

Technical University of Denmark



## Do we educate engineers that can engineer?

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# DO WE EDUCATE ENGINEERS THAT CAN ENGINEER?

Mads Nyborg, Christian W. Probst

DTU Compute, Technical University of Denmark

## ABSTRACT

Since 2008, the Bachelor of Engineering education at the Technical University of Denmark has been CDIO-based, including the software technology and IT and economics study lines. Consequently, the study plans of these study lines were revised to include cross-disciplinary CDIO projects in each of the first four semesters. These projects replaced 11 smaller, course-specific projects in the old study plans. The first three semesters contain design-build projects spanning several courses, and the fourth semester centers around a stand-alone CDIO project. These team-based projects aim at training the students' engineering skills (CDIO competence category 4) and at improving the students' skills in CDIO competence categories 2 and 3. In the tenth year of operation, we now decided to investigate, how content students and employers are with our students' engineering skills. To this end we have designed a survey to provide us with insights for improving our study lines and to address the question: "Are we educating engineers who can engineer?" The questionnaire is aligned with the CDIO syllabus and can also serve for surveying other study lines, since it is not study line specific. To obtain meaningful results, we decided to target students who have at least passed the first four terms, and companies that have hosted a significant number of students in the last 3 years in internships or for the final thesis. These companies interact with the students for almost one year at the end of their studies, providing a good foundation for the company supervisors to answer questions about the students' abilities as an engineer. In this paper, we discuss the design and result of the questionnaire, and the obtained results. As mentioned above, the survey will give us and the CDIO community detailed insights as to how our students and their employers experience the result of our education.

## KEYWORDS

CDIO-based study programs, Stakeholder involvement, Program evaluation, Standards: 1, 2, 3, 12

## INTRODUCTION

Since 2008, the Bachelor of Engineering education at the Technical University of Denmark has been based on the CDIO concept. The goal of adapting the CDIO concept was of course to improve the engineering skills of our graduates. Given the vast effort invested in redesigning the education, we decided to investigate the effect of the CDIO education on our students' assessment of their qualifications and their employers' satisfaction with the students' engineering capabilities. In this paper, we report on the design and results of a questionnaire to answer the question whether we succeeded - whether we actually *are* educating engineers who can engineer.

For most of the study programs, the migration to CDIO has called for significant revisions of their study plans. For the software-related B.Eng. study lines (Software Technology (SWT) and IT and Economics (ITE)), the study plans were revised to include cross-disciplinary CDIO projects in each of the first four semesters. These projects replaced 11 smaller, course-specific projects in the old study plans. The first three semesters contain design-build projects spanning several courses (Nyborg et al. 2010), and the fourth semester centers around a stand-alone CDIO project. These team-based projects aim at training the students'

engineering skills (CDIO competence category 4) and at improving the students' skills in CDIO competence categories 2 and 3. The fifth semester contains elective courses together with a 10 ECTS course in innovation. Finally, in the sixth semester, the students work as interns in companies, and in the seventh semester, they write their final project. Usually the internship and the final thesis are carried out in the same company with the same company supervisor (Nyborg et al. 2012).

To assess the effectiveness of the curricula in educating engineers, we have designed a questionnaire, aligned with the CDIO syllabus. The overall goal of this questionnaire is to address the question: "Are we educating engineers who can engineer?" To obtain meaningful results, we decided to target students who have at least passed the first four terms, and companies that have hosted a significant number of students in the last 3 years. We chose companies that had students for both the internship and the final thesis. These companies interact with the students for almost one year at the end of their studies, providing a good foundation for the company supervisors to assess the students' abilities as an engineer. We collected answers from 18 companies and 34 students, summarized in this article.

The goal of this survey is to provide us and the CDIO community with detailed insights into our students' abilities to act as engineers and how they and their employers experience the result of our education. The results should also be very useful in guiding improvements and tuning measures for the study lines. Since we do not have a baseline from before the adaptation of the CDIO concept in our study lines, we cannot evaluate the relative success. However, this survey evaluates the absolute success and will serve as a baseline for future surveys, planned to be performed regularly in the future.

The remainder of this paper is structured as follows: after a presentation of the involved study lines, we present the survey for companies and students, and their results. We then discuss the results, and conclude the paper with some remarks about possible consequences.

## **THE STUDY PROGRAMS**

As mentioned above, the students questioned in our survey follow the B.Eng. study line on Software Technology or IT and Economics, as part of which they work in internships at the companies questioned. The current curricula of the two study lines originated from earlier B.Eng. study lines on computer systems engineering and IT and Economics (Sparsø, et al., 2011) as part of a merger between the Engineering College Copenhagen and the Technical University of Denmark (Nyborg, Probst, & Stassen, 2015).

Throughout the first 4 obligatory terms, the study lines cover software engineering and core computer science with a focus on systematic approaches to requirements engineering, design of system models, system implementation, and finally the deployment of the system. In addition, the Software Technology line covers more advanced computer science disciplines like operating systems and compiler design, whereas the IT and Economics line covers basic economic theory like business law and managerial economics. In each of the first four terms, several courses contribute to a (smaller) CDIO project, eventually leading up to a "real" CDIO project in the fourth term. Both study lines clearly map to the core competencies in the CDIO syllabus (Crawley, Malmqvist, Östlund, & Brodeur, 2007). Per year, approximately 60 students start with their internship or final project.

In order to strengthen the dialogue with employers and graduates on the further development of the B.Eng. study lines, each study line has an advisory group with employers and graduates. The purpose of these advisory groups is to develop an ongoing dialogue about education quality and relevance, leading to input to the overall DTU advisory board.

The members of the advisory groups are relevant employer representatives who have a thorough knowledge of the specific engineering skills required from graduates, and graduate

students who have graduated within the last two years. The groups meet once a year.

### THE COMPANY SURVEY

In total 34 companies fulfilling the criteria mentioned in the introduction section were selected to participate in the survey. Out of these, 18 answered the questionnaire. The distribution of the number of employees of the participating companies is shown in Figure 1



Figure 1: Number of employees for participating companies

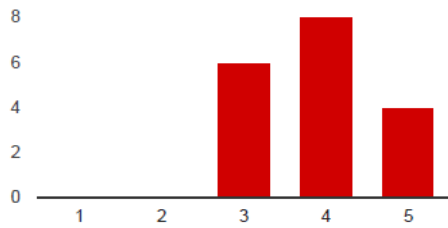
The company questionnaire consists of 17 questions grouped according to the CDIO syllabus, (2 questions in category 1, 7 questions in category 2, 4 questions in category 3 and 4 questions in category 4). The results of the survey is shown in table 1.

Table 1. Questions and results of the company survey grouped according to the CDIO syllabus. In all charts, 1 represents poor, and 5 represents excellent.

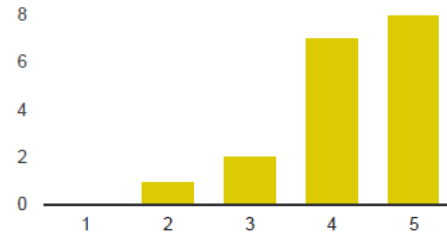
1. Technical knowledge																									
1.1: How did you experience the students' technical skills?	1.2: How adequate were the students' qualifications and previous experience for the work performed in your company?																								
<table border="1"> <caption>Data for Question 1.1</caption> <thead> <tr> <th>Rating</th> <th>Count</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>0</td> </tr> <tr> <td>2</td> <td>0</td> </tr> <tr> <td>3</td> <td>8</td> </tr> <tr> <td>4</td> <td>5</td> </tr> <tr> <td>5</td> <td>4</td> </tr> </tbody> </table>	Rating	Count	1	0	2	0	3	8	4	5	5	4	<table border="1"> <caption>Data for Question 1.2</caption> <thead> <tr> <th>Rating</th> <th>Count</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>0</td> </tr> <tr> <td>2</td> <td>5</td> </tr> <tr> <td>3</td> <td>4</td> </tr> <tr> <td>4</td> <td>5</td> </tr> <tr> <td>5</td> <td>4</td> </tr> </tbody> </table>	Rating	Count	1	0	2	5	3	4	4	5	5	4
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## 2. Personal and professional skills

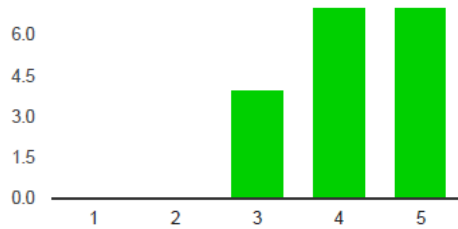
2.1: How did you experience the students' ability to take initiative?



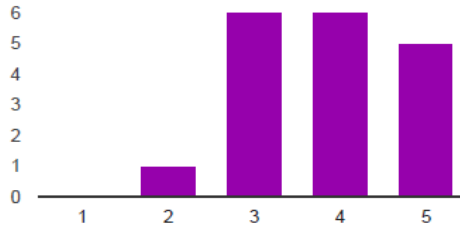
2.2: How did you experience the students' feeling of responsibility for the projects they were involved in?



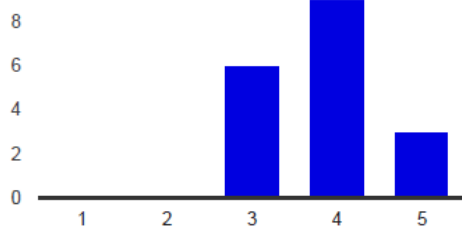
2.3: What is your opinion of the students' ability to acquire and apply new knowledge?



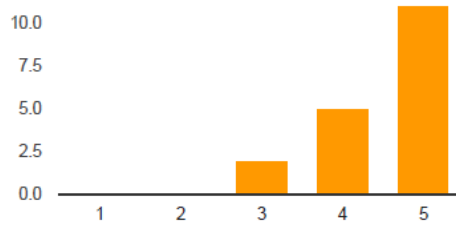
2.4: How were the students' ability to think in systems?



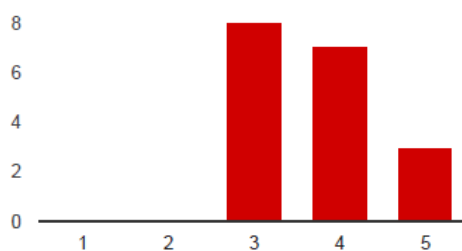
2.5: How creative has the student been (ability to conceive new ideas)?



2.6: How good were the students' motivation?

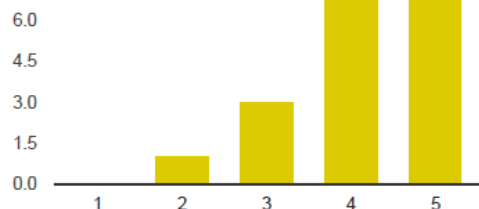


2.7: How good were the students' task and resource management?

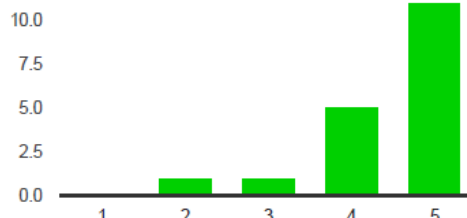


### 3. Inter-personal skills

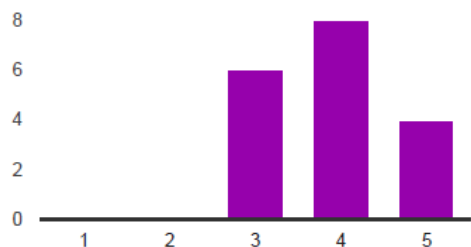
3.1: How good were the students to work in teams?



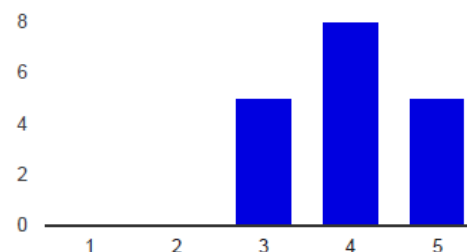
3.2: How good were the students to interact on a social level?



3.3: How good were the students to observe deadlines?

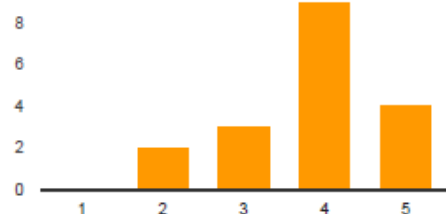


3.4: How were the students' communication skills?

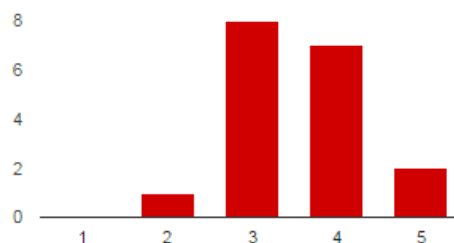


### 4. Engineering capabilities

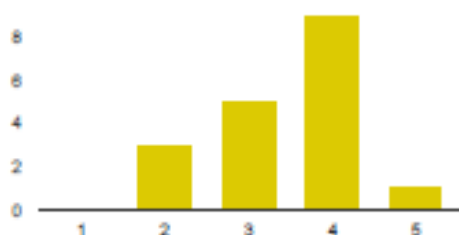
4.1: How do you experience the students' ability to understand requirements?



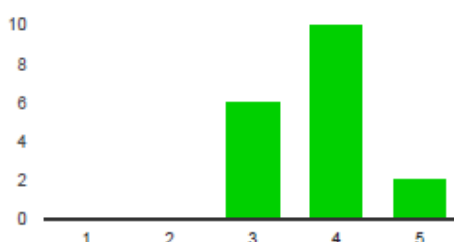
4.2: How do you experience the students' ability to design/implement a (sub) system?



4.3: How do you experience the students' ability to test and document a (sub) system?



4.4: How well did the students solve their tasks from an engineering point of view?



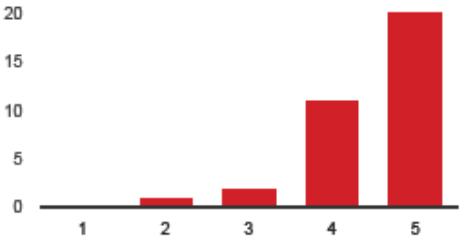
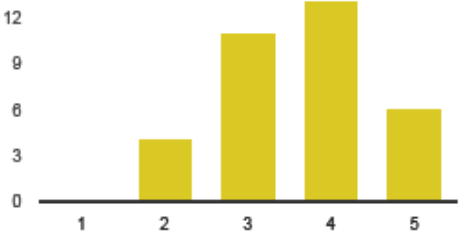
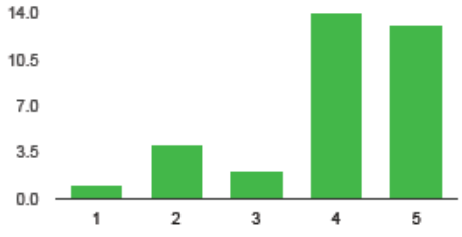
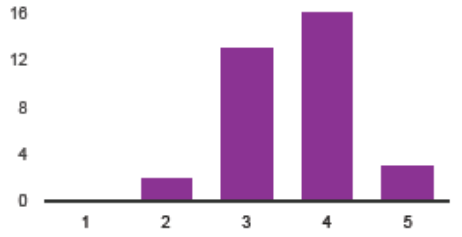
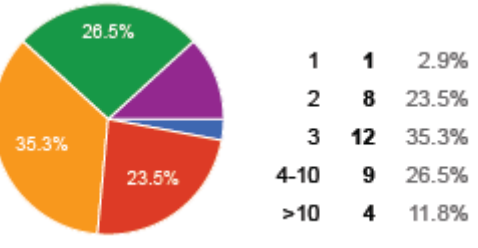
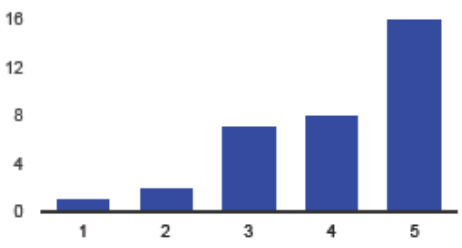
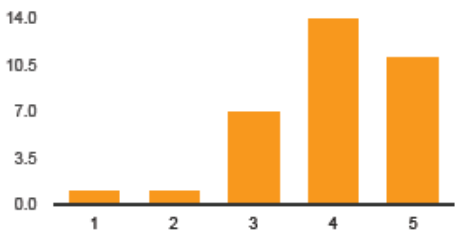
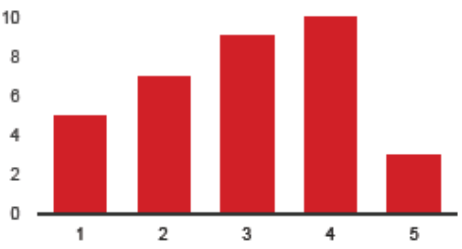
## THE STUDENT SURVEY

Like the company survey, the student survey comprises questions from four areas of the CDIO syllabus: technical knowledge, personal and professional skills, interpersonal skills, and engineering capabilities. While the company survey tries to assess the outside view on our study lines' results, that is how content the companies were with the students' skills and knowledge, and their preparedness for the job market, the student survey assesses the inside view, that is how well did our students feel prepared to fulfill their tasks, and how did they experience the process.

The 34 companies selected hosted together 83 students, who were invited to participate in the student version of the survey. Of these, 34 students answered the questions. Since both surveys are anonymous, we can not reflect on the mapping between student and company answers. The summary for the student survey is shown in Table 2.

Table 2. Questions and results of the student survey grouped according to the CDIO syllabus. As before, 1 represents poor or none, and 5 represents excellent or very much.

1. Technical knowledge																						
1.1: Did you feel well prepared on a technical level for your work in the company?																						
<table border="1"> <caption>Data for Question 1.1 Bar Chart</caption> <thead> <tr> <th>Rating</th> <th>Number of Students</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>0</td> </tr> <tr> <td>2</td> <td>6</td> </tr> <tr> <td>3</td> <td>8</td> </tr> <tr> <td>4</td> <td>18</td> </tr> <tr> <td>5</td> <td>1</td> </tr> </tbody> </table>	Rating	Number of Students	1	0	2	6	3	8	4	18	5	1										
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2.1: Did you have the possibility to take initiative in relation to your work in the company?	2.2: How responsible did you feel for the project you were involved in ?																					
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<p>2.3: How much new knowledge did you acquire during your work in the company?</p>	<p>2.4: How creative could you be in your company work?</p>																														
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<p>2.5: How motivated did you feel for your work in the company?</p>	<p>2.6: How well were you able to perform task and resource management?</p>																														
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<p><b>3. Inter-personal skills</b></p>																															
<p>3.1: How big a team did you work in?</p>	<p>3.2: How well were you integrated in the company on a social level?</p>																														
 <table border="1"> <thead> <tr> <th>Team Size</th> <th>Count</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>1</td> <td>2.9%</td> </tr> <tr> <td>2</td> <td>8</td> <td>23.5%</td> </tr> <tr> <td>3</td> <td>12</td> <td>35.3%</td> </tr> <tr> <td>4-10</td> <td>9</td> <td>26.5%</td> </tr> <tr> <td>&gt;10</td> <td>4</td> <td>11.8%</td> </tr> </tbody> </table>	Team Size	Count	Percentage	1	1	2.9%	2	8	23.5%	3	12	35.3%	4-10	9	26.5%	>10	4	11.8%	 <table border="1"> <thead> <tr> <th>Rating</th> <th>Count</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>1</td> </tr> <tr> <td>2</td> <td>2</td> </tr> <tr> <td>3</td> <td>7</td> </tr> <tr> <td>4</td> <td>8</td> </tr> <tr> <td>5</td> <td>16</td> </tr> </tbody> </table>	Rating	Count	1	1	2	2	3	7	4	8	5	16
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<p>3.3: How important were deadlines for your work in the company?</p>	<p>3.4: How much did you need to communicate results in presentations or reports?</p>																														
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4. Engineering capabilities																									
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## DISCUSSION AND COMMENTS

### *Company survey*

Almost all results in the company survey are positive with an average in the upper range of the used scale. This is highlighted by a general comment from a company:

“We have employed the student and are very pleased with him”

In general, the students’ technical skills (Q1.1) are considered very satisfactory, but it seems that the qualifications were not always right for the project they were involved in (Q.1.2). This is mostly explained in the students’ lack of domain knowledge in the particular company business area, which cannot be obtained at DTU.

As examples for the technical skills, some companies commented:

- He exceeded the expectations for him. A fast learner of the competences he didn't already possess
- Need more information about agile development and next generations of web tools.
- It's a bit unfair to expect experience when it's a person under education.
- A lot of knowledge regarding regulatory limitations (which the student has no chance of knowing about beforehand) are required to make any alterations to existing systems in the pharma industry.

The students’ personal and interpersonal skills are in general rated high by the companies (Q2, Q3). One of the recurring themes in the below comments is that students are perceived as shy and do not ask for help. Also, planning and status reports need more attention.

Comments on professional, personal and interpersonal skills included:

- More initiative is preferable. Instead of trying to solve issues for many days do ask colleagues.
- A bit shy at first, but when he became comfortable, there was a lot of initiative.
- Planning and estimation and status to colleagues need more attention.
- Status, feedback and inspiration from colleagues should have more focus. Don't be afraid of asking.

- Very shy at first.

Overall the engineering capabilities score high (Q4.4), however a bit lower scores are seen for Q4.1 and Q4.3, which address the students' ability to understand requirements and to test and document a system.

*This is highlighted by comments on engineering capabilities:*

- Ask, ask, ask...
- Draw sketches, describe, plan need more focus.

## **Student survey**

Like the company survey, the student survey also shows for most questions a satisfaction score in the high end of the used scale.

The students have been much more eager to provide comments in the different categories. The most important comments within each question category are summarized below.

*Summary of comments on technical skills*

- More courses in front-end web technologies.
- Better alignment with technologies used in companies.
- Provide better tools for teamwork.
- Knowledge of object-oriented programming languages obtained at DTU was a strength.

*Summary of comments on professional, personal and interpersonal skills*

- Good opportunity to take initiative in their projects.
- Main responsible for the project, sometimes too much.
- Learned a lot new stuff.
- Could be creative to some extend.

Most students have been motivated, but some didn't feel that they had sufficient support: [we would need] Better tools for resource management (JIRA for instance) to create tasks, track time etc.

- In-house project deadlines are not as important as customer deadlines.
- Big part of what we did have to do was documentation.
- During booth projects we had loosely scheduled, irregular meetings where we presented our progress.

*Summary of comments on engineering capabilities*

- Was able to provide satisfying solutions.
- A lot of space for improvements.

Completed the task (maybe did a bit more than expected)

*Summary of general comments*

- DTU provides a great theoretical starting point but falls behind on the challenges that are faced when joining a new company. DTU should teach the use of Issue-tracking tools, and the workflow that follows from that (Logging work, commenting, being concise etc.)
- Concepts around algorithms, data structures, databases, state machines, distributed systems could easily be expanded based on the knowledge from DTU.
- DTU lacks teaching of teamwork tools.

- We learned a lot during the internship, but would have appreciated to have learned more in our studies of the things, that the industry demanded.

## **CONCLUSION AND FINAL REMARKS**

In this paper we have presented the results of a company and student survey containing questions in all CDIO competence categories. The results in general shows a high degree of satisfaction, with an average above the midpoint of the used scale in most categories. In particular the comments have been very useful. According to these there are some points that need particular attention:

1. Adjusting the programs to include more courses on front-end web development;
2. Put more focus on planning and estimation of time in projects;
3. Tools for teamwork; and
4. Personal skills.

Re 1:

The ever ongoing challenge for educators in B.Eng. programs is to be reasonably updated in the technical part, i.e., using the frameworks of today that students will be expected to use in the companies. Hence, there is a constant pressure on the staff to keep up with the latest technologies. This demands a great deal of time and effort.

The survey indicates that more focus on front-end web technologies is needed. This is in accordance with the feedback we have gotten from the advisory board and therefore should be addressed in the further development of the curriculum.

Re. 2:

Many of the design-build projects in the first four semesters contain planning and resource management activities, This needs to be strengthened further by adding components that target tools supporting these activities.

Re 3:

Right now most of the students use Google Docs for collaboration on reports and GitHub for version control of programs. Introducing a general tool like Jira could be considered.

Re 4:

The companies' responses indicate that students should be better to ask other colleagues for help. This is a question of personal skills which we expect to be further developed through a new course on innovation in the fifth semester (Nyborg et al., 2016). In this course, the students work in interdisciplinary teams with very loosely specified projects suggested by companies, hence it will be necessary to interact with company staff to clarify the task and with the team members to solve the project.

As mentioned in the introduction, the results presented are absolute and cannot be compared with earlier results before CDIO was introduced, due to the absence of a similar survey before CDIO introduced. However, our results will form the basis for re-evaluations.

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