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LESSONS LEARNED FROM STUDENT SATISFACTION SURVEYS OF CDIO PROJECT COURSES

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ABSTRACT

The paper reports on a study of student satisfaction in CDIO project courses. The aims are to investigate if there are statistically significant differences in levels and variation of student satisfaction metrics between CDIO project courses and “traditional” courses, and to identify possible causes for these differences. The study was carried out at Chalmers University of Technology and focused on courses in its mechanical, automation and industrial design engineering programs. In these programs, about 20 CDIO project courses and 235 traditional courses are offered each year. In the study, student satisfaction and some other quantified metrics collected from Chalmers’ course evaluation system are compared for the two groups of courses. Further, the paper examines in more detail selected CDIO project courses, with high and low student satisfaction ratings. The results of the study provide support for the hypothesis that there are significant differences in ratings. A number of causes are identified and discussed, including course leadership, perceived workload, assessment, and freedom to select task.

KEYWORDS

CDIO Standards 4, 5, 10, 12, Design-Implement project, Educational quality

INTRODUCTION

CDIO (Conceive-Design-Implement-Operate) project courses play a key role in realizing the most common reason for applying CDIO, namely the ambition to make engineering education more authentic. In addition, including more design and innovation is the third most common reason for universities to adopt CDIO (Malmqvist *et al.*, 2015).

The student work produced in CDIO project courses is often realistic and of very high quality, for example advanced physical prototypes. It can be argued that CDIO project courses are crucial for students to demonstrate both the ability “to create, analyze and critically evaluate various technological solutions” and “to develop and design products, processes and

systems while taking into account the circumstances and needs of individuals and the targets for economically, socially, and ecologically sustainable development set by the community”, as described in the learning outcomes for engineering education in the Swedish Higher Education Ordinance (Ministry of Education, 2017). In addition, results from CDIO project courses tend to impress external evaluators.

Nevertheless, we have observed that student satisfaction evaluations of the CDIO project courses that are offered at Chalmers University of Technology have not always been favorable: there has been a strong variation in ratings from strongly negative to highly positive. Furthermore, we have had the impression that this variation is stronger than for traditional, lecture-based subject-oriented courses. There are a number of possible causes for this, including variations in project assignments leading to mismatches between problem-solving needs and course contents, variations in teacher CDIO teaching competence, and variations in students' preparedness for working in a project associated with a high degree of uncertainty. However, we have not conducted any systematic comparisons of the possible variations between student satisfaction levels in CDIO courses vs. traditional courses and its underlying causes, nor are we aware of any other such study.

Thus, this paper aims to:

- Compare student satisfaction evaluations of CDIO project courses and traditional, lecture-based, subject-oriented courses at Chalmers University of Technology, Gothenburg. The sample of courses is from Chalmers' programs in Mechanical, Automation, and Industrial Design Engineering.
- Provide an in-depth study of CDIO project courses with very low and very high student satisfaction ratings, and investigate how success and problem factors correlate to guidelines for design of design-build-test projects (Malmqvist *et al.*, 2004).

We first summarize earlier work on the topic. We then outline the research methodology applied in the paper. The results chapter contains a quantitative section based on data from course evaluation questionnaires as well as a qualitative section based on case studies of selected CDIO project courses. A discussion and conclusions wrap up the paper.

EARLIER WORK

The literature on CDIO project courses is dominated by case descriptions of a single course (see, e.g., Kontio & Lakanmaa, 2017; Van Torre & Verhaever, 2017) or attempts to summarize experiences into guidelines for design of such courses (Malmqvist *et al.*, 2004; Dym *et al.*, 2005; Hermon & McCartan, 2017). This body of work typically places a high emphasis on describing student working practices, product outcomes and assessment procedures, rather than on providing and discussing evidence of the learning or satisfaction resulting from the learning activities.

Examples of papers that consider student satisfaction in CDIO project courses do exist (see, e.g., Liu & Lin, 2010; Schrey-Niemenmaa & Piironen, 2017) and report positive results. However, Helle *et al.* (2006) argue in a review paper on project-based learning that the literature on project-based learning provides mainly anecdotal evidence for its positive effects on student satisfaction, and that there are few or no serious attempts at understanding the motivational aspects of project-based learning. Nevertheless, Joyce *et al.* (2013) used student feedback to systematically transfer a course in Design and Manufacturing from traditional lecturing to a design-build-test team project. They found that if students are to

engage effectively with the project they must view it as being relevant and authentic, that there is a delicate tension between students' wishes for autonomy and their wishes for supervision and, that students perceive a higher workload in project-based courses compared to traditional courses. Recently, a study performed at the Norwegian University of Science and Technology (Wallin *et al.*, 2017) that examined an interdisciplinary project course "Experts in teams", found strong variations in student satisfaction.

The study of student satisfaction in CDIO project courses is essential for understanding student motivational factors. Low student satisfaction with CDIO project courses, especially early in the education, may lead to students choosing more traditional courses towards the end of their studies, and even affect their career choices. Understanding student satisfaction is also essential for guiding quality improvement.

This paper contributes to the field by (a) studying student satisfaction in multiple CDIO project courses and by (b) connecting student satisfaction levels to underlying causes. Guidelines for design of CDIO project courses provide a multitude of possible causes.

RESEARCH METHODOLOGY

The study was based on courses from Chalmers' programs in mechanical (ME), automation (AE) and industrial design engineering (IDE). Chalmers offers 3-year Bachelor of Science and 2-year Master of Science programs in these disciplines, including 5-year Master of Science in Engineering programs delivered in a 3+2 year format.

The CDIO project courses selected for the study are listed in Table 1. The main criterion for considering a course to be a "CDIO project course" was that it to a large extent is carried out as a team-based design project. The coverage of the full CDIO cycle varies somewhat, as indicated in Table 1. (Capital letters C, D, etc. indicates a comprehensive coverage of the phase in the course project, whereas small letters c, d etc indicates a minor coverage of the phase). The CDIO project courses were then compared with all of Chalmers' courses within these programs.

The data for the study was collected from Chalmers' course evaluation system. The questionnaires in Chalmers' system are based on 11 common questions. The common questions are chosen to reflect a constructive alignment view (Biggs & Tang, 2007) on education, i.e. emphasizing learning outcomes, delivery of teaching and assessment, and to support cross-university quality enhancement. Seven of the common question are quantified on a scale 1-5, reflecting very poor-excellent, disagree completely-agree completely or similar. Four of the standard questions are free text, such as *"Is there anything that should be changed for the next round of this course, and if so: How?"* The students can also comment on the quantified questions. Further, the responsible teacher and the students can agree on adding additional questions for a certain course.

In the analysis, we first studied averages and variation for the quantified metrics. The averages of four aspects (student satisfaction, delivery of education, prior knowledge, and workload) were compared between the two sets of courses using Independent Samples T-tests.

Each test produces a p-value, which indicates the probability that the difference is random (Gosset, 1908). The standardized significance thresholds of 5%, 1% and 0.1% are used. The aims were to identify general patterns in the data and to select a subset of the CDIO courses for deeper analysis, where we also considered the free text data. As a starting point for the analysis we also had the research questions and the hypotheses of reasons for high and low student satisfaction as described in the earlier work section. Six CDIO project courses were selected for deeper analysis, based on that the courses had either very high or very low student satisfaction rating, or had been redesigned with significant changes in student satisfaction rating as a result.

Table 1. Studied CDIO project courses

Course	Program/ level	Year (1-5)	Credits (ECTS)	# students	CDIO
MMF176 Introduction to mechanical engineering	ME BSc	1	7	150	CDIo
PPU175 Integrated design and manufacturing	ME BSc	2	7.5	150	CDIo
MMF092 Machine design	ME BSc	3	7.5	50	DI
MPP126 Product development project	ME MSc	4	15	65	CDIo
PPU085 Product planning	ME MSc	4	7.5	60	Cd
TME180 Automotive engineering project	ME MSc	5	7.5	30	DIO
TME047 Chalmers Formula Student	ME MSc	4	15	30	CDIO
TME131 Project in applied mechanics	ME MSc	4	7.5	45	DIo
MMA151 Marine design project	ME MSc	5	15	20	CD
PPU171 Industry project	ME MSc	5	7.5	50	CD
SSY330 Introduction to automation and mechatronic engineering	AE BSc	1	7.5	85	DIO
SSY047 Systems engineering	AE BSc	2	7.5	85	DIo
SSY226 Design project in systems, control and mechatronics	AE MSc	5	7.5	120	DI
MPP083 Introduction to industrial design engineering	IDE BSc	1	10.5	45	CD
MMF274 User oriented design	IDE BSc	2	7.5	45	CDI
MMT015 Product requirements engineering	IDE BSc	2	7.5	45	CD
PPU032 User studies - Understanding the user and its requirements	IDE BSc	3	7.5	45	Cd
PPU095 Project industrial design engineering	IDE MSc	4	15	45	CDIO
PPU195 Product development project	ME & IDE BSc Eng	2	7.5	105	DIo

RESULTS

This section presents the results from the study. First the quantitative results are presented and briefly commented. Then we discuss in more depth the six case studies of CDIO project courses with very high/low student satisfaction ratings.

Quantitative results

Results per course

For the three academic years chosen for this study (2014/2015, 2015/2016 and 2016/2017), there were a total of 763 instances given of the selected courses. Out of these, 56 were

deemed instances of CDIO project courses and 707 instances of other courses. Some courses were given more than once per academic year, and some were not given in one or more of the academic years considered. In the tables below, the data used for the study is listed for each of the included CDIO project courses for the academic year of 2016/2017. Table 2 provides an overview of the student satisfaction results.

It is worth noting that the courses which score lowest on student satisfaction are bachelor level courses, perhaps hinting at the need for students to have a solid foundation before undertaking CDIO project courses.

Table 2. Overview of data – BSc courses in white, MSc courses in gray

Course	Satisfaction 16/17		Delivery of education 16/17		Prior knowledge 16/17		Workload 16/17	
	Mean	St.dev.	Mean	St.dev	Mean	St.dev	Mean	St.dev
TME047 Chalmers formula student	4.71	0.61	4.50	0.65	4.00	0.96	4.43	0.94
MMT015 Product requirements engineering	4.43	0.59	4.48	0.73	4.83	0.39	3.45	0.67
MPP126 Product development project	4.38	0.82	4.25	0.68	4.57	0.59	3.88	0.74
SSY330 Introduction to automation and mechatronics	4.28	0.85	4.03	1.00	4.28	0.89	3.31	0.64
TME131 Project in applied mechanics	4.27	0.88	3.73	1.16	4.40	0.74	4.07	0.88
MMF092 Machine design	4.14	0.79	3.95	0.94	4.50	0.69	3.62	0.67
PPU095 Project industrial design engineering	4.14	1.23	3.00	1.30	4.86	0.36	3.36	0.50
PPU032 User studies – Understanding the user and its requirements	4.08	0.92	4.29	0.61	5.00	0.00	3.36	0.50
TME180 Automotive engineering project	4.08	1.00	4.42	0.67	3.83	0.94	3.17	1.03
PPU085 Product planning	3.95	0.91	3.95	0.85	4.58	0.69	3.68	0.75
MPP083 Introduction to industrial design engineering	3.92	0.84	4.08	0.80	4.27	0.92	3.42	0.76
SSY047 Systems engineering	3.66	1.41	3.22	1.24	3.94	1.24	4.34	0.75
SSY226 Design project in systems control and mechatronics	3.56	1.19	3.36	1.45	4.32	0.88	3.41	0.66
MMA151 Marine design project	3.50	0.96	3.43	1.12	4.27	0.83	3.18	1.01
PPU171 Industry project	3.43	1.45	3.79	1.12	4.79	0.43	3.85	0.80
MMF176 Introduction to mechanical engineering	3.21	1.12	2.98	1.20	4.31	0.95	3.40	0.72
MMF274 User oriented design	3.16	1.21	2.26	1.10	4.56	0.70	3.79	0.71
PPU175 Integrated design and manufacturing	2.67	1.18	3.05	1.11	4.28	1.00	4.05	0.92
PPU195 Product development project	2.48	1.12	2.57	1.16	4.19	0.98	4.43	0.68

Aggregate level results

Table 3. Student satisfaction

	N	Mean	Standard deviation (between courses)	Standard deviation (within courses), (Mean)
CDIO project courses	56	3.68	0.72	0.96
Other courses	707	3.85	0.59	0.86

The student satisfaction of courses is measured using the course survey question “*What is your overall impression of the course?*” The answer scale ranges from 1 (Very poor) to 5 (Excellent).

Student satisfaction ratings for CDIO project courses were on average 0.17 lower than for other courses on the scale from 1 to 5 (see Table 3) The p-value for the difference is 0.044, meaning it is significant at the 5% level. The standard deviation *between* courses was on average 0.13 greater for CDIO project courses. The mean standard deviation *within* courses was 0.10 greater for CDIO project courses. The p-value for the difference is 0.001, meaning it is significant at the 0.1% level.

There is thus reason to believe that student satisfaction of CDIO project courses on average is lower than for other courses, and that the range of student satisfaction (standard deviation within courses) is greater for such courses.

Table 4. Delivery of education

	N	Mean	Standard deviation (between courses)	Standard deviation (within courses), (Mean)
CDIO project courses	56	3.58	0.70	0.99
Other courses	707	3.86	0.65	0.90

Delivery of education in courses is measured using the course survey question “*The teaching worked well*”, to which the student can answer between 1 (Disagree completely) and 5 (Agree completely).

Student opinion on the delivery of education for CDIO project courses was on average 0.28 lower than for other courses on the scale from 1 to 5 (see Table 4). The p-value for the difference is 0.002, meaning it is significant at the 1 % level. The standard deviation *between* courses was on average 0.05 greater for CDIO project courses. The mean standard deviation *within* courses was 0.09 greater for CDIO project courses. The p-value for the difference is 0.008, meaning it is significant at the 1% level.

We can thus conclude that students' rating on the delivery of education in CDIO project courses on average is significantly lower than for other courses, and that the range of student opinions (standard deviation within courses) on delivery of education is greater in such courses.

Table 5. Prior knowledge

	N	Mean	Standard deviation (between courses)	Standard deviation (within courses), (Mean)
CDIO project courses	56	4.35	0.47	0.77
Other courses	707	4.26	0.37	0.85

Students' assessment of whether their prior knowledge was suitable for the course they took is measured using the course survey question *"I had enough prior knowledge to be able to follow the course"*, to which the student can answer between 1 (Disagree completely) and 5 (Agree completely).

Student ratings of their prior knowledge for CDIO project courses were on average 0.09 higher than for other courses on the scale from 1 to 5 (see Table 5). The p-value for the difference is 0.088, meaning it is *not* significant. The standard deviation *between* courses was on average 0.12 lower for CDIO project courses. The mean standard deviation *within* courses was 0.08 lower for CDIO project courses. The p-value for the difference is 0.017, meaning that the difference is significant at the 5 % level.

We can therefore assume that students' rating of whether their own prior knowledge on the subject was sufficient to follow the course does not vary significantly between CDIO project courses and other courses, but that the range of students' assessment of their prior knowledge could be slightly greater in CDIO project courses than for other courses.

Table 6. Perceived workload

	N	Mean	Standard deviation (between courses)	Standard deviation (within courses), (Mean)
CDIO project courses	56	3.67	0.47	0.74
Other courses	707	3.37	0.36	0.66

Students' assessment of perceived course workload is measured using the course survey question *"The course workload as related to the number of credits was..."* to which the student can answer between 1 (Too low) and 5 (Too high).

Students' ratings of the workload for CDIO project courses were on average 0.30 higher than for other courses (see Table 6). The p-value for the difference is 0.000, meaning it is significant on the 0.1% level. The standard deviation *between* courses was on average 0.11 greater for CDIO project courses. The mean standard deviation *within* courses was 0.08 greater for CDIO project courses. The p-value for the difference is 0.001, meaning it is significant on the 0.1% level

We can thus conclude that student ratings of the workload in CDIO project courses on average is significantly higher than for other courses, and that the range of student opinions (standard deviation within courses) on the amount of workload is greater for such courses.

Bachelor vs. master level results

Table 7. Student satisfaction in bachelor and master level CDIO project courses

		N	Satisfaction	
			Mean	St. dev.
BSc courses	CDIO project courses	29	3.38	0.81
	Other courses	378	3.81	0.64
MSc courses	CDIO project courses	27	4.00	0.40
	Other courses	329	3.89	0.53

When we disaggregate student satisfaction for CDIO project courses and other courses by bachelor or master level, certain patterns emerge (see Table 7).

The difference between CDIO project courses and other courses at master level has a p-value of 0.271, meaning it is not significant. The difference between other courses at bachelor and master level is also not significant, with a p-value of 0.104. The difference between CDIO project courses at bachelor and master level is however significant at the 0.01 % level with a p-value of 0.001. The same significance and p-value can be observed for the difference between CDIO project courses and other courses at bachelor level.

We can thus conclude that CDIO project courses on average get a higher student satisfaction rating at the master level than at the bachelor level, and that students on average are less satisfied with bachelor level CDIO project courses than other bachelor level courses. There is also no significant difference in student satisfaction between CDIO project courses and other courses at the master level, nor is there a difference in student satisfaction between other courses between the bachelor and master level.

Case studies

Below, we discuss in more detail some selected CDIO project courses. Courses with very high, low, or drastically changed student satisfaction were selected, namely:

- PPU175 Integrated design and manufacturing, Y2 ME, (low ratings)
- TME131 Project in applied mechanics, Y4 ME, (very high ratings)
- TME047 Chalmers Formula Student, Y4 ME (very high ratings)
- MPP126 Product Development Project, Y4 ME (very high ratings)
- PPU195 Product Development Project, Y2 ME BScEng program (low ratings)
- PPU031/032 User Studies - Understanding the User and its Requirements, Y3 IDE BScEng, (transition from poor to high student satisfaction rating)

PPU175 Integrated design and manufacturing, Y2 ME (low student satisfaction rating)

Integrated design and manufacturing is a design-build-test team project course in the second year of the Mechanical Engineering program. The course aim is *to provide possibilities for the students to participate in industry-related product development projects*. Learning outcomes include to be able to: create project definition, analyse customer value creation, design, analyse and evaluate concepts as well as present and argue for the chosen problem solution. The students are divided into teams of five students. The project tasks originate from industry and are focused on the early product development phase, i.e., concept study and test and evaluation of physical prototypes or simulation models, and value-based

management. The projects must be realistic, technically challenging and have wide solution spaces. Examples: Development of electric car charging connector (Volvo Cars), and development of automatic detergent dispensers for washing machines (Asko Appliances).

The students are assigned to a team and the project task without the possibilities to have any choices regarding task and teammates. Each team has two Chalmers supervisors and one company representative. The course has integrated teaching and training of project management, communication, and teamwork, and one meeting per week with supervisors. Students follow a pre-defined process consisting of nine steps to deliver the results in a systematic manner. The project results and achievements from each step are assessed and graded with continuous feedback to each team. The individual grade is built as an accumulated moving average, which the students are able to follow. At the end of course, the students' grades take into account the accumulated moving average, the quality of the product, the final report and the presentation as well as the team working process.

The course has been given since 2008 with only minor annual updates. The first course rounds were very well received by the students. The course was new and unique and both students and teaching staff were very enthusiastic and overlooked most issues related to the novelty of the approach including supervision, workload and planning. Recently, students have been less satisfied and the course has not met the high expectations from early course rounds and the marketing of the course. This is manifested in the course questionnaire responses. The mean values of the students' overall impression have been around 2.5, which is well below the approved limit of 3.0. The mean value for all courses in the ME program is 3.8. The students mean that the course idea, aims and projects are good and that they have the required prior knowledge. The students' complaints regard the supervision, planning of the course and above all the experienced workload. The workload is judged to be very high and much higher than in a traditional lecture based course of the same size. The experienced high workload creates stress. Evidently, the students work very hard and the learning is substantial. This is reflected in that all students pass the course and that the mean grade is very high: 4.4 to 4.6 out of 5. This is certainly not the case in a traditional lecture-based course in which normally 30 % of the students fail the first exam, the average grade is around 3.5 and the workload is normally experienced to be reasonable or somewhat high. We have asked students to keep track of their working hours in a diary and put a strict limit on the number of hours that is available in the project. In fact, we do not observe a very high number of actual working hours in PPU175. The explanation is believed to be found in the fact the students have little previous training in dealing with open-ended problems and related uncertainties together with the continual assessment and grading, expectations of high grades and the desire to do well for the external client. These circumstances create negative stress and anxiety, which results in the students perceiving a very high workload. The perceived workload has increased from the previous course rounds despite the teaching staff's attempts to reduce the workload by simplifying the assessment and grading system as well as reducing the number of mandatory lectures. The same contradiction is reported in (Joyce *et al.*, 2013).

To summarize, we have identified the following problem factors:

- The variety in project assignments. Not all assignments are suitable for the prescribed project management model.
- The assessment and grading system that drives some students to put too much attention on the grading itself rather than learning to solve the problem.
- Lack of competence or experience of some supervisors.
- The perceived very high workload.

TME131 Project in applied mechanics, Y4 ME, (very high student satisfaction ratings)

Project in applied mechanics is a compulsory course in the master program Applied Mechanics. The course aims *to provide the student with an opportunity to apply knowledge in mathematical modelling using computational and experimental techniques*. The learning outcomes include to be able to: formulate problem definition, master open-ended problems with limited information and uncertainties, use up-to-date simulation tools and experiments as well as to work in teams and identify and handle ethical aspects on development work.

The course has a mixture of students with different technical profiles as well as with backgrounds from different universities worldwide. The students are organized in teams of four to six students. Each team has a unique project originating from the industry or from research at the Department of Mechanics and Maritime Sciences. Most of the research is conducted in cooperation with industry meaning that almost all projects are industry related. Each team has at least one faculty supervisor and often one supervisor from the industry as well. Supervisors formulate projects and submit them to the examiners who approve and make them available to the students. Students then select at least three projects in priority order. The examiners comprise teams based on the students' selections and their grade point averages in the case of exceeded projects. This means that each project has highly motivated students and supervisors with a strong sense of ownership of the projects. In order to resist the bias that this can lead to role of the examiners is disconnected from supervision.

The projects can be design, simulation and/or experimental projects. The projects must be technically challenging, have a wide solution space and include the complete solution chain, i.e., from problem definition to a computational model or experiment. Examples of projects include: design and optimization of vertical axis sea-based wind turbine (Sea Twirl); simulation and testing of weld nut failure at belt pull (Volvo Cars) and CFD simulations and wind tunnel testing of solar-dish unit (Clean Energy).

The course includes integrated lectures and training of methodology, report writing, presentation and ethics. The students' grades are based on both team and individual achievements. Team deliverables include final report and solution, planning report, presentation and opposition that are assessed by the examiners while the individual contributions are assessed by supervisors and by an anonymous peer-assessment within each team based on predefined rubrics. The grades are generally very high with an average above 4.5. The course is very well received by the students with a mean value of the overall impression of 4.3. From the questionnaire and meetings with the students we got clear messages that the students sincerely appreciate to work with technically advanced industrial problems and that they valued the team work highly. The students reported a very high workload in the course but considered it to be worthwhile considering the outcome and, thus, it did not affect the general impression.

The following success factors can be identified:

- A variety of carefully selected projects reflecting different aspects of applied mechanics originating from both industry and research.
- Highly devoted students and supervisors with strong sense of ownership of projects.
- Structured feedback to the students from examiners and room for reflection. A student comment from questionnaire illustrates this: *"I think it was really good with the group feedback meetings at the end of the course and the possibility to really reflect on the group work and what worked well and not as well."*

TME047 Chalmers Formula Student, Y4 ME (very high student ratings)

Chalmers Formula Student is an elective course in the master programs Applied Mechanics, Automotive Engineering, Electric Power Engineering and Systems, Control and Mechatronics. The course runs over the whole academic year. Chalmers Formula Student aims to bridge the gap between engineering education and the industry by training students in a real-life project where they independently design, analyze and develop technology solutions by making data-driven decisions throughout the design, manufacturing and testing of a full-fledged formula racing automobile, and finally put their skills to the test in competitions with various other teams from the rest of the world. Each year, a team of about 30 students designs, builds and tests a new vehicle. A new team is formed every year. Team goals are set to establish aims and expectations. The common goals unify the team and create a sense of purpose to the actions of individuals. Since 2015 the car is electric and thus the course has become multidisciplinary to include mechanical and electrical engineering. It is a highly selective process to be admitted to the course. The students apply for the course and compete for positions in the course by skills, competences and grades. The examiner of the course selects students with different competences to reflect the multidisciplinary nature of the project. The course has one faculty examiner and manager and three faculty supervisors with different technical competences. The students and the teaching staff are highly devoted to the course. The students are assessed based on work performed in the project, written reports, oral presentations and peer reviews. The average grade is very high and the students are very satisfied with the course. The mean value of the students' general impression is uniquely high 4.7. The course requires a much higher workload than the 15 ECTS indicate. The examiner is open with that in the recruitment and the students are fully aware of what is expected from them.

Success factors include:

- Dedicated and competent teaching staff and students.
- A very well-structured work plan with clear milestones.
- An engaging aim in the competitions.

Product Development Project (MPP126) Y4 ME (high student ratings)

Product Development Project (MPP126) is compulsory for the master program in Product Development. It is carried out in collaboration with external partners, typically industrial companies, addressing real development challenges. The aim of the course is thus to make the students experience a real product development project. The project work is carried out in teams with 6-8 students with students from different educational backgrounds, such as mechanical engineering or automation and mechatronics, and from different countries. Each team is given a unique task from a unique external partner. Before assigning students a particular project, many options are presented and the students can vote on five.

The course set-up takes inspiration from CDIO, and covers well the chain C-D-I, starting with planning and requirements setting and ending with a prototype exhibition, while "O" is less well covered. The development tasks are generally open-ended, while the course structure and associated course memo have a relatively high level of detail. Specified learning outcomes cover associated process and method knowledge, but also team dynamics. Assessment and grading is based on the team's project result, along with individual result on written quizzes and team member assessment. For the latter, a specific fill-out form for peer assessment of team member performance has been developed (cf. Gray, 2013). In practice, about 30 % of the students get a grade different from their team project grade.

According to the course questionnaire students are generally satisfied with the course, and the average total score for the four most recent years is 4.03; 4.39; 4.30; 4.38. Looking at the free-text comments, students are consistently happy with the course structure, content, and administration. In addition, students appreciate the variety of projects to select from, as well as having a unique project. So at this education level, students are seemingly mature enough to tackle a project unique for the team, in contrast to the PPU195 case (below). Major complaints in the course refer to problems with the actual team dynamics, but also to team dynamics as a subject although opinions on this differ very much. Another rather common complaint is limited access to the prototype laboratory.

The following success factors can be identified:

- Several alternative projects and industrial partners to select from.
- The course structure has been carefully designed for constructive alignment and CDIO from the beginning and also iteratively improved based on student feedback as well problems noted by the teaching staff.
- Dedicated teaching staff with multi-year experience on the topic as well as the specific course.

Product Development Project (PPU195) for Y2 ME BScEng program (low student satisfaction rating)

Product Development Project (PPU195) is compulsory for the year 2 students of the bachelor program in Mechanical Engineering. The aim of the course is to let the students train systematic methods and tools for product development. The projects are carried out in teams and in collaboration with several industrial partners.

Intended learning outcomes for the students include theoretical concepts and models for product development and project management, as well as the ability to apply them. In addition, as specified, the students are expected to enhance their skills in compiling and presenting the results of a project, orally and in writing. Constructive alignment has been employed in planning the course, but looking deeper on the course structure, one can note a lack of detail in some areas. This applies in particular to criteria for assessment and examination, while there is a predefined four-step (fail, 3, 4, 5) grade scale in place.

The course has scored poorly several years in the course questionnaire, the average total score the four most recent years is 1.76; 2.00; 2.23; 2.48. Indeed, tracking these scores, one can note a somewhat positive trend. This is probably the result of engaging additional competent teachers in the course as well as educating the teachers in design methodology through courses for professionals. However, the student satisfaction with the course is still not acceptable. Interpreting free-text answers in the course questionnaires, possible reasons include varying teacher dedication, varying quality of teaching and supervision, as well as unclear criteria for assessment, grading and feedback. There are also many negative comments about the course literature, in particular when in the form of an app. Course administration as such is satisfactory. On further reflection, possibly the students are at year two of this bachelor's program not fully ready for this kind of project course, including among other things open-ended design tasks in individual teams tackling individual project challenges. In order to address this, the next planned course round will be centered on one large project common for all students in the course.

The following problem factors can be identified:

- Lack of quality assurance in scouting projects, course structure and course delivery.
- The very high perceived workload due to students not enough familiar with open-ended project tasks in combination with unclear communication about expectations.

PPU032 User Studies - Understanding the User and its Requirements for IDE BScEng, (transition from poor to high student satisfaction rating)

User studies - Understanding the user and its requirements (PPU032) is a project-based course with a complementary written exam, compulsory for year 3 students of the bachelor's program in Product Design Engineering. The aim of the course is to get students develop knowledge and skills regarding user requirements elicitation and user-centered design.

Particular learning outcomes after the course include; understanding of the notion user-centered design, ability to apply methods for eliciting user requirements, ability to apply methods for analyzing user data, and ability to effectively communicate user requirements. From the point of view of course design, this course is an interesting learning object, in particular when it comes to the importance of having an appropriate grade scale in place: The previous version of the course (PPU031) had just a fail/pass grade scale, and it scored poorly in the course questionnaire. The examiner hypothesized that possibly the students suppress the importance of the course, for the benefit of another graded (fail, 3, 4, 5) course taught in parallel. Along with this, the examiner hypothesized that a certain level of student dedication is necessary in order to really enjoy and learn from a course with a project-based set-up. In addition, the examiner collaborates with another examiner giving a similar course with nearly identical content, however with a more detailed grade scale (fail, 3, 4, 5), and that course has always scored well in the course questionnaire. Therefore, an effort to introduce a more detailed grade scale in PPU031 was made, along with formulating the following hypothesis: *"A course without grades (pass/fail) given in parallel with a course with grades (fail, 3, 4, 5) scores poorly in the course questionnaire. This is applicable in particular if the course (pass/fail) has a project- and problem-based pedagogical set-up"*.

When the new grade scale (fail, 3, 4, 5) had been introduced (and the course id became PPU032) and used in practice, the students' satisfaction according to the course questionnaire was significantly improved, and thus the hypothesis was supported. The hypothesis was further supported after another course round with very good student satisfaction. This phenomenon is illustrated in Figure 1 below.

A possible explanation behind the significantly improved student satisfaction includes not only the fact that the detailed grade scale made the students prioritize the course more, but also the fact that a more detailed grade scale calls for assessment criteria to be in place. Thereby, both feedback and justification behind the individual's obtained grade can be improved.

The introduction of the grading scale is identified as the dominating success factor.

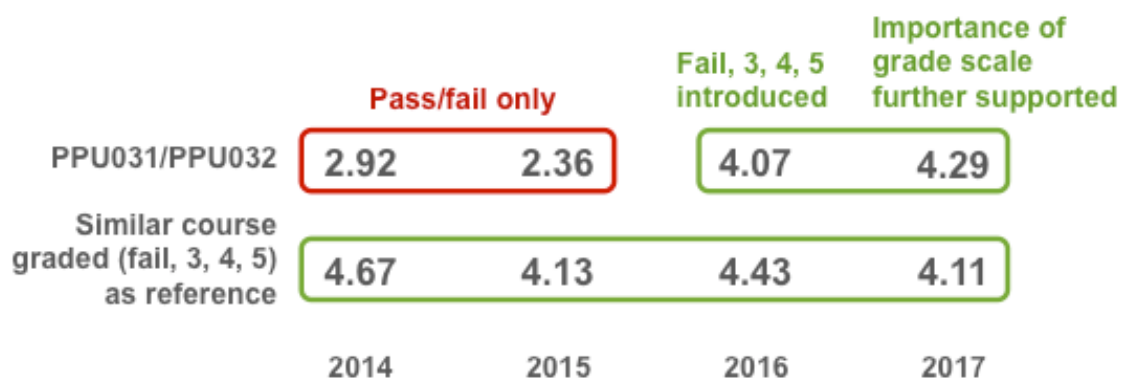


Figure 1. Evolution of students' satisfaction with the course PPU031/PPU032, as a result of introducing a more detailed grade scale, and a comparison with a similar course.

DISCUSSION

The study has found evidence for significant differences in level and variation of student satisfaction in CDIO project courses vs traditional courses for the BSc stage of education. BSc stage CDIO project courses scores are lower and with more variation (see Table 7). In the data from Chalmers, these differences are significant. For MSc level, the tendency is the opposite: MSc level CDIO project courses have higher student satisfaction levels and less variation. However, MSc level differences are not statistically significant. In the following discussion, we analyze a number of aspects that may explain the lower ratings for BSc /higher for MSc.

The study shows that students at BSc level often perceive a too high workload in CDIO project courses (see Table 2). This leads to negative stress and complaints on the course. The students also claimed that the high workload has negative effects on their studies in parallel courses. In free text comments they indicated that the high workload as a main reason for low satisfaction ratings: *"The course is far too demanding, I neglected the parallel courses"* or *"We have spent an incredible number of hours on the project. Because each submission was graded it was important that they were on top level every week"*. Measures such as simplifying assessments and course structure (PPU175 and Joyce, 2013) as well as giving each team a limit on the number of available working hours in the project have been taken without success. In fact student logbooks show that the actual working hours are as expected, and it seems that students overestimate their working hours. Possible explanations include the perceived uncertainties in the problem statement, process and what constitutes a good solution. These factors are probably more influential at BSc level compared to MSc level where students have more experience in coping with uncertainties and ambiguities. Table 2 shows that the workload is not perceived as a problem at MSc level as a high perceived workload does not decrease the overall impression ratings.

In CDIO project courses, it is essential that the technical complexity and level of the project match the students' skills, knowledge and capacity as well as the size of the course. Course leaders need to make sure that projects are appropriate for separate but yet integrated work and sufficiently complex so that the students need to rely on each other's knowledge and skills (Malmqvist *et al.*, 2004). For Formula Student and Product development project - courses with high student satisfaction, the projects are either quite structured or the process

is more situation-based but at BSc level the projects have an inherent potential conflict in needing to both be based on industry problems and to apply a highly prescribed methodology. Project products and assignments need to be chosen with special care to train the use of the methodology, being authentic and satisfy industry expectations, e.g., methodology may put most attention on concept development while a company may expect more detailed results.

Assessment and grading is a particularly important challenge for CDIO courses. We have observed that it is important to have a grade scale, e.g., fail, 3, 4, 5, rather than just fail or pass. This is to engage the students in the course and to propel quality of project work. In addition, having a more detailed grade scale paves the way for having more appropriate assessment criteria in place (cf. Gray, 2013). However, in a large course with many student teams it may be difficult to provide feedback timely and to provide each team enough time, and the student satisfaction might decrease. On the other hand, in Chalmers cases where the strategy has been promptly implemented the students have been highly satisfied (TME131). In some other Chalmers CDIO project courses, e.g., PPU175, continual assessment and grading is heavily used. The original intent of this was to motivate students to start work early and to enable the examiner to continually secure that the students follow the predefined methodology. However, there is a risk that this set-up dominates daily work too much and creates negative stress and discomfort. To conclude, there has to be an assessment and grading system in place but the level must be balanced regarding content and detailing level.

Above, we have discussed course structure and students' experiences. Important, as well, is the teaching staff and their performance during the course. It is clear that the professional engineering competence of teachers has been an issue in PPU175 and PPU195. It is also noted as a challenge in the global CDIO survey (Malmqvist *et al.*, 2015). To address this issue, staff planning must consider the need for well-prepared and appropriate teachers in the CDIO courses. In addition, there is a need for having plans for competency development in place. Secondly, during delivery, the coordination and communication are crucial both within the teaching team and between teachers and student.

Student satisfaction metrics reflect the impression in direct connection to the course round. Possibly, a different view evolves later in the education or in the work life as the importance and the relevance become more obvious. In addition, a positive experience of early courses affects the students' selection of later courses and specializations. Thus also, CDIO courses at BSc level need to be received sufficiently well among students in order to attract students to the advanced CDIO courses. This is to ensure that the graduates are well prepared for work practice and demands from the industry in line with the cornerstones of the CDIO initiative.

As noted, the study found significant differences in level and variation of student satisfaction between CDIO project courses and regular courses, in particular early in the education. The study only studied one university and the disciplines were mechanical engineering or close to it. It cannot be excluded that a relatively small number of CDIO project courses had a strong influence on the results. Another source of error is that also traditional courses may include CDIO learning experiences to some extent. However, taking this factor into account would likely increase the difference in student satisfaction levels, rather than even out. Further studies at other universities and with additional disciplines would be desirable in order to examine the generalizability of the findings.

CONCLUSIONS

According to student satisfaction data from Chalmers University of Technology, students at BSc level are less satisfied with CDIO courses compared to traditional ones. Still, it is essential to include these courses already on BSc level because students need to gradually develop competences in project management and methodology, team work and communication in order to be prepared for more advanced MSc level CDIO courses.

For CDIO project courses it is particularly important to consider (constructive) alignment between course intended learning outcomes, teaching & learning activities and assessment. Since project-based courses inherently include open-ended problems with a high degree of uncertainty, a relatively high formalization of course structure is needed. Particularly, in CDIO project courses early in the curriculum, it is important to give the students clear timeframes and plan the deadlines for submissions and presentations well. This to avoid that the students work too much and experience stress due to that they want to perform well in industry-sponsored projects. In addition, feedback is crucial but needs to be delivered timely.

Finally, it is crucial with well-prepared, visible and engaged course leaders, and with continual motivation of the relevance of non-technical course content, including ethics, sustainability, and team dynamics.

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