CHALLENGE-BASED LEARNING:

Quality Criteria and Learning Outcomes

Bettina Renz, University of Nottingham, England

Sindre M. Dyrstad, University of Stavanger, Norway

Maria Swartz, Linköping University, Sweden

Marija Bezbradica, Dublin City University, Ireland

Annemarie Arets-Meulman, University of Twente, The Netherlands

Kęstutis Jankauskas, Kaunas University of Technology, Lithuania

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Table of Contents

Glossary

CBL	Challenge-Based Learning
Challenge	Real-life problem/challenge provided by stakeholders to be solved by learners participating in a CBL course
PBL	Problem-Based Learning
Learning Outcome	The deliverable of a study program – competences to be developed through CBL that can be clearly defined and assessed
Stakeholder	Challenge provider – real actors from the private or public sector (for example, companies, NGOs, local and national government) providing challenges in need of a working solution.
ECIU	The European Consortium of Innovative Universities
Learner	Student participating in CBL
Facilitator	Teacher/academic facilitating CBL
InGenious	International educational platform for collaboration between University and Industry where the students earn credits while working with real challenges from industry and society

Problem Context

Using Linköping's knowledge assets ('expertise') in order to contribute to societal development ('impact') is one of four prioritised areas in the University's operational plan for 2019-21. In order to align itself with the ECIU University approach to challenge-based learning and education, Linköping University is in the need of a systematic approach for mapping its available knowledge assets and expertise to relevant societal challenges.

The benefits of challenge-based learning (CBL) are clear, both in terms of ensuring the societal relevance and impact of academic work and in terms of developing students into independent learners. Studies of CBL in the academic context have clearly demonstrated improvements in key transferrable and professional skill areas that are not usually exercised in a more traditional learning environment [MB2]. These areas include deficitary skills like leadership, collaboration, innovation, initiative, problem solving and critical thinking. In this context, upskilling and training university staff through e.g. leadership training programmes (such as the one provided by the ECIU) directly aligns to the need for highlighting and addressing those deficits in both staff and students.

However, there remains uncertainty about how to operationalise CBL in higher education. In particular, more clarity is required on how best to identify criteria for selecting relevant societal challenges and how to develop a methodology suitable for achieving expected learning and innovation outcomes. Moreover, guidance needs to be provided for academic staff on how to properly frame and facilitate a challenge and its implementation in order to achieve teaching and learning excellence. Questions remain about how to accommodate the multidisciplinarity of challenges to be addressed in CBL when academic staff is usually single-subject versed. In the context of multidisciplinarity, cross-departmental and cross-program collaboration needs to be established. At the moment, existing CBL experiences are still implemented on the periphery of the curriculum and mainly focused on the masters level [MB3]. We address these uncertainties throughout the report.

In a Skype meeting on 24th May 2019 with Jan Axelsson, the Director of Collaborations at Linköping University and the contact person for our project, we sought further clarification regarding the focus of our project. He explained that education of students (particularly MA students, but also BA and PhD students) was the major focus (challenge-based *learning*), rather than impact-related research carried out by academic staff and expert groups (challenge-based *research*).

He also noted that more clarity is required on how to link CBL tasks to clearly defined learning outcomes and how to accredit them: how do we ensure that students are learning what they are supposed to learn (so they are not just 'doing for the sake of doing' something) and how is their work on real-life challenges to be accredited in an academic setting? There are also some questions about the extent to which challenge-based learning, problem-based learning and project-based learning (for definitions see below) can or should be used interchangeably.

This report is organised as follows: following a list of project deliverables, the concept of CBL will be defined. Subsequent sections will outline in detail the quality criteria for a good CBL challenge and suggest steps for how good CBL challenges can be identified and, crucially, how they can be shaped with the participation of all three contributors to CBL (learners, facilitators and challenge providers). Finally, the report discusses the learning outcomes of CBL and how they can be matched with specific CBL challenges.

Project deliverables can be described by a goal of the project. The goal is to develop a strategy towards systematically and consistently mapping the Linköping university's knowledge assets and to link resources with the selected challenges. The goal can be split into these objectives:

1. To develop quality criteria for choosing real life challenges to be used in education/CBL;
2. To define strategy how challenges can be shaped for use in CBL;
3. To find ways to match these challenges with learning outcomes.

Challenge-Based Learning Methodology

Exponential growth of the world-wide-web and of other information technologies made information available on demand and students can access information anytime and anywhere. Young people no longer have to graduate from a university in order to accumulate valuable knowledge, which previously had been "safeguarded" by academics. Furthermore, concepts and technologies are evolving so fast that professors may find it hard to adapt their courses continually to cutting-edge findings. As a result, the role of academia has changed. Today, the main task of students is to learn how to look for information and how to process it efficiently. As such, university education in the 21st century prepares students for life-long learning.

Pedagogical literature is rich in methods that are different from traditional lecture formats [6, 8]: Design Thinking, Blended Learning, Personalized Learning, Maker Movement, Coding, Service Learning, Agile, Computational Thinking, Problem-Based Learning, Project-Based Learning, Case-Based Learning, Inquiry-Based Learning, and Challenge-Based Learning. What unites these new learning methods is the diversion of attention away from the teacher and to the student. In student-centered learning methods like Problem-Based Learning (PBL) and Challenge-Based Learning (CBL), students - and not the teacher - take responsibility for what they learn and how they learn it. The teacher's role is that of a facilitator, guiding students through the learning process without taking a full control. CBL traces its origins to a project started by Apple in 2008 to introduce modern learning principles in K-12 education in the United States. It has since, as a concept, expanded into use in higher education worldwide.

Various authors define PBL and CBL differently. Some authors state that PBL and CBL share the same origins and therefore focus on their similarities [8]. Others look for differences [5, 7] in both approaches. The major difference between both approaches is in the nature of the problem or challenge to be addressed: while PBL tasks students with coming up with a solution to a problem posed by a teacher and often in a traditional classroom setting, CBL is aimed at the solution of a specific real-life challenge provided by external stakeholders, such as a company or other organisation. While in PBL the desired outcome is the discussion of the solution devised by the learners, in CBL the desired outcome is the actual implementation or prototyping of a solution in a real-world setting and often includes technology [13].

As such, CBL is more than a further development of PBL. CBL allows students to acquire new knowledge and at the same time develop important skills such as communication, presenting, creative thinking, work ethics, teamwork, networking, time management, flexibility, critical thinking and motivation by working in teams to develop solutions for the challenges. Such skills are generally conceived as enterprise skills and belong to the realm of enterprise education [14, 15].

Based on the above, the major components of CBL (the first three are shared with PBL, the last four are specific to CBL) can be summed up as follows [5, 7, 8]:

- CBL is a student-centred learning process;
- CBL occurs in small groups;
- The teacher acts as a facilitator who guides, but does not direct;
- Challenges in CBL are taken from the real world/provided by real-life stakeholders;
- Challenges are intentionally defined in a rather abstract way and students may interpret them in different ways and propose different solutions;
- During CBL student solutions are implemented and real impact can be observed;
- The solution of a CBL challenge requires multidisciplinary knowledge.

CBL is seen as successful, because it has an in-built motivation system. Taking ownership of the process of learning, creation, and actual change stimulates students. Students do not ask "why do I have to learn this?" because they learn the theoretical material and develop practical skills while applying them to real-world situations. Research has indicated that CBL (and PBL) classes performed slightly better than traditional classes in terms of learning content, because the learning process was more engaging [3, 4, 5, 7]. **Figure 1** below illustrates the CBL process as summarized in [8, 9].
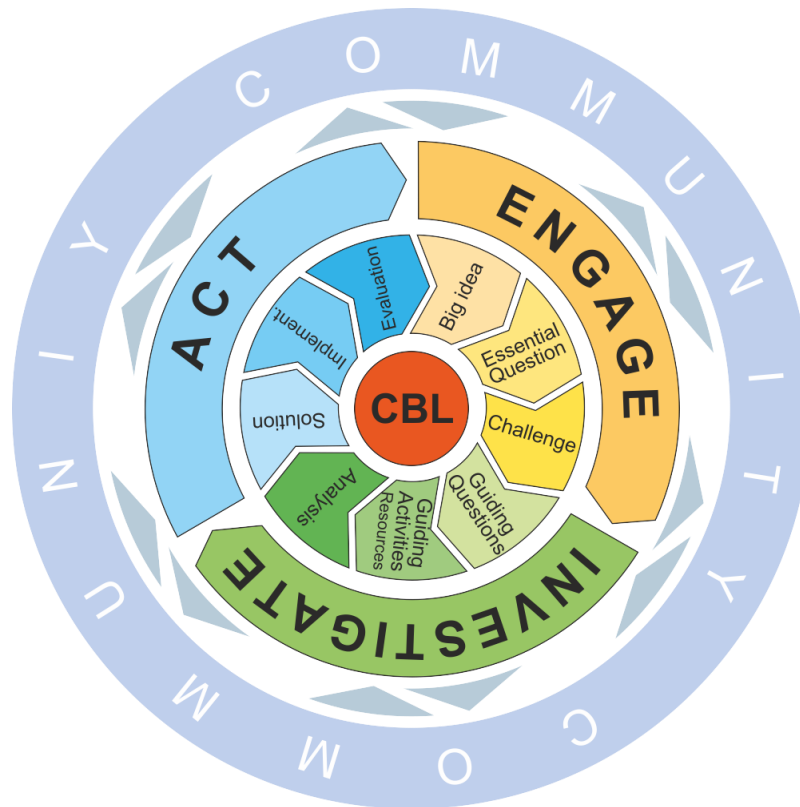
Figure 1 - The phases of Challenge-Based Learning [8, 9]

The CBL process can be broken down into three phases: engage, investigate, and act:

1) The 'engage' phase can be decomposed further as follows [8]:
   - The **Big Idea** is a broad concept that can be explored in multiple ways and is relevant to the learners and to the Community;
   - **Essential Questions** allow learners to contextualize and personalize the Big Idea;
   - A **Challenge** turns the Essential Questions into a call to action by tasking participants with learning about the subject and developing a solution.

2) The 'investigation' phase can be broken down into the following elements [8]:
   - **Guiding Questions** indicate the knowledge the learners will need in order to develop a solution to the challenge;
   - **Guiding Activities** and **Resources** are used to answer the Guiding Questions developed by the Learners;
   - **Analysis** of the lessons learned through the Guiding Activities and Resources provides a foundation for the eventual identification of solutions.

3) The 'act' phases consists of several steps as well [8]:
   - **Solution** concepts emerge from the findings made during the investigation phase;

- **Implementation** of the Solution takes place within a real-life setting with an authentic audience, including the stakeholders;
- **Evaluation** provides the opportunity to assess the effectiveness of the Solution, make adjustments and deepen subject area knowledge.

Learners reflect, document and share not only among themselves in the team, but also with a community. Feedback from the community is vital in creating the solution/prototype and improving it.

Developing quality criteria for choosing CBL challenges

Challenges can come from various sources: business companies, policies set by governments, specific community needs, global trends in society, or our personal everyday life [1, 3, 8]. For examples of the range of challenges put forward by various stakeholders for the University of Stavanger's *InGenious* call, see Appendix 1: Challenge Examples.

Challenge Quality Criteria

According to the academic literature on CBL and to the interviews we conducted with persons with experience of CBL at the University of Twente, Linköping, and Stavanger, the following criteria mark out a 'quality' challenge for CBL:

- **Significance** – students must recognize the personal relevance of a challenge or its global importance. To see students fully engaged, a challenge needs to be relatable. Seeing how a challenge relates to a student's personal life, or understanding its impact on the well-being of the community at large, will improve motivation and rally the CBL team for engagement [5, 6, 8]. Moreover, the solution to a CBL challenge should also generate enough significant added value to be recognized by stakeholders (challenge providers), thus, motivating them to collaborate [3, 8]. As a spokesperson involved in CBL at the University of Twente noted, the challenge not only needs to be significant for the students, but also for the stakeholder. The stakeholder needs to have a stake in the process and be willing to be a participant, not only as supplier of the challenge, but also in the role of facilitator and learner. A challenge can only be effectively addressed, if its significance motivates learners and stakeholders to work together towards the realisation of a successfully completed challenge.

- **Scale** – it should be possible to ideate and implement a solution to a substantial level with given resources (including time) [1, 3, 8]. Depending on the specific challenge in question, it can have different time demands on students. The University of Twente, for example, has previously worked with CBS challenges that were as short as a couple of days, a month, 3-5 months or long term (strategic). The scale of the challenge should therefore be tailored to the time allocated to a CBL task, or students can choose a challenge depending on their availability/interests. If a challenge is too broad for a given timeframe, learners might not be able to push a solution to a substantial level, which would discourage them.

- **Innovation potential** – students like taking ownership of the learning process and its outcome if it is not constrained too much [4]. As such, challenges that are too well-structured and dictate a specific solution strip away the chance for innovation and a genuine "Eureka" moment in learners [1, 3, 4, 6, 8]. According to Raymond Loohuis, *InGeniuos* spokesperson at the University of Twente, innovation and creativity should always be at the forefront of CBL. As such, CBL should always be at the front end of Henry Chestbrough's concept of the Open Innovation 'funnel', as exemplified in **Figure 2** below. Spokespersons at both Twente and Stavanger underlined the centrality of innovation potential in CBL and the need to avoid challenges representing a form of consultancy task for stakeholders. When suggested challenges are interesting, but do not meet the criteria for CBL in this respect they can be tweaked in consultation between facilitators/academics and stakeholders, or in some cases might instead be used

as topics for PBL or for individual student assignments. The following challenge was submitted to Linköping University by a construction and environmental company.

Example from Linköping University:

"We are not experts in design and how Excel or a web solution would be built up, we can calculate and make logic for how numbers are calculated. This project will culminate in a modern way of entering the data, presenting various types of diagrams and pictures that describe how much the customer will save, the customers who want the corresponding presentation they have previously been able to receive, but above all, water and the energy savings are now presented in pictures and via the web with login. The login must be for both NGL and its customers but with different rights. You should also be able to do so that the customer can enter his consumption statistics in the system himself so that we and the customer can follow up on what the measure has produced for results."

This was deemed by the CBL team as too narrow, as the company essentially wanted to 'buy' or gain a complete system to solve their problem - essentially a consultancy task. Following discussions between the InGenious team and the stakeholders, the challenge was reframed as follows in order to make it broader and allow for various solutions and forwarded to a CBL team:

BACKGROUND: *We have templates we work on to create energy calculations, quotes and profitability calculations. We enter information into the templates, which then generate various documents that are presented to the customer. The templates are developed by us and need to be coordinated, modernized with web solution and made more attractive to the customer.*

CHALLENGE: *We believe that people would engage more in their consumption and in the long term become more sustainable against the environment and their wallet if there was a more stimulating, simpler and more efficient way to measure and monitor their consumption and costs. Therefore, we ask ourselves how to use the technology of tomorrow to visualize, invoice, quotes and the consumption process. Can there be any type of tool that both we and the customer can use?*


- **Content coverage** – all the technical details of a probable solution are 'hidden' in multidisciplinary areas that academia traditionally likes to keep apart, e.g. mathematics, law, computer science, business, arts, social sciences, etc. Therefore, it is important to diagnose what major disciplines a particular challenge involves in order to position it in a specific semester of a specific study program [3, 6, 8].

- **Failure resilience** – it is important to bear in mind that in some cases, challenge solutions may be only partially successful or even a complete failure. Mechanisms of dealing with this eventuality need to be in place. For example, it is important to acknowledge that failure resistance in learners developed during the CBL engagement is also a very important element and potential learning outcome of the process [4, 5, 8]. The possibility of a sequence of sub-solution steps as a quality criteria of a 'good' CBL challenge is important in this respect, in order to avoid the outright failure of a challenge. Even if a 'complete' success of a challenge might not be possible in some cases, outcomes and success can still be achieved with the provision of sub-solutions as an intermediate step. The University of Twente's experience with CBL gained through an *InGenious* pilot in 2018, which was embedded in a Minor (Entrepreneurship

& Innovation and New Technology and Business Development), serves as an example of how partial solutions still lead to successful outcomes. All outcomes of the pilot were considered successful and will be followed up. In this case, three teams with 4 or 5 students finished projects in March 2019 and presented the solutions to the challenge providers. Overall, the solutions offered by the student teams were considered a success ranging from very good ideas that deserve further exploration up to concrete user-friendly solutions that, with some technical adjustments, are ready to be implemented.

Furthermore, the structure and complexity criteria taken from PBL [1] can help in the determination of quality criteria for a CBL challenge:

- **Structure** – a good challenge is more ill-structured than well-structured.
  - It should not be too transparent – a great number of variables about which forecasters are uncertain, therefore student may come to a solution based on assumptions or guesswork.
  - It should not be too homogenous and have no single straight-forward interpretation;
  - Interdisciplinary and/or multidisciplinary – a good challenge involves content from more than one discipline;
  - Dynamic – elements of a challenge are changing in time;
  - A challenge should have multiple solutions – a challenge should not dictate a single specific solution.
- **Complexity** – a good challenge is more complex than simple:
  - Knowledge breadth – challenge must require broad enough prior knowledge (general or in specific disciplines);
  - Comprehension difficulty – the difficulty of concepts that must be applied to come up with a solution and implement it must be moderate;
  - Solution path – the sequence of sub-solution steps is appropriate for a given time-frame (neither too long, nor not too short). Although the challenge needs to be complex and not too narrow, a solution should be realistically achievable. For example, a CBL challenge that led to a highly successful solution at the University of Linköping was the task to identify a solution about what to do with a certain industry by-product. Finding a 'sweet spot' between too abstract and too specific or between too global and too local must be performed with the available resources in mind [1, 3, 8].
  - Non-linearity – a set of measurable values that are used to determine a solution effect on its environment are related in a nonlinear fashion.
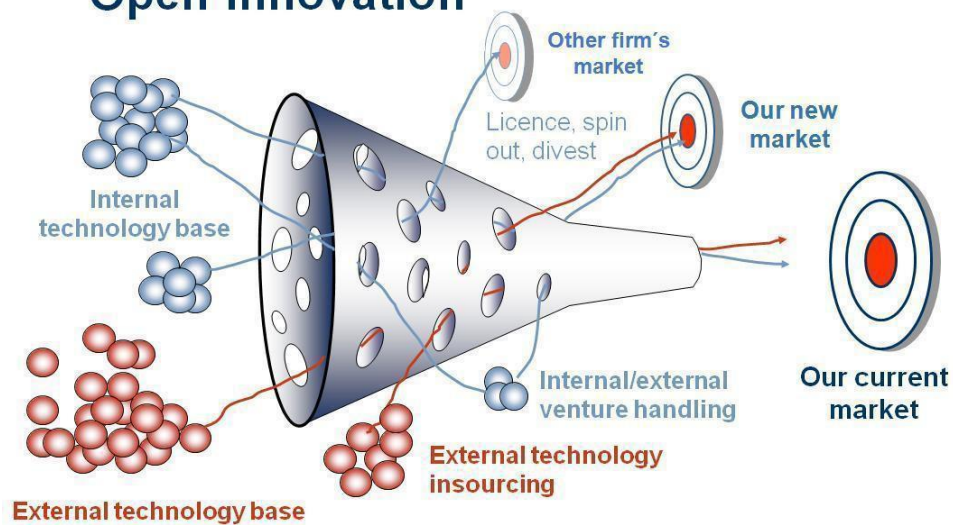
Figure 2 - Chestbrough's Open Innovation "Funnel"

The open innovation "funnel" is a visual model of the open innovation definition. It visualizes the position of:

- The blue internal technology base and the red external technology base;
- The various inflows and outflows of knowledge, including in-sourcing, licensing, spinning out, divest and venture handling;
- The various combinations of market(s) from a company's current market, a new market or another firms market.

Shaping Challenges

There are three major contributors/participants in CBL: stakeholders (challenge providers), facilitators (academics/teachers), and learners (students). All three groups should be actively involved in the identification of good challenges and in the process of shaping each challenge to make it fit with the specific CBL task and team.

The Role of Stakeholders

Stakeholders (be they businesses, municipalities or other organisations) are central to the identification and shaping of CBL challenges, because they provide the real-life challenges at the very heart of the process. According to our interviews at Twente, Linköping and Stavanger, stakeholders get involved in CBL for the following reasons:

- Enriching their recruitment process through access to new talent.
- Creating visibility and attraction to their company/organisation.
- Getting new ideas about the solution of specific problems.
- Access to creative, non-conformist thinking by students, which is especially important in the first stage(s) of innovation. For example, a company involved in the University of Stavanger's *InGenious* initiative had built up expertise in the field of Augmented Reality and saw possibilities for expanding its use to previously unexplored spheres, in this case health. The challenge was aimed at getting fresh ideas on how the company could expand the use of this technology. CBL was seen as particularly suitable for exploring an 'unploughed field'.
- Opening avenues for further cooperation with universities.
- Small and medium sized businesses/organisations might be most open to engagement with CBL, because they have the most to gain if students come up with good solutions to challenges. In return, they might give students more than larger organisations in the form of help/input.

Stakeholders can be encouraged to provide challenges for CBL in the following ways:

- Open call for challenges, as done, for example, by the *InGenious* initiative at the University of Stavanger. Challenges can be submitted through a website (https://uis.service-now.com/sh). In 2019, 8 challenges by different stakeholders were offered to interested students. Sufficient interest was expressed in six of these challenges, which were then taken forward with the involvement of a total of 28 students. Note that none of the cases at UiS this first year were submitted through the portal, but were individually recruited through facilitators network and events, and through 1:1 dialogue, composed, tweaked and translated before they were put in the portal for students to assess.
- Networking at places where you can meet and speak to organisations (conferences, trade fairs, etc). This is successful especially if contacts already exist, but new relationships can also be built. In these cases it is important to have a great pitch that can lead to a more in-depth meeting afterwards.
- Utilising existing contacts (with business and other organisations) of academic staff at respective universities. According to various interviewees (including the student placement officer at the University of Nottingham), drawing on existing networks by academics is the most successful way of attracting quality challenges from external stakeholders.

- It is important to identify the right person within a specific stakeholder. The availability of a named person enthusiastic about cooperation and buying into the CBL process is more important than the organisation itself.
- The advantages of engagement with CBL (as outlined above) should be explained to any potential stakeholder.

In the experience of *InGenious* leaders at Linköping and Stavanger University, stakeholders need to commit to the following in order to ensure the success of CBL:

- Be available for and favour the interaction with university students, provide help and input required for the solution of the specific challenge.
- Identify a named employee with personal engagement in the challenge and with a mandate to run the challenge through to completion.
- Confirm that the challenge is validated and signed at management level.
- Ensure that the challenge is prioritised and of real significance.
- Open their knowledge base to students

The Role of Academics

Academics/facilitators play an important role not only in using their existing networks to build relationships with external stakeholders for the provision of CBL challenges, as described above. Academics/facilitators involved in CBL also are central to ensuring the quality and workability of a challenge.

- Academics/facilitators can enhance the quality of a challenge by rewriting/tweaking any offered challenge that is out of balance in order to ensure its fit with the educational programme in question. This includes liaison with the stakeholder to agree on the final wording of the challenge. This requires in-depth knowledge of the stakeholder. A clear description of the stakeholder and what it stands for is just as important as the clear description of the challenge itself.
- Academics/facilitators are responsible for maintaining the stakeholder's interest in the collaboration high during the often long cycles required to bring a good challenge to fruition. In the experience of Linköping *InGenious*, it can take up to 1.5 years from a challenge being identified and described to the start of the course. The relationship and communication between the university and the organisation during that time needs to continue. A relationship of trust is therefore important.
- During challenge selection, academics/facilitators need to bear in mind CBL team composition and environment versatility. A team can/should be composed of students from different disciplinary fields and will be exposed to stakeholders with very different knowledge backgrounds.
- Academics/facilitators are responsible for offering qualified mentoring to students, ensuring the success of a challenge from the outset. There was widespread agreement amongst our interview respondents that what matters most in CBL is not only identifying or providing 'quality' challenges. The quality of the facilitation (coaching, mentoring and support) offered to students involved in CBL is as, if not more, important [2, 4, 8]. A challenge is only as good as the guidance provided in order to avoid students from going in circles, bumping into insurmountable obstacles, or merely 'doing for the sake of doing something' without direction. As such, facilitators/academics involved in CBL need to be able to provide not only generic guidance, but specific guidance tailored to the challenge in question. In order to uphold the quality of the CBL process, this guidance needs to be specific enough to be of use, but at the same time not too

prescriptive in order to avoid pushing students towards a particular solution. As the skill of providing such guidance for CBL is not part of the 'traditional' training of academics, universities interested in CBL need to take the training of facilitators serious. Guidance for multidisciplinary challenges, moreover, might require input from various experts.

The Role of Students

CBL is a student-centred approach. The involvement of learners in the identification and shaping of challenges is therefore essential. Although trained facilitators/academics need to ensure that a challenge has the required quality criteria and is suitable to the specific educational programme, learners can be involved in the preparatory phase as follows:

- A range of possible challenges is forwarded to students, in order to gage interest. At the University of Stavanger, for example, students were asked to rank challenges in the framework of the *InGenious* initiative from 1-3 according to their interests and skills. Based on their interests and a written motivation letter, students were then assigned to specific challenges. The University of Twente has used a similar 'matchmaking' system to bring together students and challenges. A new online platform is currently under development (https://output.webhare-test.utsp.utwente.nl/ingenious/challenges/).
- Students at Stavanger University were also tasked to an extent with ensuring qualified facilitation of the CBL process. They were tasked with contacting academics and other relevant experts themselves, who they believed to be able to help them with solving the challenge.
- Once students are assigned to a specific challenge, they interact with the facilitator to turn a broad challenge into a manageable task, to make the challenge their own and to decide how to solve the challenge.

Matching Challenges with Learning Outcomes

The identification of 'quality' real-life challenges for CBL is a crucial first step in the process. However, it has to be borne in mind that CBL is above all an educational activity and approach, whose outcome goes far beyond finding a solution to a specific problem. In order to avoid a situation where students simply do something for the sake of doing, or in the worst case act as free consultants/labour for an external stakeholder, a process needs to be put in place in order to ensure that, from an educational point of view, students are learning what they are supposed to learn, are developing clearly defined skills and transferrable competencies, and there is clarity on how their work on real-life challenges can and will be accredited in an academic setting. In other words, the selection of challenges and design of CBL programme needs to be based on the understanding that there needs to be a strong relationship between content, course objectives and the competencies you seek to develop in students from challenges. As such, matching CBL challenges with clearly defined learning outcomes is essential.

Learning Outcomes in CBL

According to our interviewees at the Universities of Twente, Linköping and Stavanger, the major learning outcomes of existing CBL-related programmes (such as the *InGenious* initiative) can be summed up as follows:

- Learn to work in interdisciplinary groups;
- Handle contracts between each other in the group;
- Develop good practice through exchanging views and experiences with other professionals;
- Acquire updated knowledge in relevant areas of expertise and skills, and also other areas within a subject;
- Convey key subject matter through the relevant forms of expression;
- Reflect on ethical issues within the discipline;
- See a topic in a broader context from a societal perspective;
- Write a business plan;
- Identifying and researching markets, brainstorming and evaluating ideas;
- Organizing the finances for a new venture;
- Apply the acquired expertise of innovation in established companies;
- Present their idea, learn how to sell;
- Solve a challenge/create a prototype/solution .

These learning outcomes align broadly with the three major elements of CBL as delineated in the literature on the subject [8], which further align with the three main contributors/participants in CBL. In deciding on how to assess students' performance in CBL, appropriate emphasis should be placed on all three elements:

- **Process** – students engaged in a programme of CBL will benefit most from the creative process of CBL itself. Aside from discipline content knowledge, they will gain additional insights into the machinations, advantages and pitfalls of teamwork, learning from communication with other learners, facilitators and stakeholders. Students also will build personal experience and a sense of ownership over their work and the results. Communication inside and outside of the team will provide valuable insights into how different stakeholders see the challenge and how to develop a common language, which would be understandable to a general audience without a specific technical background.

Reflection by the students about what they learned from the process (how they achieved the learning outcomes related to process) is an important part of CBL and should be a part of the evaluation.

- **Content** – content knowledge in predefined discipline areas can be selected and fine-tuned by academics/facilitators. This should be done in the early stages of challenge selection. On completion of the course, student knowledge coverage and depth attained during CBL can be evaluated/tested.
- **Product** – stakeholders providing a challenge hope to benefit the most from the product/solution created during a CBL course. By providing a challenge, they will expect a certain improvement for their organisation or business within clearly defined parameters. At the end of the course, they should be able to evaluate how valid and effective a product/solution is from their point of view.

Matching Learning Outcomes with Challenges in CBL

In deciding on a CBL course's learning outcomes, facilitators can start by using standardised content and then proceed to connect this to 21st century skills through the process [9]. In the design of the course and decision of learning outcomes, it should be borne in mind, however, that CBL is a student-centred approach and students should take responsibility of the learning process from the outset. This includes their ability to relate what they are learning/have learned to predefined standards. On the one hand, challenges can be designed to meet specific curriculum standards and objectives and focus on the achievement of expectations. On the other hand, in line with a student-centred approach, challenges can include the learners in aligning the experience to applicable standards and curriculum goals.

One way of doing this is to involve students not only in the choice of challenge, but also engage in a conversation with the facilitators and stakeholders about what would make for a successful completion of the challenge. In other words, let students be a part of the mapping from the outset. This improves learners' sense of autonomy and relatedness and a sense of purpose [16]. Involving learners in the establishment of learning outcomes also allows for taking the multidisciplinary nature of CBL into account. As the *InGenious* spokesperson at the University of Twente noted, although some basic learning outcomes regarding process, content and product have to be defined upfront, learning outcomes can also differ for different learners in the team depending on their background and experience, even if they work on the same challenge. Individual learning goals should be determined and logged. As such, CBL can also be used to assist learners in achieving specific academic goals. Throughout the CBL process, students should reflect, individually, in the team and with the facilitators whether they are still on track towards achieving their goals/learning outcomes.

Ensuring that a CBL challenge and process aligns with specific standards and curriculum goals is best done during the investigation phase of CBL (see above) when guiding questions are developed and guiding activities and resources are identified. Through these steps, all contributors/participants in CBL (learners, facilitators, stakeholders) can contribute towards the creation of a curriculum map that reflects personal and group interests, is aligned to standards and curriculum requirements and will lead the team to a thoughtful solution to the challenge. Being able to draw on this map, learners embark on an organised journey to answer the questions and collect evidence of learning along the way [8].

Conclusions

The advantages of CBL for the quality of teaching and learning in higher education are clear. However, in order to ensure the success of CBL, various factors regarding the selection and shaping of quality challenges and the matching of these challenges to specific learning outcomes need to be taken into account:

1. **Selecting and shaping challenges to hit the 'Sweet Spot'.** Challenges should not only be interesting, but need to be carefully chosen and adjusted to ensure that the **significance** of the challenge is evident to both learners (relevance to own life/community) and the challenge providers (potential for real-life impact of the students' findings for their work and activities); the **scale** of the challenge needs to be realistic regarding its scale, which needs to be tailored to the time and resources available; the challenge needs to have true **innovation potential** and not be a consultancy task; content coverage needs to be **multidisciplinary** and pertain to the expertise available in the CBL learner team; **failure resilience** needs to be taken into account when a challenge is chosen and shaped. Not all challenge can be solved fully. The possibility of sub-solution steps is crucial, as is the acknowledgement that (partial) failure to solve the challenge will not negate other important learning outcomes achieved by students as a result regarding process and content coverage.

2. **Process matters.** CBL is not only about learners/students creating a solution to a real-life challenge and having real-world impact. Transferrable skills gained through the teamwork process of CBL, as well as new content mastered as a result of this process, are as important, or even more important than the resulting product/solution itself.

3. **The need for collaboration in all phases of CBL.** CBL has three main participants – learners (students), facilitators (teachers) and challenge providers (external stakeholders). CBL will only be successful if all three participants collaborate throughout the process, from the early stages of selecting and shaping the challenge, the matching to learning outcomes, the process itself and the creation of a solution.

4. **Generic and individual learning outcomes.** Each challenge needs to be matched individually to tailored learning outcomes. A range of generic learning outcomes regarding process (teamwork skills, presentation skills, communication, etc) can be used as a starting point. However, given the multidisciplinary nature of CBL, individual learning outcomes regarding content coverage also need to be identified for each learner in line with their specific interests, requirements and expertise.

5. **Pedagogics and challenge go hand in hand.** The central rationale for developing CBL as a tool for teaching and learning in higher education is to make students' skills and experience more explicitly relevant to the 'real world' through the solution of real challenges. However, it needs to be borne in mind that true learning can only be achieved if the real-world challenge goes hand in hand with a process grounded on clear pedagogical principles. As such, universities need to take serious the need for training in best practice in CBL for academics/facilitators, many of whom are not familiar with the practice.

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Appendix 1: Challenge Examples

Challenges submitted to via the University of Stavanger's *InGenious* online platform in 2018:

- Onshore oil waste management is particularly in demand in North America, Russia and the Middle East, due to the large number of onshore wells. Offshore exploration, meanwhile, also generates waste that must be transported for processing. Ennox's technology is well suited for offshore installations, eliminating the need for expensive onshore transport logistics. What is the best market approach for this technology, and how can the technology scale and serve society and the environment in the best way?

- Höylytt (a music- company) has created a product that gives children an immediate mastery feeling and joy of creating music. How can the company reach out to their target audience, and find the entry point to a larger market?

- Esoft (the company) delivers an ERP (Enterprise Resource Planning) system for small and medium-sized businesses that have engineering and production activities. Development of the system will be done from the bottom up and launch to the market is planned for Q1 2020. A separate team is dedicated to this, but need assistance both on the commercialization, the go-to-market strategy, marketing, design, commissioning and for user experience. The key word here is commercialization, software programming and design, and the case is suitable for students with different backgrounds. The development of Esoft is supported by Innovation Norway and a separate project team of 6 people working continuously with the completion and development.

- Bate (the company) is setting up a climate plan to form a common basis for the development of living environment, projects, and services to meet sustainability and climate goals. As the developer, we can influence the choice made in development projects directly, but we also want to influence the individuals to contribute to reaching the sustainability and climate goals. We already do this today through our communications strategy, and have several ways to influence the members and residents. Regardless of what action we, or others, will take, it will always be a challenge to motivate individuals to act more sustainable. The majority of individuals will always be concerned with "whats in it for me" at the current time. The question is therefore; how do we motivate the individual to act more sustainable? How can Bate with our long-term ambitions help ensure that individuals are stimulated to contribute to a sustainable future?

- SolidRock (a new and sustainable low carbon concrete for buildings and civil engineering constructions) can potentially use all of the waste from the mining industry and apply this in the construction sector, building bridges, houses or roads. It is assumed it needs to compete with traditional concrete both on price and quality in order to be successful. How should a business case look like for SolidRock that will utilize the benefits of the product to the maximum. What market should SolidRock target and how should this be marketed. Should there be any incentives from the government in order to help SolidRock to the marked?

- Technological advances recently made in Augmented Reality (AR) , have made the technology ripe and ready to be introduced to more areas/sectors. Bouvet has historically been targeted to traditional industry, but see that aspects of this technology is also relevant for tasks within the health sector. It will be interesting to look at the possibility of contributing to efficiency and distribution of services through the use of AR technology.

Appendix 2: List of Interviewees

Name of interviewee	Role(s)
prof.dr.ir. Tom Veldkamp	Dean of the Faculty of Geo- Information Science and Earth Observation (ITC) University of Twente; Dean of the University College Twente
dr.ir. Jasper Homminga	Assistant professor University College Twente
drs. Barend Köbben	Senior Lecturer -University College Twente
prof. dr. Norman Kerle	Faculty of Geo- Information Science and Earth Observation (ITC) University of Twente
dr. Raymond Loohuis MBA	Senior lecturer & researcher at NIKOS (department for entrepreneurship, strategy & innovation management
ir. Frank. van den Berg	Head Centre of Expertise in Learning and Teaching University of Twente
prof. Charlotte Norrman	Senior lecturer in the Division of Project, Innovations and Entrepreneurship Linköping University
Albert Rudholm	Facilitator at Almi East Sweden/*InGenious*
Lars Urheim	Community Manager and bridge between students and firms, LevelUp & InGenious, University of Stavanger
Minnah F. Haniffa	Head of Centre for Entrepreneurship, University of Stavanger
dr. Elisa Thomas	Post-doctor, Center for Innovation Research, University of Stavanger Business School, University of Stavanger
Steffen Myklebust	Contact person at Bouvet (company using InGenious), Stavanger, Norway