COMPARATIVE ANALYSIS OF CHALLENGE-BASED LEARNING EXPERIENCES

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ABSTRACT

A challenge-based learning experience is a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. It is typically multidisciplinary, takes place in an international context and aims to find a solution, which is environmentally, socially and economically sustainable. Challenge-based learning has become a buzzword in the last decade, following the US National Academy of Engineering creation of a list of "grand challenges" for engineering for the 21th century. Since then, many universities have introduced challenge-based learning in their educational offerings. However, there has so far been little overview or comparison of possible implementation of challenge-based learning experiences. This paper aims to address this gap by reviewing and comparing four selected challenge-based learning experiences. We identify commonalities and unique traits amongst them and identify avenues for future development in this area.

KEYWORDS

Challenge-based learning, Sustainability, Social Responsibility, CDIO Standards 1, 4, 5

INTRODUCTION

In 2008, the US National Academy of Engineering (National Academy of Engineering, 2008) asked an expert committee to identify "grand challenges" that it will be critical for societies worldwide to address during the coming century. The committee identified fourteen grand challenges, ranging from Making solar energy economical to Engineering the tools for scientific discovery (See Figure 1). The challenges can roughly be grouped into four areas: Sustaining life on earth, Living secure from threats, Promoting healthy living, and Living and learning with joy.

The idea of “grand challenges” has quickly spread across the world, and it is increasingly popular in government agencies and in academia to state research & innovation problems as “challenges”. Examples include the DARPA Grand challenge (autonomous vehicles), Grand challenges in Global Health (www.grandchallenges.com), the Swedish National Agency for Innovation’s (VINNOVA) program in Challenge-driven innovation, and non-governmental groups such as Engineers Without Borders. It follows that “challenge-based learning experiences” are being included already in bachelor and master-level education. Examples include "Global Challenges in Engineering" at the University of Western Australia and the "Green Challenges" student competition arranged by the Technical University of Denmark. Challenge-based learning is also addressed on the program level, where it is argued that a program that addresses grand challenges should include research experience, have an integrated curriculum, train entrepreneurship, provide a global dimension and offer service learning. Taylor’s University in Malaysia outlines such a program and reports on some initial positive student reactions (Al-Atabi, 2013).

However, challenge-based learning is a relatively new concept, with few (if any) comparative studies done so far. There are many aspects that require further investigation, including to understand how to design such learning experiences and their effects on student learning, design appropriate learning spaces, develop needed faculty competence, cost-effectiveness and scalability. The aims of this paper are thus to:

- Provide a survey of examples of innovative university-level challenge-based learning experiences across the world
- Describe in some more detail one particular challenge-based learning experience, i.e., the Challenge Lab at Chalmers University of Technology
- Identify common and unique characteristics of the surveyed challenge-based learning experiences as well as success factors for their execution.

It should be pointed out that we are focusing on university-level challenge-based learning. The concept is also used for primary and secondary learning experiences (e.g. Apple (2011)). Such challenge-based learning experiences typically are rooted in one of the grand challenges (e.g. “Make solar energy economical”), but lack the technical difficulty and combination of social and technological problem-identification and –solving associated with the university-level challenge-based learning experiences considered in this paper.

The remainder of the paper is structured as follows: The first section has provided an introduction to the area. In the second section, we discuss the term “challenge” and how it is used to drive research and to some extent education. We will also provide a definition of a “challenge-based learning experience”. In the following two sections, we review four typical challenge-based learning experiences and then compare them. The final section of the paper concludes the paper and outlines directions for future work.

CHALLENGE-BASED LEARNING EXPERIENCES

Now let us discuss what a “challenge” might be in the context of engineering education. What skills are needed to address a “challenge”? How can these skills be developed?

The Swedish National Agency for Innovation (Vinnova, 2015), which runs challenge-based research & innovation programs on future cities, healthcare, IT and production, claims that challenges are international, multidisciplinary, pertain to environmental, social and/or economic sustainability and therefore cannot be solved by a single actor: university, industry and the public sector need to mutually work with the issues.

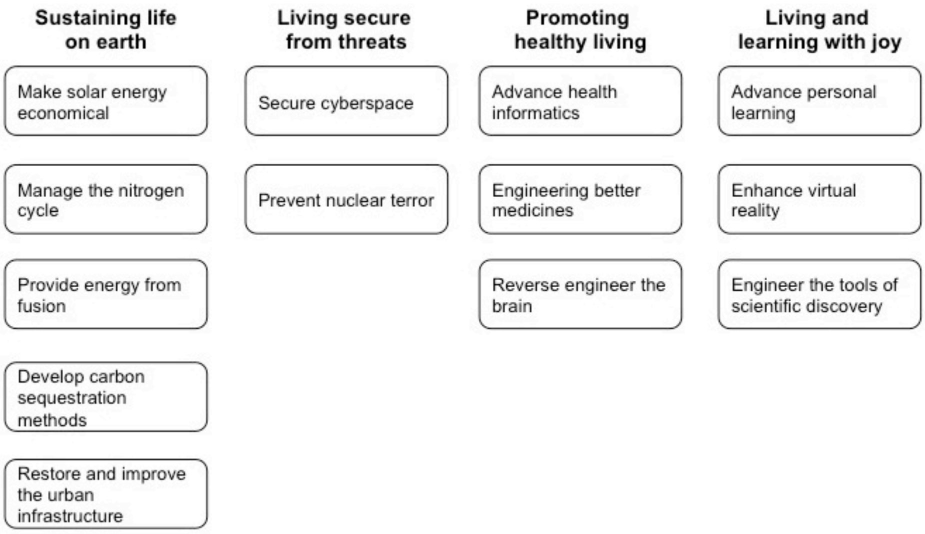

Figure 1. US National of Academy Grand Challenges
(Based on National Academy of Engineering, 2008).

Vinnova argues that a particular role of the public sector is to pose challenging requirements on future solutions. Hence, addressing challenge requires the skills to work with very ambitious goals, with a multitude of actors with different goals, with many technologies, and with an understanding of the long-term effects of proposed solutions, in addition to disciplinary knowledge and basic professional skills.

There are similarities between a challenge-based problem setting and the concept of wicked problems, which describes situations in which it is “less apparent where problem centers lie, and less apparent where and how we should intervene even if we do happen to know what aims we seek” (Rittel and Webber, 1973). Lönngren (2014) describes five characteristics of wicked sustainability problems: 1) the understanding of the problem cannot be separated from the understanding of the solution; 2) there is no single right solution, but there are multiple different ways of addressing the problem that are not always compatible with each other; 3) a solution may be favorable at one point in time, but highly problematic at another; 4) each problem is novel and unique since each problem is embedded in a unique context, and solutions need to be carefully developed on that basis, and 5) competing value systems and objectives exist for each problem, since problems and solutions concern multiple stakeholders who each have different interests.

A main pre-cursor to challenge-based learning experiences is problem-based learning, where students (teams) are posed with a design, research or diagnostic “problem”, and the learning takes place through the process or working out the solution. However, challenge-based learning experiences raise the level of difficulty of the problem (addressing “societal challenges”), are inherently multidisciplinary but without knowing what disciplines are needed prior to project start, and often have the stated aim that solutions should not only be proposed, but also implemented. Challenge-based learning experiences further, as shown later, often combine addressing societal goals (sustainability) with business development. High ambitions concerning results are combined with compressed time frames. This development from traditional and problem-based learning to challenge-based learning is outlined in Figure 2.

Thus, we suggest the following definition of a challenge-based learning experience:

A challenge-based learning experience is a learning experience where the learning takes places through the identification, analysis and design of a solution to a sociotechnical problem. The learning experience is typically multidisciplinary, takes place in an international context and aims to find a collaboratively developed solution, which is environmentally, socially and economically sustainable.

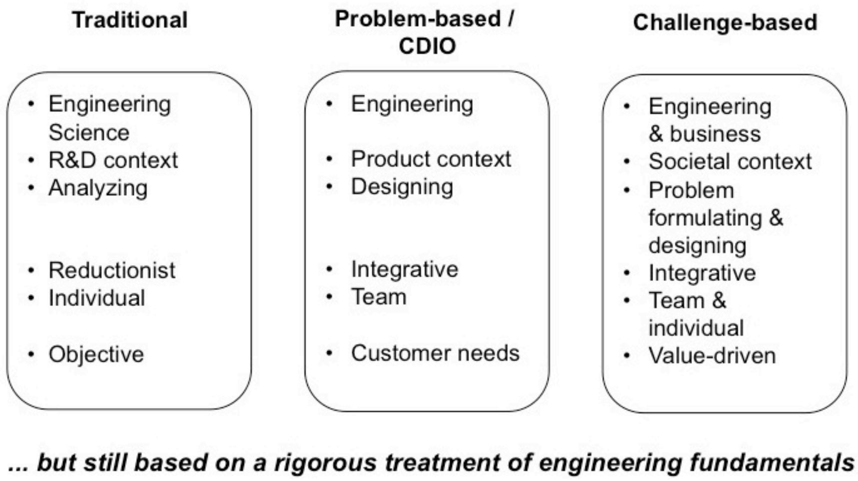

Figure 2. Evolution from traditional to problem-based to challenge-based education.

EXAMPLES OF CHALLENGE-BASED LEARNING EXPERIENCES

In this section, we will review a few selected challenge-based learning experiences. They are selected to illustrate that challenge-based learning experiences can be implemented in a variety of ways across (and outside of) the curriculum. We start with a first-year experience and end with a master thesis experience. On the way, we review an umbrella program that organizes a large number of student projects and one challenge-based learning experienced arranged as a competition.

Example 1: University of Western Australia's Global Challenges in Engineering

The University of Western Australia offers a first year Civil Engineering course based on challenge-based learning, namely "Global Challenges in Engineering" (Baillie et al. 2014; University of Western Australia, 2014).

The course description argues, "Engineers conceive ways to rearrange objects, materials and systems to achieve beneficial outcomes". Students develop these skills by carrying out a real project in a geopolitical context, working in collaboration with a non-government organization. Poverty and waste problems are typically in focus. Examples projects include "The Briquette Press" (made from refuse wood), "Composting in the Shire of Roebourne", and "Safe Water Provision in Condo-Timor Leste".

The course aims to develop a large number of learning outcomes including communication, enquiry & literacy, teamwork & project management, cultural and gender diversity, critical thinking related to environmental, legal, ethical, health and safety impacts of engineering, environmental, social and economic context in which engineering is practice, and design processes including creative thinking, evaluation, failure modes assessment.

Teaching activities during a typical course week (the course duration is 13 weeks) comprise one information session (lecture on, e.g., “Waste, environment, and society”) and one practical workshop session (project teamwork). The assessment considers workshop attendance and participation, weekly progress reports, project proposal including oral presentation and the final report including oral presentation.

In summary, the Global Challenges in Engineering course demonstrate that first-year engineering students can successfully take on projects with both technical and societal components in faraway countries. The course introduces a broad view of the engineering profession and thus sets the scene for the entire program.

Example 2: Purdue University’s EPICS program

The EPICS (Engineering Projects in Community Services) program has been operated by Purdue University in the US since 1995 (EPICS Purdue, 2015). The program offers a framework by which teams of undergraduates from different disciplines collaborate to “design, build, and deploy real systems to solve engineering-based problems for local community service and education organizations”.

The basic idea of EPICS is to bring together community service agencies who need development of specific technological solutions, but may not have the financial resources to pay for professional consultants work with students who need to complement their disciplinary knowledge with design, collaboration and communication skills, in order to become successful professionals.

The intended learning outcomes from EPICS include design-build-test skills, teamwork and communication, project planning & leadership, customer-awareness and understanding of ethical, economic, and legal issues.

The course organization (Spring term 2015) includes weekly lectures on design, ethics, empathy, interviewing & observation, leadership and prototyping/craftsmanship. There is a detailed schedule for the project work including deliverables per week, indicating that the projects are run in a highly structured and similar way.

Examples of projects include “Shelters for safe-housing to impoverished and natural disaster areas”, “Alternatives to firewood for fuel in Uganda”, “Water resources management”. However, the EPICS projects are diverse and some are somewhat less challenge-based than the mentioned.

EPICS is a large program, which typically runs thirty projects per year, each with 8 to 18 students. It has a management and administration staff of about ten people, circa 50 scientific advisors and twelve teaching assistants.

In summary, EPICS offers a model for enabling many students to get involved with community service agency-driven design-build projects. The variety of needs amongst the “customers” may however not guarantee that a project involves a “challenge” in the sense of this paper.

Example 3: TU Denmark’s Green Challenge

A student competition is another variant of the challenge-based learning experience. The Technical University of Denmark (DTU) operates a student competition with the ambition of promoting green designs, “The Green Challenge” (Hussman et al., 2010; Technical University of Denmark, 2014). The competition has been run bi-annually since 2010, and annually since 2014.

The competition has categories for BSc thesis projects, MSc thesis projects and other projects. The latter category includes ideas and concepts that are developed through project work in standard courses at bachelor and master level. In 2014, the competition was spilt into 8 categories, namely the 8 combinations of "ideas" and "concepts", and MSc thesis/BSc thesis/MSc course/BSc course, respectively. A large number of DTU students enter their projects into the competition: In 2014, there were 276 participants.

The competition incentivizes DTU students to address green issues with visionary, bold approaches still aiming towards implemented solutions. The incentive comes partly from cash prizes, partly from access to a number of events that bring companies in contact with students interested in green business development. Further, the competition is voluntary, but not extra-curricular. DTU aimed for a design that provided “a lot of carrot, but no stick” (Hussmann et al., 2010).

The competition is based on an overall assessment of the effectiveness of project presentation, to what extent is the project likely to have a positive environmental or energy impact, to what extent is the project technically applicable and likely to be realized, and to what extent is it visionary and/or innovative. Students have to argue that their projects address these issues in their presentations, and it can be claimed these assessment criteria are intended learning outcomes of the competition.

Examples of winning projects include “Covering System for Orchards that Reduce the Pesticides, while Producing Solar energy”, “Substitution of Hexavalent Chromium”, “Waste Management in Rural India”. Most projects focus on environmental sustainability, but some (such as the last mentioned project) also address societal sustainability.

There is a minimum of taught topics in the Green Challenge, although some instruction of how to carry out an “innovation pitch” is provided. In addition, a series of events (Green Week, Green Career, Lunch talks, Next Step, Pre-Burner Saturdays) are designed to create a community of the students taking part in the competition, DTU researchers and sponsoring companies.

An interesting property of the Green Challenge is that it can be run at little additional cost. The students would have carried out their BSc and MSc projects anyway, and regular faculty carries out the main part of the student supervision across DTU.

In summary, the Green Challenge constitutes a flexible, inclusive and relatively low cost way of arranging challenge-based education for a large student group.

Example 4: Chalmers University of Technology's Challenge Lab

Our final example is the Challenge Lab (C-Lab) course at Chalmers University of Technology (Holmberg, 2014). C-Lab aims to be an arena where students, based on dialogues with multiple stakeholders on issues for a sustainable society, initiate projects that take a challenge-driven perspective on sustainability issues as their master thesis. The C-Lab can be classified as a "social lab" (Hassan, 2014) i.e. a lab characterized by being *social* (the actors participate actively, not just as experts but as co-creators), *experimental* (solutions are developed and prototyped in an iterative process), and *systemic* (solutions should not only mitigate symptoms or parts of the problems but aim to identify and address the root cause of the problems).

The course is run as a set of collaborating MSc thesis projects open for students from all disciplines at Chalmers. A space ("The C-Lab") is dedicated to the group of projects, with the purpose to be an arena for stakeholder dialogues stakeholders, which the students arrange when working on their projects and thesis. The common space further allows a deeper collaboration between the students and opens up for discussions between disciplines and projects. The C-Lab is located at the intersection of Chalmers and a neighboring science park in order to create a "neutral" arena where stakeholders from industry, academia and the public sector can meet and work towards addressing long-term challenges.

The course aims to develop student skills in working across disciplines and from a challenge driven perspective. A key idea is that students can in this context simultaneously be unthreatening and challenging, and thus take on the role of change agents to society. This means going further than the typical MSc thesis projects, i.e. not only designing the solution but also implementing it. The intended learning outcomes of the course include (selection)

- Describe critical sustainability challenges and reflect upon unsustainable trends and necessary paradigm shifts.
- Apply a systems perspective on sustainability challenges.
- Apply relevant frameworks and methods for sustainable development, from a challenge driven approach.
- Understand basic theories and methods for transformative leadership in a challenge driven process, including applying self-leadership and dialogue tools.
- Reflect upon important critical factors and lock-in effects on societal, organizational and individual levels, relevant for system transitions.
- Understand how systems design thinking and multi-level design can be applied to sustainability challenges.

In addition, students should develop the intended learning outcomes of MSc thesis projects at Chalmers, including specialized knowledge within their discipline, ability to work independently, written and oral communication skills etc.

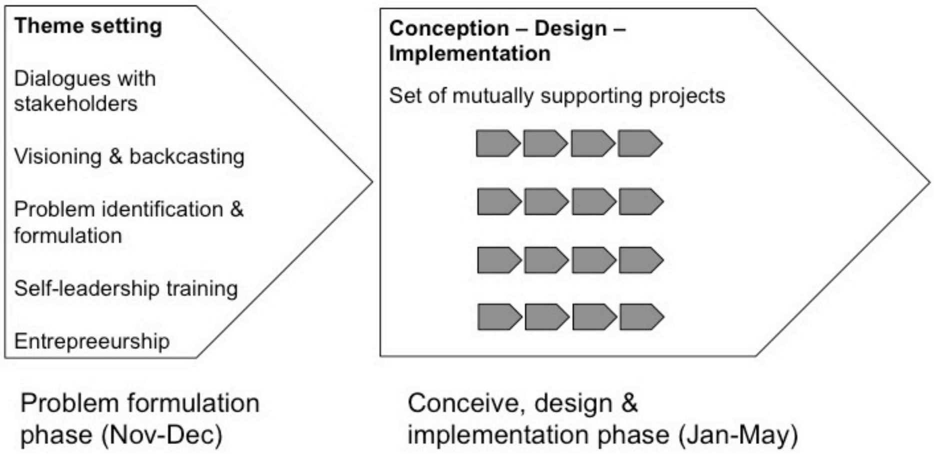

Figure 3. Challenge Lab course process.

The course is organized in two phases. In the first phase, the students start from a theme, and then work towards formulating the projects that they will carry out in the second phase, see Figure 3.

The first phase "problem formulation" is carried out in dialogue with local industry and public sectors. In order to support this activity, lectures and workshops on dialogue tools, backcasting, self-leadership, design thinking and entrepreneurships are offered. The aim is to develop the students' skills in independently formulating the problem to be addressed. In the second phase, the students work independently or in pairs on their MSc projects. However, the projects collectively address the theme, and the students work in the same space, continually updating and supporting each other's projects. The teacher team reflects the multidisciplinary setup and includes faculty members from Chalmers' departments of energy and environment, technology management and economics, and product and production development.

The theme for 2014 was "Urban Transportation", based on examples in the Gothenburg Region. Example projects include "Biodiesel fuels in Sweden: drivers, barriers, networks and key stakeholders", "A Mobile Application for Public Transport - How can gamification be used to promote the use of electric buses for a sustainable future?", and "Redefinition of transport sharing system for a sustainable future". The projects thus lean towards the local environment sustainability goals, but also reflect the broad range of disciplines involved in the lab.

In order to evaluate the setup of the C-Labs course, the 12 students who participated in the C-Lab 2014 were all interviewed. Positive experiences included the stakeholder interaction, the C-labs space, the working and socializing with people from different theoretical and cultural backgrounds (network), learning about themselves including self-leaders, and the opportunity to themselves form the questions rather than do assigned task. However, the students also expressed difficulties with the process (understanding how and when to contribute), and did not think that the project had significantly deepened their specialized knowledge and were overwhelmed by the number of new tools and concepts.

Furthermore, it became evident that the lectures on the subject of sustainability, and the training in methods for enabling them to take a challenge driven perspective on their work and thesis were demanding. Nevertheless, this was needed as the students had many different educational backgrounds. During the evaluation, it was concluded that a compulsory preparatory course was needed before going into the C-Lab. Finally, the C-lab team of teachers came to the conclusion that if the number of students would be many more, the methodology would be difficult to hold on to. Scalability is an issue for set-ups such as C-Labs.

In summary, the C-Labs course at Chalmers is an advanced challenge-based learning experience, involving students from across the university and with ambitions to make a difference locally. It is carried out in a dedicated space and supported by faculty from three different departments. Specialist supervisors to the student teams are also involved in the process. The supervisors are selected based on and related to the specific subject areas of the theses, to secure the quality of the master theses and to add deeper knowledge in the specific subject areas of the students. It places a specific focus on developing problem identification and formulation skills.

COMPARATIVE ANALYSIS

Table 1 summarizes the main attributes of the reviewed courses.

We can first notice that the courses are spread through the curriculum, from the first-year to master theses. However, also the master thesis projects at DTU and Chalmers seem to require little pre-knowledge or skills specific to challenge-based learning. They all seem to be designed as a first challenge-based learning experience. (The C-Lab at Chalmers has noticed the drawbacks with this and decided to introduce a 7,5 ECTS compulsory preparatory course for the coming C-Labs master thesis projects). That raises the question of what a second challenge-based project should look like, or if there might not be a need for one? Is there a best place in the curriculum if there is only one challenge-based learning experience?

The courses (except for DTU) share a core of intended learning outcomes and taught topics related to design, teamwork and communication. It seems that the master level course at Chalmers places a higher emphasis on some advanced but general learning outcomes, e.g. dialoguing and systems thinking. The introductory at UWA addresses some specific topics, i.e. waste and poverty. The typical projects are nevertheless rather similar (except for some of EPICS projects) and one might assume that the actual learning achieved is also similar.

The courses differ somewhat with respect to focus on social/economic sustainability or environmental or both. The Chalmers and DTU course are primarily aimed at environmental sustainability while the UWA and EPICS have a first focus on social/economic sustainability. However, many of the projects listed on the courses' website require consideration of both social and environmental sustainability.

The courses further lean somewhat differently towards “saving the world” or “saving the world and doing business”. The UWA and EPICS courses lean towards the former whilst the DTU and Chalmers courses embrace the second.

The EPICS course is the largest in terms of number of students each year, and has a staffing designed to cater for a large student group. The DTU course also reaches out to many students because of its design as an add-on to the master thesis. The UWA and Chalmers courses are smaller and may be difficult to scale up due to their somewhat more specific nature. Chalmers is investigating how to connect a higher number of students to the C-Lab in other ways. One idea is to develop mechanisms for developing associations to other courses, e.g. by developing a module that can be integrated in other courses.

The cost per student is likely highest for the Chalmers course, which has a low number of students/year and yet a dedicated space. DTU's Green Challenge probably has the lowest cost per students. However, the Chalmers course also seems to have the highest ambitions regarding the skills that the student will develop and the contributions that they will make ("act as change agents"). Partly this comes naturally from its placement last in the curriculum, but there is also a strong dedication to raise the bar for what students can achieve in society.

The UWA course has an interesting position in the curriculum. Being a first-year course it sets the scene for the educational program, and if subsequent courses and projects build on this foundation, the students may reach very far.

CONCLUSIONS

Challenge-based education has emerged as the new "buzzword". A large variety of learning experiences marketed as "Challenge-based" have been introduced. They include K-12 (i.e. primary and secondary education, prior to college) classes, first-year university courses, student competitions, and BSc and MSc thesis projects.

Challenge-based education can be seen as an evolution from problem-based learning, but brings forward some unique characteristics such as, a starting point in large open-ended problems, a value-driven approach to problem formulation & decision-making, training of self-awareness and self-leadership in combination with teamwork in projects that require addressing engineering problem-solving, societal concerns and a entrepreneurial mindset and working method.

Challenging-based learning experiences pose new demands on faculty, also in comparison with design-build-test projects: A more dynamic course process can be expected – there is a need to accommodate very open problems and for multidisciplinary student teams. Faculty will probably be less able to offer subject-related feedback. Students may experience this as a lack of support and feel more insecure. The typical multidisciplinary project or project portfolio character implies a need for a cross-departmental and cross-program teacher and supervisor team, as seen in the example of C-Lab.

Challenge-based learning raises the level of ambition of engineering education to go beyond the technical systems domain into the socio-technical system domain, and can as shown in the paper be arranged in a multitude of ways. Challenge-based learning experiences further harness the desire of many students for a sense of meaning with their education while effectively training key skills such as multidisciplinary teamwork and decision-making, advanced communication, ethics and leadership of self and others. However, almost all challenge-based learning experiences surveyed here are on the periphery of the curriculum, operated as introductory or special courses or master thesis projects. Challenge-based courses still have a way to go before they are part of the regular curriculum.

Table 1. Comparison of Challenge-based Learning Experiences

	UWA Global Challenges	Purdue EPICS	DTU Green Challenge	Chalmers C-Labs
Student year	Year 1	Year 1-4	Year 3-5	Master thesis
Learning outcomes (targeted)	Many, see taught topics below	Design-build-test Teamwork Communication Project planning Leadership Customer-awareness Ethics, economic, & legal issues	Communication, Environmental assessment, Visioning	Sustainability Systems thinking Leadership Design thinking
Taught topics	Project planning Waste Social impact Design Environment & sustainability Diversity, ethics and justice	Design Ethics Empathy Interviewing & observing methods Presentation Leadership Prototyping	Innovation pitch presentation	Backcasting Dialogue tools Design thinking Self-leadership Entrepreneurship
Typical project	Briquette press	Shelters for natural disaster areas	Improved efficiency of wind turbines	Biodiesel introduction analysis
Magnitude	10 ECTS	5-10 ECTS	5-30 ECTS	37.5 ECTS
Perspective	Global	Local – global	Local – global	Local
Focus	Social – environmental	Social	Environmental – social	Environmental – within the frame of a theme
Teacher team	Small	Large & including admin staff	Project-dependent	Moderate, multi-departmental + specialist supervisors related to subject areas
Cost/student	Moderate	Moderate-high	Low	High
Students/year (estimated)	45	400	250	20
Unique advantage	**Sets the scene for the entire program**	**Outreaching and inclusive. Large-scale**	**Flexible and inclusive**	**May lead to the deepest competence & implementation of results**

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