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Learning Outcomes in Challenge Based Master's Theses for Sustainable Development at Chalmers University of Technology

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***Abstract*—Challenge based learning (CBL) is a multidisciplinary approach that encourages students to work actively with peers, teachers, and stakeholders in society to formulate relevant questions, identify complex challenges, and take action for sustainable development. The first Challenge Lab at Chalmers started as a Master's thesis course and has now been running for two years. Challenge Labs around the world, similar to the one at Chalmers, have the potential to work as student driven transition arenas. In this paper the learning outcomes of the two first years have been evaluated. The aim is to give input to the continued development of the Chalmers Challenge Lab and to similar projects at other universities. The results show that Challenge Lab students perceive that they have developed deep skills in: ability to identify, formulate and manage complex problems in a critical, independent and creative manner from an overall perspective; and ability to identify which problems need to be addressed to observe sustainable development. Additionally, the students perceive that they have developed skills in working across disciplines and with stakeholders, which is not offered or usually developed in traditional Master's theses.**

***Index Terms*—Challenge based learning, active learning, cross disciplines, stakeholder involvement, sustainability**

I. Introduction

CHALLENGE based learning (CBL) is a multidisciplinary approach that encourages students to work actively with peers, teachers, and stakeholders in society to formulate relevant questions, identify complex challenges, and take action [1]. CBL gives a great opportunity for active learning and to integrate sustainable development.

The first Challenge Lab at Chalmers started as a Master's (MSc) thesis course and has now been running for two years. In total 25 students have done their theses within Challenge Lab (C-Lab).

A key assumption is that students possess the position of being unthreatening and challenging at the same time, which gives a potential to take on sustainability challenges within society. Thus, Challenge Labs around the world [2], similar to the one at Chalmers, have the potential to work as student driven transition arenas, and for students to gain action competence for sustainability [3].

The operating costs in the Chalmers C-Lab are higher than for traditional MSc theses, which could be motivated by the outcomes. Thus, the results of the two first years have been evaluated.

The aim of this paper is to give input to the continued development of the Chalmers C-Lab and to similar projects at other universities. The objectives are:

1) to compare the self-assessed learning outcomes of the students to the intended learning outcomes in MSc theses at Chalmers,
2) to compare the self-assessed learning outcomes of the students to the specific ambitions of the C-Lab, and
3) to compare the results of the theses to the specific ambitions of the C-Lab.

The remainder of the paper is structured as follows: first there is a description of Chalmers C-Lab, followed by descriptions of the method and results, and finally there is a discussion.

II. Chalmers Challenge lab

The ambition with Chalmers Challenge Lab (C-Lab) is to establish 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 MSc thesis [4]. C-Lab can be classified as a "social lab" [3] 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).

C-Lab can be described as a set of collaborating MSc thesis projects open for students from all disciplines at Chalmers, and where the participating students design the projects and research questions. C-Lab has its own physical space ("The C-Lab"), where the students meet on a daily basis and to which stakeholders are invited for dialogues. Here the students arrange dialogues and meetings, when working on their projects and thesis. The common space further allows a deeper collaboration between the students and opens up for discussions between

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disciplines and projects. 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 pedagogical purpose with C-Lab is to develop student skills in working across disciplines and from a challenge driven perspective. This means going further than the typical MSc thesis projects, i.e. not only designing the solution but also identify critical aspects of a system in order to formulate relevant questions before designing the solution and thereafter also implement the solution. 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.

C-Lab is organized in two phases, the problem formulation phase and the execution phase. The MSc thesis is a 30 hec thesis project, carried out as the final work for a MSc degree. In C-Lab, the initial problem formulation phase, the students start from a common larger theme, such as "Urban transportation", as it was in the first pilot, and then work towards formulating the projects that they will carry out in the second phase, see Figure 1.

In formulating the problem, in the first phase, the students carry out dialogue meetings with regional public sector, industry and researchers. In those meetings different perspectives of viewing a problem comes forward that guide the work in how to formulate the research question to allow the different perspectives to be included. To be prepared for this, all students that attend C-Lab have (since the second year in which C-Lab is running) participated in a preparatory course [5], where approaches and methods on dialogue tools, backcasting, self-leadership, design thinking and entrepreneurships are introduced to the students. 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 thesis 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.

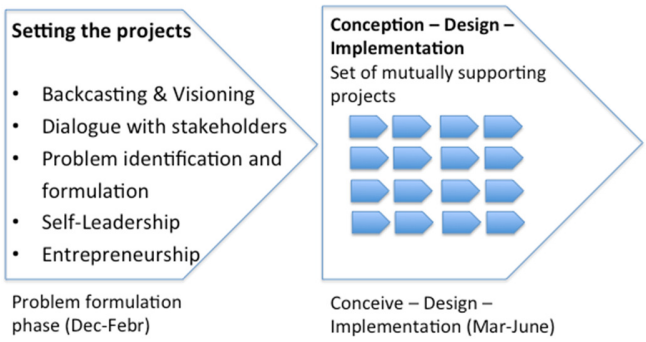

Fig. 1. The Challenge Lab process.

The theme for 2014 was "Urban transportation", and for 2015 "Urban development", based on examples in the Gothenburg Region. The titles of the thesis projects are listed in Table 2. The projects thus lean towards the regional environment sustainability goals, but also reflect the broad range of disciplines involved in the lab.

In summary, C-Lab 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 different departments. In addition, supervisors to the student teams are 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 MSc theses as to add deeper knowledge in the specific subject areas of the students. It places a specific focus on developing problem identification and formulation skills.

III. Method

The research has been conducted mainly through a qualitative approach, with elements of action research, as one of the authors was active as a project leader and thesis supervisor. Data was primarily collected through interviews where a self-assessment questionnaire was included. We also looked at thesis project results (thesis reports).

The interviews were semi-structured with about 30 questions in categories demographics, project preparation, project execution, project and learning evaluation, and effects on future career. An important component was the self-assessment of how the thesis project had advanced the respondents mastery of the intended learning outcomes of Chalmers MSc thesis projects, which are largely similar to the full set of intended learning outcomes of Swedish MSc in engineering degrees [6].The interviews were carried out by two interviewers and lasted about 1 h. In total, 24 (of 25) students (11 in 2014 and 13 in 2015) have been interviewed.

In order to investigate how well the MSc thesis projects have led to implementation or real change, the results were classified with respect to their coverage of a typical problem-to-implementation pathway. The pathway starts with: 1) problem formulation, is followed by the phases: 2) idea or model

TABLE 1
SELF-ASSESSMENT OF HOW THE PROJECT HAS ADVANCED THE STUDENTS' MASTERY OF THE LEARNING OUTCOMES OF CHALMERS MSC THESIS PROJECTS.

Intended learning outcome	2014			2015		
	Average	Standard deviation	Range	Average	Standard deviation	Range
1. Specialised knowledge within your main field of study including insight into relevant research and development work	4.2	0.83	2-5	3.7	1.07	2-5
2. Specialised knowledge of methods within the main field of study of the study programme	3.6	0.92	2-5	3.3	1.45	1-5
3. Ability to contribute to research and development work	3.3	0.75	2-4	3.9	1.00	2-5
4. Ability to identify, formulate and manage complex problems in a critical, independent and creative manner from an overall perspective	4.8	0.39	4-5	4.2	0.80	3-5
5. Ability to plan and use adequate methods to implement advanced tasks within given frameworks, as well as evaluate these efforts	3.9	0.67	3-5	3.6	0.84	2-5
6. Ability to create, analyse and critically evaluate different technical/architectural solutions	3.4	1.34	1-5	3.4	1.15	1-5
7. Ability to integrate knowledge in a critical and systematic manner	4.4	0.88	2-5	3.8	1.10	2-5
8. Ability to in writing clearly describe and discuss his or her conclusions in English, including the knowledge and arguments that form the basis of the conclusions	3.8	0.57	3-5	3.5	1.15	1-5
9. Ability to orally clearly describe and discuss his or her conclusions in English, including the knowledge and arguments that form the basis of the conclusions	4.4	0.66	3-5	3.8	1.05	1-5
10. Within the framework of the specific degree project, ability to identify which problems need to be addressed to observe sustainable development	4.4	0.77	3-5	4.5	0.63	3-5
11. Awareness of ethical aspects related to research and development work	3.4	0.83	2-5	3.5	1.22	1-5
12. Ability to work independently as a holder of a Civilingenjör, Master of Architecture or Master of Science degree	4.5	0.67	3-5	4.0	1.04	1-5

Possible answers in the self-assessment: 1=not at all, 2=a little, 3=to some extent, 4=significantly, 5=very significantly

generation, 3) concept development, 4) test/evaluation within an academic setting, and concludes with: 5) test/evaluation by external stakeholders.

IV. RESULTS

A. Learning outcomes

Table 1 includes the results for the self-assessed learning outcomes of the students for the intended learning outcomes (ILOs) of Chalmers MSc thesis projects. The average values for all the ILOs are showing a good result for how the students' perceive their learning (all at least or above 3.3), even though there is a range for their individual answers.

The results show that there is a difference between the two years: in 2014, 6 of the 12 ILOs got an average value above 4 while in 2015 only 3 of the ILOs were above 4. Additionally, the standard deviations for 2015 are higher than in 2014. It has not been possible within this study to understand the reasons behind this difference between the years. It should be noted that the difference is not caused by deviating answers from one student.

Problem formulation and sustainability

Three of the ILOs have received average values above 4 (i.e. significant learning) in both years. Two of them are (no. 4 in Table 1) "*ability to identify, formulate and manage complex problems in a critical, independent and creative manner from an overall perspective*" and (no. 10 in Table 1) "*within the framework of the specific degree project, ability to identify which problems need to be addressed to observe sustainable development*". Some citations from the students that support this result are:

"*Learning to frame the question in collaboration with different stakeholders and with a practical relevance has been unique.*" (student 2)

"*Going to fast into solution is the risk. The difficulty is to understand how to frame the common problem, or challenge, to which to identify solutions to. This require the ability to listen and communicate across disciplines.*" (student 5)

"*When I started I did not realize the difficulty of "defining the problem" across disciplines. It caused me a lot of frustration, but it has been a very valuable experience.*" (student 6)

"*I have done my degree in industrial management and economics, if I would have understood earlier what sustainability was about, I would have showed much more interest to it earlier. Now I will have difficulties of not working with that perspective. Earlier I understood sustainability as something that was non-business, non-growth.*" (student 11)

Ability to work independently

The third ILO that has received values above 4 in both years is (no. 12 in Table 1) the "*ability to work independently as a holder of a Civilingenjör, Master of Architecture or Master of Science degree*".

Work across disciplines and with stakeholders

The results from the interviews show that the students perceive that they have developed an additional skill that is not

TABLE 2
HOW FAR THE MASTER THESIS PROJECTS HAVE COME TOWARDS IMPLEMENTATION

Year	Title of Master Thesis Project	Discipline that the students come from	How far the thesis has come towards implementation* 2	3	4	5
2014	1. Backcasting approach to Sustainable Transport and Mobility in Gothenburg. A stakeholders' perspectives on challenges, barriers, and opportunities for sustainability transition	Environment *2	■	■		
	2. How could a platform for sharing of things be designed? - linking to Chalmers "Green Campus"	Environment	■	■	■	■
	3. Biodiesel in Sweden - Barriers, networks and key stakeholders	Physics / Environment	■	■		
	4. Redefiniton of transport sharing system for a sustainable future	Technology management *2	■	■		
	5. A prestudy of a potential diffusion of small electric vehicles in the Gothenburg area	Technology management *2	■			
	6. A mobile application for public transport	Civil engineering *2	■	■	■	
2015	1. Analysis of perceived insecurities among potential domestic photovoltaic adopters and interface development for a faster diffusion of photovoltaics in Sweden	Energy	■	■	■	
	2. Circularity assessment for companies for a general framework	Environment	■	■	■	
	3. Interorganizational collaboration in a living lab context HSB Living Lab as a case study	Technology management *2	■			
	4. Stakeholders requirements and perspectives for future collaboration in solar projects	Technology management	■			
	5. Design of bioretention planters for removal of toxic metals and organic contaminants in stormwater	Environment / Civil engineering	■			
	6. Insights from a benchmarking study of backcasting processes. Applied on the low carbon transition of West Sweden	Energy / Civil engineering	■	■	■	
	7. Positive impact on wellbeing and energy related behaviors in office	Civil engineering *2	■	■		
	8. Criteria of sustainability for new residential buildings	Civil engineering *2	■			

* How far a thesis has come towards implementation:
2 = Idea or model generation
3 = Concept development
4 = Test/evaluate within an academic setting
5 = Test/evaluate by external stakeholders

offered or usually developed in traditional MSc theses; i.e. to work across disciplines and with stakeholders. A citation from the students that support this result is:

"*Us students representing different educational backgrounds, coming from many different countries and working with stakeholders form industry, academia and government, it took some time and a lot of frustration to understand how to navigate. I think we found a way where we discussed a lot to make sense of for instance the meaning of "sustainability" or "system*"." (student 7)

B. Towards implemented solutions

The results in Table 2 shows how far the thesis projects have been advanced by the students towards implementation. The range 2-5 is used to indicate how far a thesis project has been advanced into phases towards implementation. The ambition in C-Lab is to open up for students to reach beyond the model phase (no. 2), in order to develop their skills related to action competence, by having the project advancing into later phases in collaboration with stakeholders. The results indicates that 36% has come to the second phase to generate an idea or model, 29% has come to the third phase to develop a concept, 29% has come to the fourth phase to test/evaluate within an academic setting, and just one thesis project (7%) has come to the last phase to test/evaluate by external stakeholders. It should be noted that it has not been a requirement but an ambition to reach the final phase towards implementation and all the projects in Table 2 are considered to have been successful and have got a passed result.

C. Students from different disciplines

It has been possible for students from different disciplines to generate successful results in C-Lab, see Table 2. However, it is clear that students from some disciplines have been especially attracted to C-Lab: Civil engineering (8 students), Technology management (7 students), and Environment (5 students).

The ILOs no. 1 and 2 in Table 1 are both about specialized knowledge within the main field of study of the students, and the average values in the self-assessment of these ILOs show a good result. However, it should be noted that in year 2015 the standard deviation for the ILO about specialized knowledge of methods within the main field of study (no. 2) is the highest for all ILOs during the two years.

V. DISCUSSION

The high average values for the ILOs no. 4 and 10 in Table 1 for the results of the self-assessment questionnaire were anticipated since they are in line with the specific ambitions of C-Lab. Both of them include parts on problem formulation and one of them include problem formulation in the context of sustainable development. This shows that the arrangement of C-lab has been working well for the students to get practice and gain skills for these ILOs, which are in line with the specific ambitions of C-Lab.

The first year that C-Lab was running, it became clear that there was not enough time for the students within the thesis projects to reach the final phase towards implementation, which is one of the ambitions of C-Lab. A preparatory course was therefore developed and started in the second year, which has given the students more time for their thesis projects, but this has not resulted in that the theses projects have reached further towards implementation. A reason for this can be that more time is needed for sustainability theory and methods since the students come from different disciplines. A common aspect among the thesis projects that advanced far towards phases of testing has been that the students in these projects have had a strong driving idea of reaching implementation, already before starting the theses project.

In the second year, several students got the opportunity to continue their work in projects after they had completed their theses. These projects gave the students a chance to take part in implementation and test their developed action competence.

In the future development of C-Lab, one focus is to start projects that takes some of the thesis projects further towards implementation where the students can take part after having finished their degree and then in collaboration with stakeholders. As many stakeholders have shown interest in collaborating with students in the Lab, discussions have been initiated with stakeholders how to arrange for projects taking the next step. In the establishment and development of C-Lab, the role of the students is one important component. However, the role of stakeholders, having a collaborative role is of equal importance in enabling the development of solutions towards a sustainable society.

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REFERENCES

[1] J. Malmqvist., K. Kohn, U. Lundqvist, *Comparative Analysis of Challenge-Based Learning Experiences,* in Proceedings of the 11th International CDIO Conference, Chengdu, China, 2015.

[2] Z. Hassan, *The Social Labs Revolution: A New Approach to Solving our Most Complex Challenges,* Berrett-Koehler Publishers, 2014.

[3] E. Almers, "Pathways to action competence for sustainability – six themes", *The Journal of Environmental Education*, vol. 44, No. 2, 2015, pp. 116-127.

[4] J. Holmberg, "Challenge Lab at Chalmers – Transformative learning and leadership for a sustainable future", in *Intergenerational Learning and Transformative Leadership for Sustainable Futures*, P. B. Corcoran and B. P. Hollingshead, Eds., Wageningen, The Netherlands: Wageningen Academic Publishers, 2014.

[5] Chalmers University of Technology, *ENM145 - Leadership for sustainability transitions - Challenge Lab preparational course*, Syllabus, https://www.student.chalmers.se/sp/course?course_id=22996, accessed on October 16, 2015.

[6] Ministry of Education, *Högskoleförordningen, bilaga 2*, SFS 2006:1053, pp. 66-67, Stockholm, Sweden, 2006. In Swedish.