lens of teachers, researchers, and change agents (Healey, Bovill, & Jenkins, 2015), which has been found to have positive effects on graduate attributes and employability (Pauli, Raymond-Barker, & Worrell, 2016).

While society always needed future-proof learning (Kirschner, 2017; Walma van der Molen & Kirschner, 2017), what is so new in the current situation is the speed at which the new knowledge and skills need to be acquired. It is expected that all employees, regardless of the level of their qualifications, will be continuously updating their skills. At the same time, professional careers are expected to become more flexible and will therefore require more self-management, although employers are also expected to become more proactive in upskilling (Kirschner & Stoyanov, 2020). The "on stock" education will become less and less relevant, as complexity and uncertainty of the world that we live in increase. Universities play a key role in innovation and entrepreneurship ecosystems, and therefore there is a need to change their education models to develop the engineers (and learners) of the future. In that respect, CBL offers a flexible model of this change, in which education focuses on creating lifelong learners who are knowledgeable about their discipline, but also have broader views, as well as focus on environmentally and socially responsible consumption and production. The key competencies for students and staff should be the ability to collaborate with a variety of stakeholders, think at a system level, have an entrepreneurial mindset, and deal with uncertainty.

Conclusion

In this chapter, we presented a case study of TU/e innovation Space, a center of expertise for CBL and student entrepreneurship at TU/e and a learning hub for educational innovation. The hub facilitates the exchange of knowledge between students, researchers, industry, and societal organizations for the development of responsible solutions to real-world challenges. Since its setup, TU/e innovation Space has made positive steps toward the wider understanding and implementation of CBL at TU/e. This is reflected in more than 2,000 students per year in almost 40 courses involving over 200 challenge owners, and 350 students in 38 extracurricular student teams supported by the hub. Students are offered challenges they are passionate about, often with a strong societal impact. Students can work on and learn from challenges in projects during course work, as well as through extracurricular activities pursued by student teams. While the current CBL model works well within the learning hub, the ambition of the hub's education team is to create structural changes in education at the university level and broader. To enable upscaling of CBL, focus on student experiences and learning gains, and teacher involvement and professionalization are the next priorities to focus on.

Acknowledgments

This study was supported by the grant "Fostering challenge-based learning through TU/e innovation Space," awarded through the NRO Comenius Leadership Fellow program.

References

Borrego, M., Froyd, J. E., & Hall, T. S. (2010). Diffusion of engineering education innovations: A survey of awareness and adoption rates in US engineering departments. *Journal of Engineering Education*, *99*(3), 185–207. Retrieved from https://onlinelibrary.wiley.com/doi/10.1002/j.2168-9830.2010.tb01056.x

Doulougeri, K., Van den Beemt, A., Vermunt, J. D., Bots, M., & Bombaerts, G. (this book), Challenge-based learning in engineering education – Towards mapping the landscape and guiding educational practice.

Gallagher, S., & Savage, T. (2020). Challenge-based learning in higher education: An exploratory literature review. *Teaching in Higher Education*, 1–23. doi:10.1080/13562517.2020.1863354

Gast, I. (2018). *Team-Based Professional Development: Possibilities and challenges of collaborative curriculum design in higher education*. Enschede: University of Twente. doi:10.3990/1.9789036546454

Gómez Puente, S. M., Van Eijck, M. W., & Jochems, W. M. G. (2013). A sampled literature review of design-based learning approaches: A search for key characteristics. *International Journal of Technology and Design Education*, *23*(3), 717–732. doi:10.1007/s10798-012-9212-x

Graham, R. (2018). *The global state of the art in engineering education*. Massachusetts Institute of Technology (MIT), Massachusetts, USA. Retrieved from https://jwel.mit.edu/assets/document/global-state-art-engineering-education

Gryszkiewicz, L., Lykourentzou, I., & Toivonen, T. (2016). Innovation labs: Leveraging openness for radical innovation? *Journal of Innovation Management*, *4*, 68–97. Retrieved from https://repositorio-aberto.up.pt./handle/10216/102610

Healey, M., Bovill, C., & Jenkins, A. (2015). Students as partners in learning. In J. Lea (Ed.), *Enhancing learning and teaching in higher education: Engaging with the dimensions of practice* (pp. 141–162). Maidenhead: Open University Press.

Kirschner, P. A. (2017). *Het voorbereiden van leerlingen op (nog) niet bestaande banen* [*The preparation of pupils for non-existent/not yet existing jobs*]. Arnhem: NSVP Innovatief in Werk.

Kirschner, P., & Stoyanov, S. (2020). Educating youth for nonexistent/not yet existing professions. *Educational Policy*, *34*, 477–517. doi:10.1177/0895904818802086

Kohn Rådberg, K., Lundqvist, U., Malmqvist, J., & Hagvall Svensson, O. (2020). From CDIO to challenge-based learning experiences–expanding student learning as well as societal impact? *European Journal of Engineering Education*, 1–16. doi:10.1080/03043797.2018.1441265

Lazendic-Galloway, J., Reymen, I. M. M. J., Bruns, M., Helker, K., & Vermunt, J. D. (2021). Students' experiences with challenge-based learning at TU/e innovation Space – Overview of five key characteristics across a broad range of courses. In SEFI 49th Annual Conference Engaging Engineering Education: Proceedings.

Malmqvist, J., Kohn Rådberg, K., & Lundqvist, U. (2015). Comparative analysis of challenge-based learning experiences. In Proceedings of the 11th International CDIO Conference, Chengdu, Sichuan, PR China. Chengdu University of Information Technology.

Martin, D. A., Herzog, C., Papageorgiou, K., & Bombaerts, G. (this book), Three European experiences of co-creating ethical solutions to real-world problems through Challenge Based Learning,

Olmstead, A., Beach, A., & Henderson, C. (2019). Supporting improvements to undergraduate STEM instruction: An emerging model for understanding instructional change teams. *International Journal of STEM Education*, *6*, 20. doi:10.1186/s40594-019-0173-4

Pauli, R., Raymond-Barker, B., & Worrell, M. (2016). *The impact of pedagogies of partnership on the student learning experience in UK higher education*. York: HE Academy. Retrieved from https://www.advance-he.ac.uk/knowledge-hub/impact-pedagogies-partnership-student-learning-experience-uk-higher-education

Pepin, B. (2018). Enhancing teacher learning with curriculum resources. In L. Fan, L. Trouche, C. Qi, S. Rezat, & J. Visnovska (Eds.), *Research on mathematics textbooks and teachers' resources – Advances and issues. ICME 13 monograph* (pp. 359–374). Cham: SpringerSpringer.

QS. (2019). *2019 global skills gap report*. QS Quacquarelli Symonds Ltd, London. Retrieved from https://www.qs.com/portfolio-items/the-global-skills-gap-report-2019

Reymen, I., Bruns, M., Vermunt, J. D., Pepin, B., Rijk, C., Lemmens, A., & Hulshof, S. (2020). Fostering Challenge Based Learning through TU/e innovation Space. Comenius proposal, Eindhoven University of Technology.

Roach, M., & Sauermann, H. (2017). The declining interest in an academic career. *PLoS ONE*, *12*(9). doi:10.1371/journal.pone.0184130

Valencia, A., Bruns, M., Reymen, I., & Pepin, B. E. (2020). Issues Influencing Assessment Practices of Inter-Program Challenge-Based Learning (CBL) in Engineering Education: The Case of ISBEP At TU/e innovation Space. In SEFI 48th Annual Conference Engaging Engineering Education: Proceedings.

Valencia, A., Bruns, M., Reymen, I., & Pepin, B. E. (2021). Defining Intended Learning Outcomes (ILO's) of Inter-program CBL towards achieving constructive alignment in the context of ISBEP. In SEFI 49th Annual Conference Engaging Engineering Education: Proceedings.

Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. *Journal of engineering education*, *109*(3), 508–555. doi:10.1002/jee.20347

Velasco Montanez, M., Talmar, M., & Bruns, M. (2019). How can universities enable student-driven valorisation? An evidence-based approach. In Proceedings 35th EGOS Colloquium 2019, Edinburgh, United Kingdom (pp. 1–18).

Vermunt, J. D., Ilie, S., & Vignoles, A. (2018). Building the foundations for measuring learning gain in higher education: A conceptual framework and measurement instrument. *Higher Education Pedagogies*, *3*(1), 266–301. doi:10.1080/23752696.2018.1484672

Vermunt, J. D., & Verloop, N. (1999). Congruence and friction between learning and teaching. *Learning and Instruction*, *9*(3), 257–280. doi:10.1016/S0959-4752(98)00028-0

Walma van der Molen, J. H., & Kirschner, P. A. (2017). *Met de juiste vaardigheden de arbeidsmarkt op [With the right skills in the labour market] (White paper Nederlandse Vereniging voor Psychotechniek [NSvP]—Innovatief in Werk)*. Arnhem: Nederlandse Vereniging voor Psychotechniek.