UPSCALING CHALLENGE BASED LEARNING FOR HUMANITIES IN ENGINEERING EDUCATION

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ABSTRACT

This article analyses “Challenge-Based Learning (CBL)” as a method to contribute to Engineering Education engagement and limits its scope to humanities in Engineering Education. It reports on two studies of the User-Society-Enterprise (USE) program of Eindhoven University of Technology.

It asks the following questions: (1) Are students more satisfied about, motivated for and engaged in CBL humanities courses compared to non-CBL courses in Engineering Education? (2) Does upscaling of CBL approaches in humanities courses in Engineering Education have an impact on students’ experience and engagement?

The first study compares at course level a 15 ECTS small-scale (30 students) CBL pilot with 67 other USE courses. Students conceive, design and implement solutions for technical real-life sustainability challenges of innovators from the private and public sector who coach them through the project. Students work in multidisciplinary teams in Innovation Space, TU/e’s maker space. The second study compares at student level an up-scaled (180 students) CBL ethics track with 2 other ethics tracks in a same course.

Results show that students’ evaluation of *effort* and *intrinsic motivation* (measured by Self-Determination Theory) are higher, but *identified regulation* is lower for CBL approaches. Students’ experiences are only higher in the small CBL course, indicating limitations of scaling CBL.

CBL can be a motivating approach for humanities in Engineering Education. CBL can be scalable but “small-scale strengths” can be lost with gradual scaling. The research on CBL needs more elaboration and specification on what CBL is in order to compare differences of CBL approaches.

1 INTRODUCTION

1.1 Ethics, Humanities and Challenge-Based Learning

The SEFI 2020 theme on engagement of engineering students is important for students' engagement in general, but also for their engagement in ethics and humanities courses [1]. Challenge-Based Learning (CBL) in the conference description is mentioned as method to increase engineering students' motivation in general. However, literature on experiments of CBL including ethics and humanities in Engineering Education are missing. This article will contribute to this gap by studying students' experiences, effort and motivation in CBL. It will also discuss effects of upscaling for ethics and humanities CBL courses.

2 BACKGROUND

2.1 Motivation

Self-Determination Theory (SDT) is used to study the motivation of students. SDT considers several types [2] of motivation. Two types will be considered in this article. Students are *intrinsically motivated* when the activities and materials of the course are inherently enjoyable for them. *Identified regulation* reflects a conscious valuing of a goal, such that the action is considered as personally important and entails self-endorsement, self-knowledge and cognitive view of one's own functioning [3]. An engineering student might not be very attracted to humanities course itself. However, if she considers herself as becoming a good engineer, she acknowledges that humanities are nevertheless essential for her and she will therefore be driven to study these courses.

2.2 Challenge-Based Learning with and for society

Challenge-Based Learning (CBL) as a concept was first founded in collaboration with Apple Inc. for ages from kindergarten to high school [4]. Later, it was also used in higher education and discusses in contrast to problem-based, project-based, or design-based learning as an answer to lecture-based learning [5]. The definition given here is that "Challenge-Based Learning is a collaborative learning experience in which teachers and students work together to learn about compelling issues, propose solutions to real problems, and take action. The approach asks students to reflect on their learning and the impact of their actions and publish their solutions to a worldwide audience." [4]

CBL and its 'predecessors' have a common educational design characteristics basis to engage students. Roughly speaking, they all start from problems that are linked to the real world and show students the link between conceptual abstract theory and the concrete actual practice. These problems are open-ended and wicked. Students work in groups, often multidisciplinary in nature. As a group, they are responsible for the process to solve the problem. They therefore have to define the scope of their approach based on time and resources [6], define methods, collect empirical information, do some calculations and communicate their results in a clear manner. The role of the teacher shifts from guiding students in information processing to guiding the process when tackling their problem [6], [7]. Students are therefore in charge of their project and determine the direction of their research and final product or solution [3],[5].

One specific element however makes a difference between CBL and its predecessors, which is the way they aim to engage students. On the one hand, project-based learning for example can perfectly engage students to a very high degree by proving disciplinary real problems that are not per se societally relevant (like mathematically prove why a riding bike is a stable system). It aims to realize high levels of engagement by using students' *intrinsic motivation* for their own discipline (or 'disciplinary passion' as called here).
CBL on the other hand has a substantially stronger 'with and for society'-focus. The real problem starts from a "big idea", a societal challenge like contributing to the solution of decreasing global warming, stopping pandemics, ending poverty or solving mobility challenges. CBL links this global significance with a local component, via the local stakeholder. This stakeholder can be a community, an entrepreneur, a citizen group or other local actors. This stakeholder formulates an external appeal and call for action to the students' knowledge, skills and attitudes and abilities to use certain technologies. The elements in the project-based approach (like scoping based on time and resources, coming to a final product, students' responsibility …) receive some extra pressure. Assessments also need to be linked with the stakeholders' experiences about the product and the process. CBL can be seen to aim for realizing high levels of engagement by using students' commitment to the societal challenge. The role of the teacher shifts even more to a coach than is the case for the CBL predecessors, since students can even more easily start doing things outside the teacher's core expertise. And the Apple definition above should explicitly contain stakeholders: "Challenge-Based Learning is a collaborative learning experience in which students*, stakeholders* and teachers work together to learn about *with-and-for-society* issues, propose solutions to real problems, and take action."
Although "with and for society focus" seems an important difference, it needs to be stressed that the difference is only gradual. Also problem-based, project-based and design-based learning use societal importance, but to a lesser degree [9].

Several studies have illustrated benefits of CBL. Johnson et al. [6] showed increased engagement and commitment of students towards the challenge, which could further contribute to their motivation and development of 21st century soft skills, such as communication, leadership, civic literacy and social responsibility. CBL is also said to increase authentic learning in for example the processes and application of relevant math and science concepts [10] and lead to improved creativity and innovation skills, learn more flexibly, and being more open to risk taking [8].
However, CBL also has disadvantages, such as the heavier time commitment needed from both students and instructors; and CBL also requires the availability of the willingness to change at the teachers' side, as teachers sometimes find adjusting

their teaching practice to the new educational method of Challenge-Based Learning difficult [11]. Last but not least and important to take into account if quality of humanity courses in general [12] is considered, scaling CBL is an issue, as Engineering Education often has to deal with large class sizes, but the CBL approach faces difficulties to be organized [13].

As engineering departments or technical universities face difficulties to motivate engineering students for humanities courses [14]–[16], CBL could be a promising approach. However, little is known about CBL's efficiency for these courses for engineering students. The effect of CBL to engineering students' motivation and engagements in general and in large classes in particular is therefore of particularly interest.

3 RESEARCH QUESTIONS

The following research questions can therefore be formulated:
RQ1: Are students of CBL humanities courses more satisfied about, motivated for and engaged compared to students in non-CBL humanities courses in Engineering Education?
RQ2: Do students of small scale CBL humanities courses in Engineering Education have same students' experience and engagement compared to students in large CBL courses?

4 CONTEXT

4.1 USE program at TU Eindhoven

Eindhoven University of Technology (TU/e) offers its bachelor students 4 'USE'-courses (20 out of 180 credits) in which they learn to be aware of, reflect on and model User, Society and Enterprise aspects of technologies. In their first year, students take a USE basic course (USEb) on ethics and history of technology. This 8 week 5 ECTS course is provided to around 2000 first year students. In the second or third year, students choose one out of 16 learning lines (three courses of in total 15 ECTS) on a particular theme or technology such as "The Future of Mobility", "The Secret Life of Light", "Patents and Standards" and "Responsible Innovation for the world".[1] The learning lines aim for a 50-50 balance between technical and humanities input.

4.2 Experiment 2: Large CBL courses in USE (USEb)

In the fourth quarter of 18-19, 180 students of the 5 ECTS introductory ethics course (USEb) were divided in three tutorial groups of 60, each containing 12 assignment groups of 5 students from different study backgrounds. For each tutorial group of 60 students there were 4 stakeholders. During the 8 weeks quarter, the students met

[1] A full list of choices and more information can be found at https://educationguide.tue.nl/programs/bachelor-college/use-learning-trajectory/

their stakeholders four times, together with 2 or 3 other groups. At the first meeting, the stakeholders introduced themselves with a short presentation. The meetings after that were feedback sessions where the student groups talked with their stakeholders and got feedback on their ideas. At the end of the course, there was an end-event where the students presented their end-product to the stakeholders in a poster-market style.

316 other students followed the standard approach in which students got weekly lectures in two groups and weekly tutorials in groups of 45. In these tutorials, they got guidance on applying the ethical theories to a real life cases without external stakeholder.

5 METHODOLOGY

5.1 Experiment 1: Small CBL courses in USE learning line (USELL)

In the three first quarters of the academic year 18-19, 30 students were enrolled in a learning line of three courses that decisively opted for 1 coherent CBL approach. Students conceive, design and implement solutions for technical real-life sustainability challenges of innovators from the private and public sector who coach them through the project. Students work in small multidisciplinary teams in Innovation Space, TU/e's maker space. Supervision happens by TU/e faculty and by external business partners and social entrepreneurs. Every student group worked for a single stakeholder with up to weekly interactions. The students' outcomes contribute directly to real-life projects or innovations, on which businesses and NGOs are working at that moment.

The results of these three courses with the other courses in the USE program will be compared. Several other USE-courses have some degree of "with and for society", but none of the others in 18-19 had it that much up and front. Next to the CBL approach and set-up, other aspects can determine the students' perception of a course, but these elements will be averaged out by considering the entire set of USE courses.

5.2 Study 1

The first exploratory study compared the 3 CBL courses in the first experiment with the other 67 non-CBL courses in the same USE program at course level (because data at student level was not available). In total 1869 responses from student evaluation of teaching questionnaires were used of which 41 responses of the three courses of experiment 1.

Project courses are often small and are spread over different quarters. Since the response rates have to be very high in the small courses to be significant, the decision was taken to combine the same courses who were provided two or three times. This is an important research design choice, but two arguments can be given. First, the research focusses on stable course design characteristics, so stable over different runs of the same course. Secondly, relevant comparative data would otherwise be lost, since project courses are of specific interest for the comparison.

So students' evaluation data were nine times merged for courses from two different runs and once for three runs of one course. Nulty's criteria for significance were used to analyse the significance of the response rates of these 59 courses, with sampling error 10% and 80% confidence interval [17]. After this, 41 course remained, 2 of the CBL courses (31 individual responses) and 39 others (1653 individual responses) with an average response rate of 36%. In the scope of this article, we cannot focus on the different design characteristics individually. All 39 courses contain lectures, assignments to apply theories to a certain case and tutor feedback, but all in different formats. We therefore assume using the results of the 39 courses averages out the individual differences. None of these explicitly uses external stakeholders in the assignments, making the difference between the CBL and non-CBL courses.

Six existing university evaluation items were used (see Table 1). Data was collected after the final assessment. Factor analysis using principal component analysis and varimax Kaiser Normalisation (see Table 2) provided two clear factors *experience* and *effort* with good reliabilities (respectively Cronbach alpha's of .85 and .79).

Table 1. Items used in the two studies.

Variable	**Item**
Grade	How would you rate this course?
Setup	The educational setup (e.g., structure, content, teaching/learning methods, level, and coherence) worked well and was suitable for this course.
Organisation	The course was well organized (e.g., availability of lecturers/supervisors, availability of information, scheduling, and planning).
Material	The course material was clear and motivated me to study for this course.
Level	Overall, how would you describe the level of difficulty in this course?
Credit-load	The effort I applied to complete this course corresponds with the number of credits (5 ECTS = 140 hours.
Intrinsic1	… it's an exciting thing to do.
Intrinsic2	… it's fun
Identified1	… the subjects of this course are an important life goal to me.
Identified2	… this represents a meaningful choice to me.

Table 2. Factor loadings of the six existing university evaluation items in the two studies

		USE LL		USEb	
		1	2	1	2
Experience	Grade	**.970**	-.001	**.830**	.111
	Setup	**.976**	.026	**.817**	-.078
	Organisation	**.902**	.207	**.844**	-.088
	Material	**.964**	.030	**.853**	.107
Effort	Level	-.052	**.924**	-.076	**.854**
	Credit-load	.174	**.891**	.101	**.862**

5.3 Study 2

For the second exploratory study, the same 6 existing university evaluation items (see Table 1) were asked after the final assessment. For the CBL population, 47 out of 183 students (RR=26%) responded. For the detached population, 91 out of 316 responded (RR=29%), being a sufficient response rate [17]. The last week of the course, before the final assignment had to be handed in, data was collected with a validated questionnaire on *intrinsic motivation* and *identified regulation* [18] (see items Table 1). For the CBL population, 56 out of 183 students (RR=31%) responded. For the detached population, 56 out of 316 responded (RR=18%), being a sufficient response rate [17].

Factor analysis (see Table 2) provided again two clear factors. Reliabilities were good with Cronbach alpha's of .81 for *experience*, .72 for *effort*. The items for *intrinsic motivation* and *identified regulation* from the "Self-regulation questionnaire – Academics' questionnaire" [19] strongly correlate, respectively with r= .92 and r=.80.

5.4 Analysis

To exploratory answer the first research question (RQ1: "Are students of CBL humanities courses more satisfied about, motivated for and engaged compared to students in non-CBL humanities courses in Engineering Education?"), the results between CBL and non-CBL group were compared for the two studies. For experiment 1, data was used on course level. T-tests could not be performed, but a precautious standard deviation was chosen to get an idea of the effect size. For experiment 2, t-test were performed. Cohen's d effect sizes were analysed, with 0.5>d ≥0.2 considered as small, 0.8>d≥0.5 as medium and d>0.8 as large [20]. Differences at item level were analysed to exploratory answer the second research question (RQ2: "Do students of small scale CBL humanities courses in Engineering Education have same students' experience and engagement compared to students in large CBL courses?"). A t-test was performed to compare the small CBL (USE LL) courses with the large CBL (USEb) course.

6 RESULTS

For experiment 1, data was analysed on course level. The weighted average was calculated for the factors *experience* and *effort*, being both higher for the CBL courses. T-tests were not performed since we do not have the standard deviations. As an alternative, results indicated with " * " of the effect size was obtained if 1.0 was taken as standard deviation which is larger than all individual standard deviations (average SD 0.7, maximum SD 0.9). We are aware this is an uncommon statistical solution, but it at least gives an idea of the differences.

For experiment 2, t-tests showed no significant difference for the *experience* factor, a higher *effort* and *intrinsic motivation* for the CBL group with medium effect size and a lower *identified regulation* with large effect size.

T-test between the small USELL-CBL and the upscaled USEb-CBL approaches showed a higher course grade with large effect size and a higher credit load with small effect size. See Table 3 for all these t-test results.

Table 3.T-test results for the two studies between CBL and non-CBL and between USELL and USEb; with number of respondents (N), mean (M) and standard deviation (SD); differences in mean (ΔM) and Cohen's d effect sizes. * for calculations with SD=1.0.

	N	M	SD	N	M	SD	ΔM	d
	CBL			non CBL				
Experience - 1	31	4.34	1.0*	1653	3.25	1.0*	1.09	1.09*
Effort - 1	31	3.25	1.0*	1653	2.93	1.0*	.32	0.32*
Experience - 2	46	3.77	0.85	91	3.51	0.67	0.26	-
Effort - 2	47	2.86	0.71	90	2.42	0.74	0.43	0.60
Intrinsic motivation - 2	54	3.38	0.77	54	2.76	0.97	0.62	0.71
Identified regulation - 2	54	2.06	0.97	54	2.93	1.07	-0.87	-0.85
	USELL-CBL			USEb-CBL				
Grade	16	8.9	0.9	46	7.2	1.9	1.4	1.00
Credit-load	16	3.3	0.7	47	2.9	0.9	0.4	0.47

7 DISCUSSION

This research was labelled as explorative from the beginning onwards. Several assumptions had to be made. First, the differences in weighted means in experiment 1 are very substantive, however, t-tests are only indicative taken the SD=1.0 assumption into account. In view of the averages of the SD's, this seems an acceptable assumption to illustrate the substantive differences. Second, a strict distinction between CBL and non-CBL courses was made. This is a strong simplification of what happens in reality. Many courses labelled as non-CBL have important with-and-for-society aspects. However, the courses that are labelled CBL have a very strong focus on these aspects, so the decision could be considered as justified.

Taking these limitations into account, we can answer the first research question. *Effort* is higher for CBL in both experiments. Although the *effort* concept is different from engagement, it gives an indication that engineering students are more willing to invest in CBL courses compared to non-CBL courses.
Intrinsic motivation is higher in the CBL case, but *identified regulation* is lower with larger effect size in the CBL case. It was postulated that students really like the CBL approach and that therefore the *intrinsic motivation* is higher. The lower *identified regulation* for the CBL approach compared to the non-CBL approach was considered as an intriguing result. The for-and-with-society aspect of the CBL approach (like scoping based on time and resources, coming to a final product, students' responsibility and so forth) seemed to have created some awareness of the

difficulties of the future profession. Providing structure and openness at the same time seems an important solution here [21]. Becoming or being an engineer is also struggling to get to a consensus among involved stakeholders, coping with strict deadlines for real clients, etc. These “new” insights and the experienced difficulties might lower the current *identified regulation*.

The *experience* factor is much higher in the small CBL courses than the non-CBL courses in experiment 1. In experiment 2, no significant difference for this factor is found. This is an answer to the second research question. Upscaling has it challenges. Stakeholders in experiment 2 said having 3 to 6 groups of first year’s students working on an ethics assignment said it was relevant for them to participate. However, the scaling factor here clearly has an impact. Next to challenges of in-depth coaching [22], a commitment of a stakeholder meeting with a group up to once a week is much more intense and supportive for students compared to a stakeholder meeting 3 to 6 groups once every 2 or 3 weeks. Based on the exploratory study of these two experiments, it is conclude that scaling CBL is certainly possible, but scaling at the same time loses important strengths.
The current scaling experiment consisted of a 5 ECTS ethics course for 180 students. One solution to this dilemma is to imbed the course more in the curriculum. Instead of 4 5 ECTS CBL courses for 180 students, one single 20 ECTS course including three technical subjects and ethics, could be a solution here.

We conclude that CBL can be a motivating approach for humanities in Engineering Education. CBL can be scalable but “small-scale strengths” can be lost with gradual scaling. The research on CBL needs more elaboration and specification on what CBL is in order to compare differences of CBL approaches.

TU/e considers the above results as encouraging to continue to build expertise on CBL in general and in humanities courses. The USE basic course will be extended to 240 students now including two external teachers in 19-20. In 20-21, two other 15 ECTS CBL USE learning lines will start and a more integrated curriculum experiment with 100 students combining other technical courses and the basic ethics course will be set up. As such, TU/e hopes to build some further expertise in CBL in (embedded) humanities courses.

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