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Published in:

Proceedings of 2nd International Conference of the Portuguese Society for Engineering Education, CISPEE

Publication date:

2016

Document Version

Peer reviewed version

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Silva, F. M. F. D. (2016). An analysis of the implementation of problem-based learning at the Department of Energy Technology – Aalborg University. In Proceedings of 2nd International Conference of the Portuguese Society for Engineering Education, CISPEE IEEE Press.

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An analysis of problem-based learning at the Department of Energy Technology-Aalborg University

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Abstract—Bachelor and Master degrees at Aalborg University (AAU) use problem-based learning (PBL) as teaching philosophy, where students learn by solving real authentic problems from day 1 until graduation. Besides developing the needed knowledge, skills and competencies, it is also claimed that PBL increases students' motivation and improves their performance resulting in better grades when comparing with traditional teaching methods. Engineering curriculums at AAU are organised in projects (i.e. problem-based) and courses (i.e. lecture-based). However, there are no systematic studies evaluating how well students do in projects and courses, and their perceptions on the respective assessments.

This paper evaluates the AAU PBL model, based on a statistical analysis of the grades obtained by students from the department of Energy Technology, together with answers given by these students in an online survey. The grades of courses and projects are compared, as well as the failure rate of both, using data from the last six years. The fairness of the project's assessment as perceived by students is assessed, together with their opinions on the efficiency of PBL in the teaching of technical concepts. A possible area for curriculum improvement, consisting in changing the project content at the first years of bachelor, is also evaluated.

The results show that the projects have consistently higher grades than courses and a lower failure rate. The students agree that PBL improves the learning of technical concepts and they think that the assessment of projects could be fairer. Changes in the curriculum divide opinions.

Keywords— *Problem-based learning; Grading; Engineering Education Curriculum*

I. INTRODUCTION

Aalborg University in Denmark bases all its educational activities in problem-based project work, known as the Aalborg model of problem-based learning. The main objective of this teaching philosophy is to provide "*students with tools for independent acquisition of knowledge, skills and competences at an advanced academic level*" [1].

The curriculum at AAU is project organized and problem oriented where groups of 4-7 students solve real authentic problems every semester. Parallel to the projects students also have courses, normally lecture-based, to support the projects

and deliver the fundamental technical knowledge (Section II) [1].

This PBL approach is practiced for more than 40 years and "*promotes critical thinking, self-learning skills, lifelong learning, self-achievement, self-regulation, self-efficacy, communication skills and interpersonal skills for students. It also increases the students' interest in a course*" [2]. The private sector also evaluates the use of PBL positively, as it helps developing soft-skills, while still teaching the required technical concepts (Section III).

It is claimed that PBL increase students' motivation and improve their performance resulting in better grades and lower dropout rates when comparing with traditional teaching methods [3][4][5]. However, at AAU, specifically in engineering education, there is not a systematic evaluation of students' performance on projects and courses, as well as their perceptions on the respective assessments. A continuous evaluation of these would enable the academic staff to better adjust the curriculum to students' needs. This paper intends to investigate how students do in projects and courses, and their perceptions regarding group assessment. The study takes a quantitative approach by comparing the average grades and failures rates of the last six years for projects and courses, for bachelor and master levels (Section V). This is followed by the analysis of a survey sent to all undergraduate students with the goal of assessing their perceptions on the projects' assessment (Section VI), the complementary between projects and courses (Section VII) and the amount of courses during the first years of the bachelor degree (Section VIII).

II. AAU CURRICULUM ORGANIZATION AND ASSESSMENT

At the Faculty of Engineering and Science from AAU the curriculum of bachelor and master programs divides all semesters into 50% project-work and 50% courses, each part corresponding to 15 ECTS (European Credit Transfer and Accumulation System). The project-work consists in one single-project running the entire semester done in group. The groups have between 5-7 students at bachelor level, typically. The number of students per group at master-level is smaller, in some cases a single student or a group of 2.

The first semester of bachelor has two smaller projects, in order to introduce the students to projects. A first project called intro-project that runs for four weeks and it is not graded, whose main goal is the teaching of good working practices, followed by a second graded project. Simultaneously, a course is held at this semester (“Problem Based Learning in Science, Technology and Society”) to teach how to: analyse and formulate problems, work in group, write good reports and manage a project. A similar structure exists in the first semester of the master programs for students that obtained the bachelor degree in other universities. The topic of the projects is not fully open and a list of knowledge, skills and competences to be acquired in the projects (i.e., the learning objectives) is defined for each semester. The curriculum for an education in Energy Technology is available at [6].

The assessment of lecture-based courses consists in oral or written exams, made by the course lecturer(s), while the projects are assessed through a group oral exam. At the department of Energy Technology (AAU-ET), the supervisor and one external person make the assessment. This external person is a staff member for semesters 1 and 4 of bachelor and semesters 1 and 3 of master; the remaining semesters use assessors external to the university. This external assessor must be chosen from a national database that includes people from industry and academia suggested by the different Danish universities. The database is updated every four years and at least 25% of the members have to be new. More information is available in [7].

III. INDUSTRY EVALUATION OF AAU STUDENTS

A large survey was made in [8] where industry evaluated PBL. The survey covered a large range of topics and only a small part of the results are presented in this section.

Figure 1 shows that the employers in the field of engineering say that they have particular reasons to prefer students educated at AAU, which can be indirectly seen as an approval of PBL (more information is given in [8]). Moreover, the employers indicated that the graduates are particularly good at project management, team work, innovative tasks and more flexible. A second survey [9] directed to recent alumni reinforced these results and it is their opinion that they are strong at the soft-competences previously indicated, because of PBL.

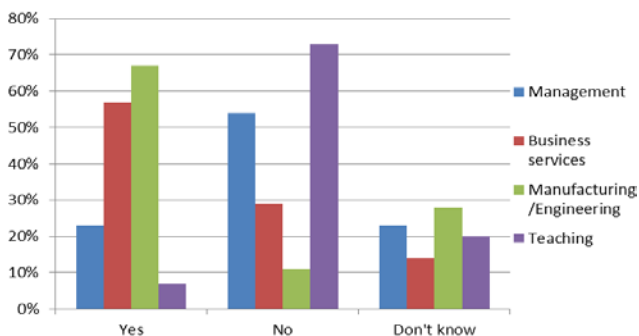


Figure 1 – Answers to the question “are particular reasons to prefer students from AAU?” (adapted from [8])

The benefits of PBL for the development of soft-skills are visible in these results and subsequent sections of this paper will focus on the students’ assessment on the learning of the more technical skills.

IV. DEPARTMENT OF ENERGY TECHNOLOGY

A survey was sent to the students of Energy Technology with the goal of assessing four aspects:

- The fairness of project’s assessment;
- If the projects contribute to the learning of technical skills;
- If the courses and projects complement each other;
- The usefulness of the projects in the first semesters of bachelor education;

The department of Energy Technology educates in three main areas at the Aalborg Campus:

- Electricity: subdivided at master-level into Electrical Power Systems and High Voltage, Power Electronics and Drives, Wind Power Systems;
- Mechatronics;
- Thermodynamics: subdivided at master-level into Thermal Engineering and Process Engineering, Fuel Cells and Hydrogen Technology;

The first two years of Bachelor contain topics of all three areas and are common to all students. The great majority of the students proceed to a master degree immediately after finishing the bachelor. Three different surveys were sent to the students and they answered to one of the surveys depending on their current situation:

- Bachelor students (93 students answered);
- Master students that obtained a bachelor degree at AAU (43 students answered);
- Master students that obtained a bachelor degree at another university (24 students answered);

A total of 272 students received the survey and only surveys with all questions answered were considered.

Besides the survey, a statistical analysis of the grades given to the different courses and projects in the last six year is performed and presented in the next section.

V. GRADES AT ENERGY TECHNOLOGY

A statistical analysis of the grades from all courses and projects between the autumns of 2010 and 2015 is made in this chapter, based on raw data available at faculty level.

The results presented next refer only to an education in Energy Technology and they do not distinguish between specialisations. Courses and projects that are not graded (pass/fail courses) are not considered; the same for students that do not attend the exam or do not deliver the answer sheet.

The results are divided between bachelor and master levels. If a student attends three exams before passing a course, the three grades are included.

The number of grades available in these conditions is:

- Courses – Bachelor: 4887
- Courses – Master: 2181

- Projects – Bachelor: 1600
- Projects – Master: 823

A. Statistical Results

Table 1 and Table 2 show the average grade of courses and projects for both bachelor and master levels. Average 1 includes all grades, including failures, whereas Average 2 includes only passing grades. Danish law forbids students to repeat exams after passing. Thus, the grade for each course in a student’s final certificate is always the grade corresponding to the first exam completed with success.

Different courses may correspond to different values of ECTS points and the same for projects; as an example, a master thesis corresponds to 30 ECTS, whereas a typical project corresponds to 15 ECTS. Consequently, the table shows the averages both with and without weighting the ECTS. The standard deviation is also provided, as well as the failure ratio of courses and projects.

A note about the Danish grading system is important, in order to interpret the results and averages. The scale is not linear, with two failures grades (-3 and 0) and five passing grades (2, 4, 7, 10 and 12).

Table 1 - Average grade, with standard deviation inside brackets, and failure rate for bachelor level

	Courses w/o ECTS	Courses w/ ECTS	Projects w/o ECTS	Projects w/ ECTS
Average1	4.5 (4.3)	4.4 (4.3)	8.5 (3.0)	8.4 (3.1)
Average2	6.4 (3.4)	6.4 (3.4)	8.5 (3.0)	8.5 (3.0)
Failure	27.5%	-	0.5%	-

Table 2 – Average grade, with standard deviation inside brackets, and failure rate for master level

	Courses w/o ECTS	Courses w/ ECTS	Projects w/o ECTS	Projects w/ ECTS
Average1	5.9 (4.4)	5.9 (4.4)	10.3 (3.8)	8.4 (3.0)
Average2	7.6 (3.3)	7.6 (3.3)	10.6 (3.6)	8.6 (2.8)
Failure	21.0%	-	2.7%	-

Figure 2 and Figure 3 show the average grade of courses and projects by academic year, for bachelor and master, whereas Figure 4 shows the failure rate. The results for 15/16 correspond only to the first semester.

The results for bachelor level are more constant than for master level, which can in part be explained by the larger number of students attending the bachelor. Additionally, the teaching staff for bachelor’s courses and projects is more stable than for master level, especially for projects, which may lead to the smaller variation of the grades at bachelor level.

In general, one can see that not many variations exist between years, with some exceptions:

- the year 11/12 saw a jump in the failure rate and a decrease in the average grade at master level. A new curriculum was introduced for master education in 12/13 and thus, it is difficult to assess if the 11/12 results are unusual;

- the average project’s grades at master level add an increasing tendency, 1.4 values between 10/11 and 14/15, but saw a decrease of 2 values from 14/15 to 15/16; however, the data of 15/16 corresponds only to the 1st semester;

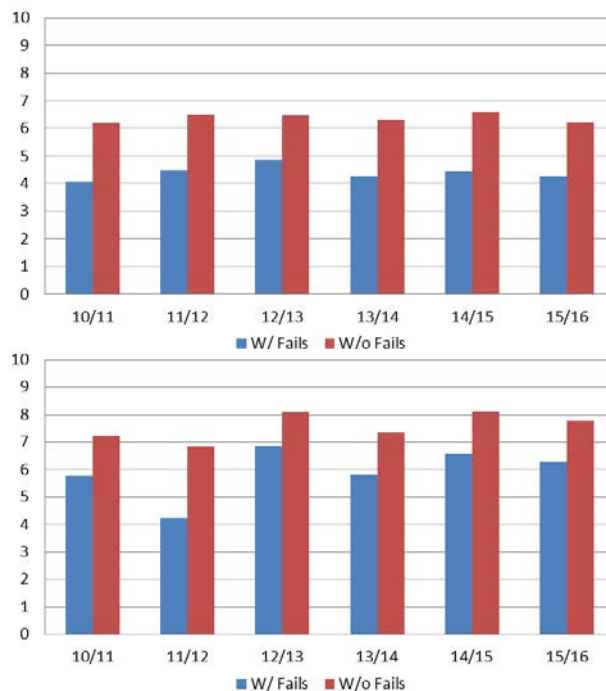


Figure 2 – Courses average grade per year, with and without fails. Up: Bachelor; Bottom: Master

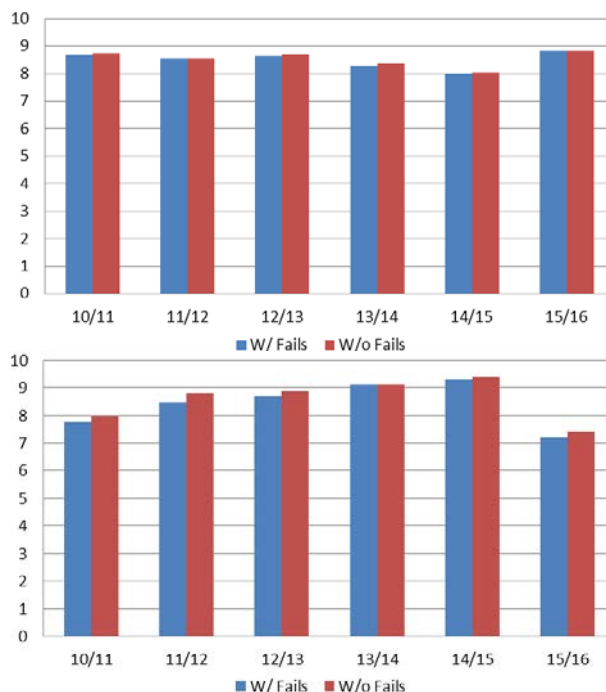


Figure 3 – Project average grade per year, with and without fails. Up: Bachelor; Bottom: Master

Table 3 shows the average grades and failure rate for all four faculties and university as a whole. The average grades of the department of Energy Technology are in line with those of the faculty, a difference smaller than 0.2%, with the failure rate being higher at the department (17.8%). Thus, the results of other engineering departments should also be in line with those previous presented.

It is important to refer that the number of courses without grading, only pass/fail, vary between educations. Those courses were not considered in the results presented in this paper and they influence the comparison between degrees.

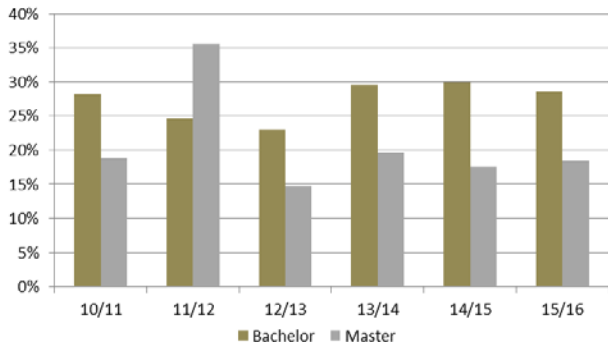


Figure 4 – Failure rate per year for Bachelor and Master

Table 3 – Average grades and failure rate for faculties and entire university

	Average 1	Average 2	Failure rate
Humanities	7.7	8.0	3.7%
Social Sciences	6.5	7.3	8.7%
Medicine	6.6	7.6	12.5%
Eng. and Science	6.4	7.5	13.0%
University	6.7	7.5	9.6%

Table 4 shows the average grading based on the survey’s answers. These average grades are higher than those in the database. The discrepancy can be explained by the students with lower grades withdrawing; they did not answer to the survey, but their grades are in the database.

Table 4 - Average grade of courses and projects, with standard deviation inside brackets, for Bachelor, local Master and foreigner Master

	Bachelor	Master L.	Master F.
Courses	7.4 (2.7)	8.8 (1.9)	7.3 (2.3)
Projects	8.8 (2.5)	9.4 (2.3)	7.7 (2.5)

VI. SURVEY – PROJECT ASSESSMENT

The statistical analysis of the grades made in the previous section shows that projects have higher grades than courses and that the failure rate of the former is almost negligible.

These results may raise questions regarding the fairness of the assessment of projects. Thus, the students were asked to assess two sentences related with assessment and PBL:

- “My knowledge is better evaluated with PBL than with traditional courses”;
- “The evaluation of the project is unfair and it benefits students that did not contribute much to the project”;

Figure 5 and Figure 6 show the answers from the students.

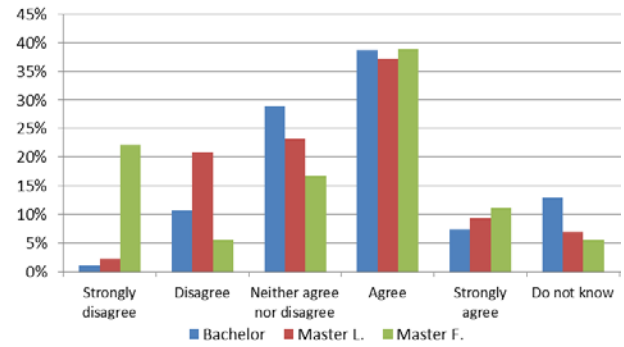


Figure 5 – Answers to the statement: My knowledge is better evaluated with PBL than with traditional courses

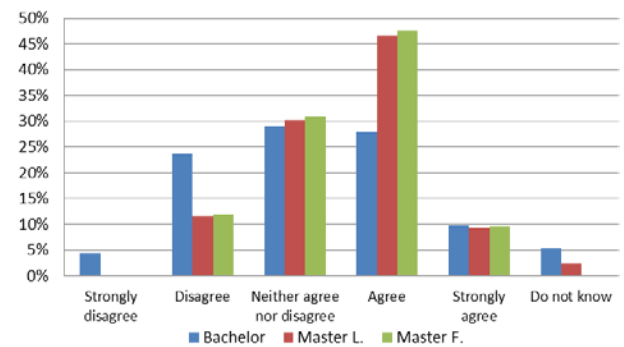


Figure 6 – Answers to the statement: The assessment of the project is unfair and it benefits students that did not contribute much to the project

There is an agreement from all students that their knowledge is better evaluated via projects. However, the statistics also showed that the projects consistently present higher grades, which may bias the answers.

The results from Figure 6 show the fairness of project’s assessment is a topic worthy of more attention. Whereas the bachelor students are divided, with a tendency to state that the assessment is unfair, 38% vs 28%, the answers from the master students clearly shows that they think that process is unfair, 56% vs 12%.

The results for master level can maybe be explained by the fact that these students have done more projects and thus, they had a higher chance of facing problems inside the group. The lower standard deviation of projects’ grades and failure rate also gives some strength to this impression from the students. However, one cannot state that unfairness exists in project assessment using only the available date and previous research indicates that the type of exam and the culture of an engineering program influence the students’ opinion on this topic [10]. As a result, more investigation is required regarding the fairness of project assessment.

Students in the same year and specialisation may have different supervisors, depending on chosen project. As a result, both the support given to the students and the assessment of their work varies. The students were asked to

evaluate the statement: “The quality of the supervisor is very relevant for a good project”. Figure 7 shows that an unanimous opinion exists and that the supervisor is a key element. Therefore, a control mechanism able to sort out the bad from good supervisors should be used. Such control system exists and the students evaluate the teaching and supervision, allowing the department to act if necessary. Additionally, supervisors are not imposed and the students can choose projects from a list renewed every semester.

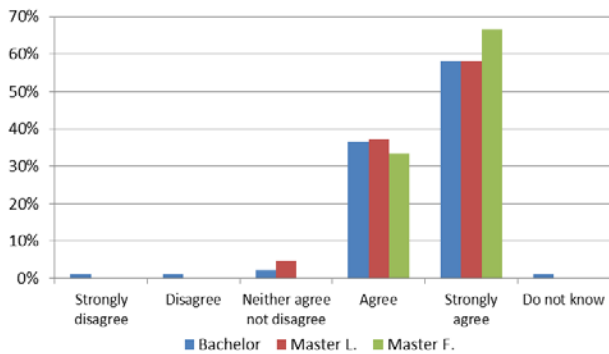


Figure 7 – Answers to the statement: The quality of the supervisor is very relevant for a good project

VII. PROJECTS VS COURSES

The results from [8] presented in section III showed that the engineering related employers have reasons to prefer students from AAU, in part due to the competences obtained in the projects. In line with these results, the students from Energy Technology were inquired to evaluate several statements related with the projects:

- “I learn more with projects than with courses”;
- “I learn the theory better with projects than with courses”;
- “I think that I will be a better engineer because of PBL”;
- “PBL improves my ability to work in group”;
- “PBL improves my ability to work in long projects”;
- “PBL increases my ability to entrepreneurship”;

Figure 8 and Figure 9 show the answers to the first two statements, whereas the remaining are presented in appendix.

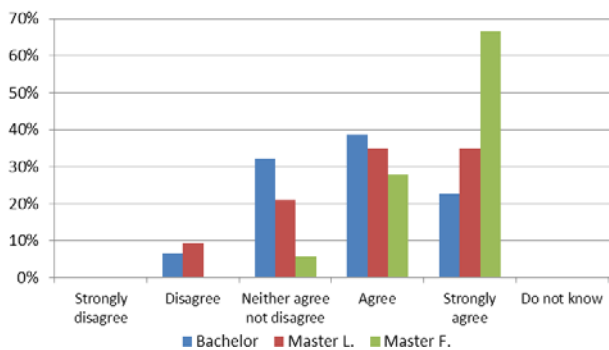


Figure 8 – Answers to the statement: I learn more with projects than with courses

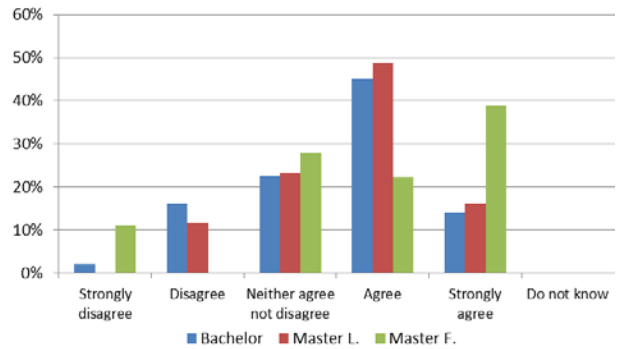


Figure 9 – Answers to the statement: I learn the theory better with projects than with courses

It is the students’ opinion that their learning outcome is better in projects than in courses, even when considering only the learning of theory. The foreigner students were also asked to compare AAU system with that used in their bachelor education and 61% said that they learn more with PBL, while 28% said that they learn less with PBL.

The philosophy behind PBL states that courses and projects must complement each other, with the courses supporting the projects. The curriculum at AAU/ET has specific project’s topics for all semesters. The topics are more open at master level, but rather specific at bachelor level (e.g., one semester focuses on control theory, other on the development of technologies that can benefit society).

To evaluate the fit between courses and projects, the students were asked to assess two statements. Figure 10 and Figure 11 show the students’ assessment of the following sentences:

- “The subjects taught in the courses are sufficient for a successful project”
- “Projects and courses complement each other very well”, not posted to foreigner master students

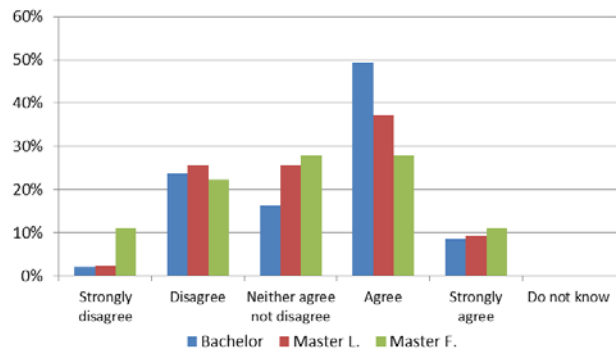


Figure 10 – Answers to the statement: The subjects taught in the courses are sufficient for a successful project

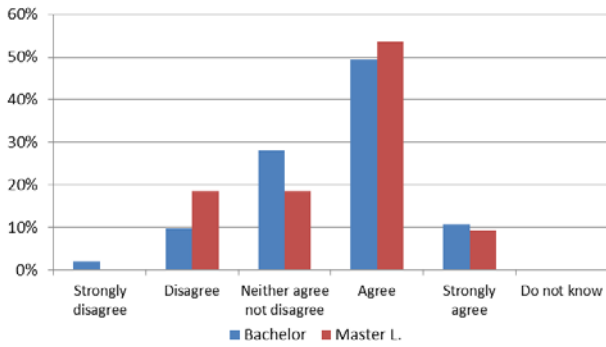


Figure 11 – Answers to the statement: Projects and courses complement each other very well

According to the results, the students think that the complementary between courses and projects is properly done, but approximately one quarter think that the subjects taught in the courses are not sufficient for a successful project. However, self-directed learning is one of the learning principles which define PBL. This means that students are responsible and autonomous learners by: 1) defining what kind of theoretical knowledge is needed to understand and solve the problem; 2) planning and carry out methods and activities to solve the problem [11].

VIII. PROJECTS DURING THE BACHELOR DEGREE

The usefulness of projects in the first years of bachelor is a topic of discussing among teaching staff at AAU, with many suggesting that the project content should be reduced during the first years of bachelor to allow a faster learning of basic concepts, both mathematics/physics and engineering subjects. The proponents of this curriculum change argue that the lack of technical knowledge limits the work done by the students in first year projects, which are often just state-of-the-art together with simple simulations. Moreover, the supervisor often ends giving almost private lectures or helping more than desired with laboratory experiments, because of the still low skills of the students. However, it is important to state that several staff members think that projects should be a part of the curriculum from the beginning and that the system should stay as it is, meaning that there is not unanimity of opinions.

In order to assess this topic from the student perspectives, they were asked to evaluate two statements. Figure 12 and Figure 13 show the assessment of:

- “I would prefer that the project was a smaller part of my education (less ECTS)”;
- “More courses should be given in the first years of bachelor and the project content reduced”, not posted to foreigner master students;

The answers present some interesting results. The students are satisfied with the number of ECTS given to project work, especially bachelor students. The same almost unanimity does not occur when asked about the amount of projects in the first years, where a division is found. 48% of bachelor students are satisfied with the status-quo against 29% that would prefer more courses. However, the master students are completely

divided, with 44% satisfied and 46% wanting more courses and fewer projects. Moreover, when asked “What would you change, in order to improve your education?”, many stated that more courses are desired, especially students attending the master level (8 master students suggested this, in a total of 20 answers, the remaining master students left this part of the survey blank). In other words, when given an open question without any direction many indicate this issue. As side note, the other main suggestion from the students was for an early separation between the three bachelor areas, but this topic was not addressed in the survey and thus, it is not further referred in this paper.

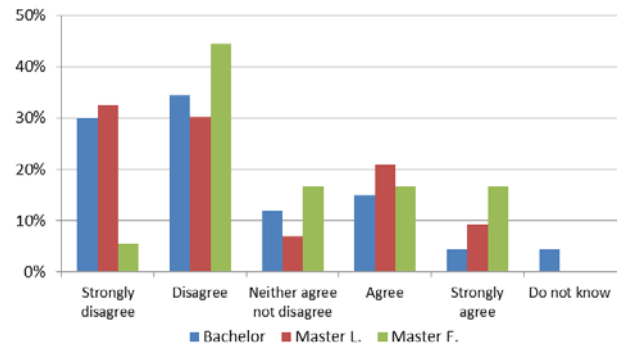


Figure 12 – Answers to the statement: I would prefer that the project was a smaller part of my education (less ECTS)

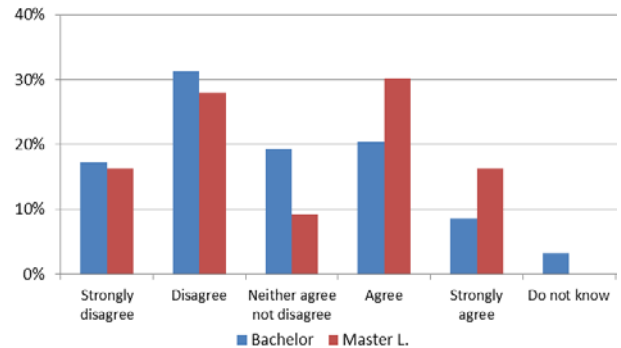


Figure 13 – Answers to the statement: More courses should be given in the first years of bachelor and the project content reduced

It is not possible to indicate the main reason for so many master students wanting fewer projects, when compared with their bachelor colleagues. A possibility, based on informal conversations with some students after the survey, is that the higher requirements of master level projects, which often intend to advance the state-of-the-art either by supporting research projects or via collaboration with industry partners, increase the need of understanding the theory of different topics in detail and they think that the available courses were not sufficient.

The master students were also enquired in the survey on two statements related with bachelor projects:

- “I did not have enough technical knowledge for the first bachelor projects” (Question A);

- “The first bachelor projects were not really problem solving, but more learning of concepts via exercises and/or laboratory work” (Question B);

Figure 14 shows the answers to these two questions and the majority of the master students agree that the first projects were technically too advance for their skills at the time and oriented to the teaching of theoretical concepts, instead of problem solving. This may help explaining the results from Figure 12 and Figure 13.

However, a more detail survey is required in order to proper evaluate the projects at bachelor level.

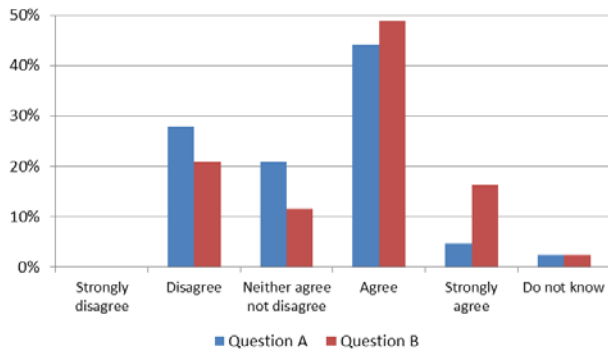


Figure 14 - Answers to the statements: I did not have enough technical knowledge for the first bachelor projects (Question A); The first bachelor projects were not really problem solving, but more learning of concepts via exercises and/or laboratory work (Question B);

IX. DISCUSSION AND CONCLUSIONS

Inferences can be made based on the data presented in this paper, both statistical analysis of the grades and answers to a survey sent to the students of AAU-ET:

- The average grade of projects is consistently higher than those of courses; 33% higher for bachelor and 13% for master, when considering only passing grades and ECTS weighting. The differences increase to 90% and 42%, respectively, when failing grades are considered (note: the grading scale is not linear);
- The failure rate of projects is almost negligible;
- The students think that their knowledge is better evaluated with projects than with courses;
- The students think that the project’s assessment is unfair and that it benefits students that contribute less for a successful project;
- The technical concepts are better learned with projects than courses, according to the students;
- Projects and courses complement each other properly;
- No agreement exists on the right amount of projects at the first year of bachelor, with an approximate equal division among those that are satisfied with the existing scenario and those that would prefer fewer projects;

From these inferences two topics are seen as relevant for a more detail analysis in future work: The fairness of project assessment and the amount of projects given at beginning of the bachelor degree.

An unfair assessment, even if it is only perceived as so without being it, will demotivate students and may lead to a decrease in work quality, besides eventual repercussions in the reputation of the university. Therefore, it is necessary to investigate if the problem really exists and if it does, to find solutions for it.

The balance between projects and courses is a bigger challenge, not only for not being unanimous, but also because changes would affect the entire curriculum. A middle way solution could be to divide the first semester projects in small projects attached to courses. The projects’ topics would be decided by the staff, the work would be made in group during some weeks. Potentially, this could hasten the learning of basic concepts, while continuing to develop soft skills. Moreover, this could be implemented as a pilot test.

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XI. APPENDIX

A. Answers to the question of section VII

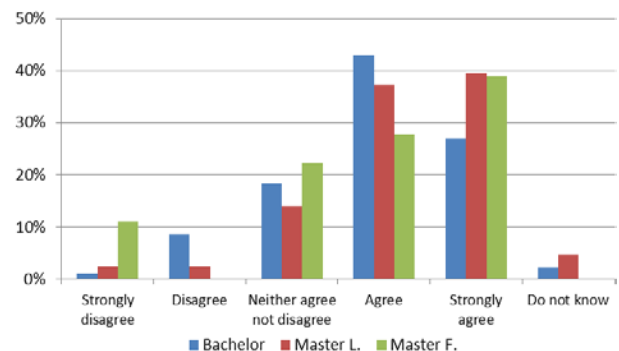


Figure 15 – Answers to the statement: I think that I will be a better engineer because of PBL

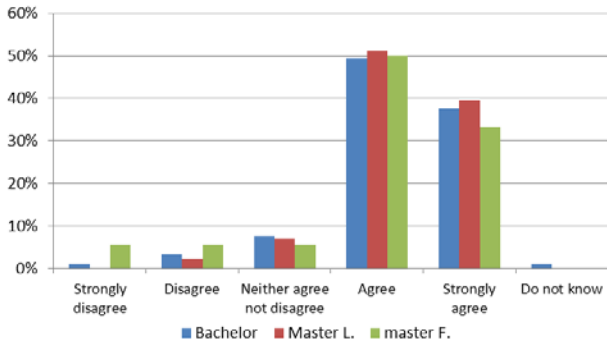


Figure 16 – Answers to the statement: PBL improves my ability to work in group

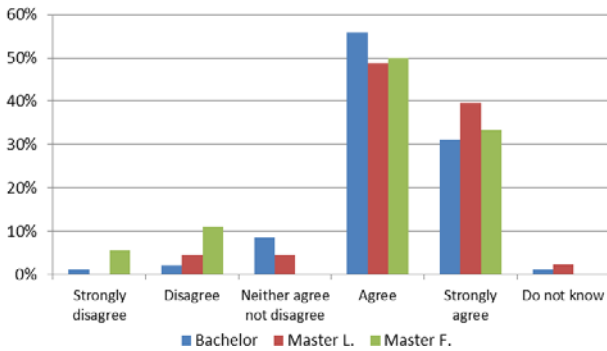


Figure 17 – Answers to the statement: PBL improves my ability to work in long projects

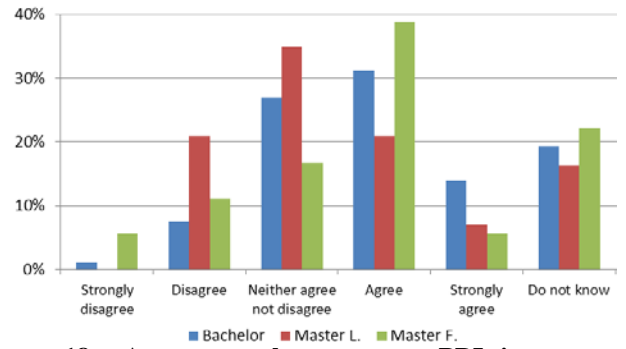


Figure 18 – Answers to the statement: PBL increases my ability to entrepreneurship

B. Extra Questions

The survey sent to the students had questions and statements that were not presented in this paper. Those interested can contact the author for receiving the answers for the following statements/questions:

- The quality of my work improved substantially during the first three bachelor projects
- The presence of an industrial partner is very important factor when choosing a project
- I chose AAU because of PBL
- I learned more with the advance semester projects than with the first projects
- The project's goals are better defined in later semesters
- I think that the master level projects prepare me to the type of work that I will have to do after finishing my education