The development of integrated professional skills in Aerospace Engineering through problem-based learning in design projects

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Introduction

Aeroplanes and space missions have always had an enormous appeal to the imagination of the general public. The desire of man to fly dates back to mythology in Ovid's Daedalus and Icarus and many proud parents and grandparents tell their children about having seen the first man set foot on the moon. And as two bicycle engineers proved 100 years ago this year, engineers are detrimental in making these major achievements for mankind possible.

In the nineties major engineering multinationals such as Philips and Shell indicated that the engineers which the university delivered to them were lacking skills other than engineering skills[1]. These competencies can be summarised in 4 categories:

- Professional knowledge and skills;
- Science, technology and society abilities;
- Knowledge skills regarding organization and management;
- Communicative and social skills.

Representatives from international companies, the biggest employers of engineering graduates, have repeatedly stated they prefer candidates who are competent in communication skills on top of their specific engineering abilities[1]. Hence the educational objectives of engineering universities must be adapted to account for this new demand, which is put upon them.

Until 1995 the competencies listed above[2] were not mentioned explicitly in the objectives of the Faculty of Aerospace Engineering, Delft University of Technology. The curriculum focussed on core engineering skills only. During a programme review in 1995 when the faculty moved to a 5 year combined Bachelor and Master of Science degree new objectives were formulated which a graduate would have to meet.

Those new objectives emphasized that graduates meet the changing requirements society puts on aerospace engineers. These final objectives act as a beacon for the study Aerospace Engineering. A typical example of the new final objectives of the 5-year degree in aerospace engineering at the Faculty of Aerospace Engineering of Delft University of Technology is cited below[2]:

" The aerospace engineer must be prepared for a broad range of engineering duties in various Aerospace engineering or related disciplines following a certain period of on-the-job learning and training. Final objectives 1-8 must guarantee that the recently graduated aerospace engineer will achieve the following:

- *A broad engineering education*
- *Accessibility to broad range of employment positions*
- *Sufficient flexibility as regards professional career*
- *Ability to think critically and creatively;*
- *Understanding of the context in which engineering is practiced*
- *Good communication skills*
- *Ability to function as a member of a team*
- *Curiosity and a desire to engage in life-long learning"*

By stating these new objectives Aerospace engineering already took into account the changing demands of future employers on their students.

In an effort to achieve those objectives project education was implemented during the next few years, resulting in a total of 5 different projects carried out over the first three years of the degree. Similar efforts were made in the US by MIT[9,10]. In line with the European Bologna Agreement[1]) these first three years now form the Bachelor degree in Aerospace Engineering. It must be stated here that the bachelor's degree aims to provide a broad education in Aerospace engineering and during these three years the student does not choose a specialist subject. When accessing the Master phase of their studies students select their specialist subject of choice. The projects during first three years of the degree can be characterised as increasing in student independence and responsibility, design freedom and planning.

This paper will focus on the way the Faculty of Aerospace Engineering in Delft is aiming to achieve these changing demands on future engineers within the constraints of the Dutch education system and the results achieved so far. It also raises questions on how we can effectively measure what students are really learning in terms of non-engineering skills at university.

Dutch Education System

Before explaining the system of project education, it is important that the reader understands the Dutch education system as it differs considerably from education system in the US. The first year at a Dutch university can be characterised as a year of natural selection. Dutch law gives every student with an advanced high school diploma (VWO, which is a Dutch abbreviation for preparatory academic education), with a "Nature & technology" or "Nature & Health" speciality, the right to study aerospace engineering. By law the first year of any university programme has to fulfil three requirements: orientation, selection and referral. Consequently, the university cannot select the students prior to entering the university; it needs to do this by a process of "natural selection" during the first year. It is very common for students in the Netherlands to take

[1]) The Bologna agreement states that all member states of the European Union must adopt the existing Anglo-Saxon university system of Bachelor's and Master's degrees.

longer than one year to complete their first curriculum year. This does not affect their enrolment rights. This system inevitably puts strain on the first year curriculum and means entry requirements must be set for projects in the next two years to ensure the required knowledge is present in participating students. On average we have some 300 students enrolling in the first year projects, some 200 in the second year and some 150 in the third year. This is a major design constraint when designing effective design projects.

The implementation of the Bologna agreement in the Netherlands as of the year 2002/2003 means that our 5 year degree has to be split into a Bachelor and a Master of Science part. The faculty has chosen not to change the curriculum but to split the existing curriculum in two. The Bachelor’s degree is a three-year degree and consists of a broad education in Aerospace Engineering without any form of specialisation. Project education is an important tool in this phase. The Master’s degree is a specialisation within the available research fields of Aerospace Engineering within our faculty. Two special system integration MSc. programmes are on offer for students who are more interested in the aircraft or spacecraft systems, analysis and design allowing students to combine research from several groups: e.g. Structures and Aerodynamics.

Project types

Before describing the projects at Aerospace engineering it is good to define the types of educational projects there are. Kolmos[5] and later De Graaff and Longmuss[1, 4] distinguish three types of projects with an increasing ‘ownership’ by the students.

- Assignment projects (AP) – Projects characterised by considerable planning and control by teachers/supervisors, where problem, methods and subject are chosen beforehand.
- Subject projects (SP) – Projects in which the teachers define the subject beforehand. Students have a free choice among a number of described methods.
- Problem projects (PP) – Projects in which a problem is the starting point. The problem will determine the choice of disciplines and methods. The problem is chosen within a wider frame set by the teachers

Project education at the Faculty of Aerospace Engineering

The projects in the first year reflect the introduction into aerospace engineering. The first project is related to Aerodynamics, Astrodynamics and Mechanics in the shape the developing, building and testing of a water rocket project and the second project is related to Aerospace structures, Aerospace Materials and Mechanics in the shape of the design to specification, the building and the testing of a wing or satellite box. Each project has a study load of 8 hours a week and lasts for 7 weeks.

The objectives of the first year projects are[3]:

- To apply knowledge gained in the lectures aeronautical and space engineering and mechanics by solving problems and acquiring insight in these subjects
- To learn how to work in teams by doing
- To get an introduction into using laboratory equipment

At the same time the Faculty has the objective to keep the students motivated for the study of aerospace engineering during a first year, which is difficult as the program consists mostly of core engineering subjects and math courses.

The projects in the first year can be very much characterized as assignment projects[1, 4, 5], as both topic, activities and methods are predetermined, although it must be stated the outcome is not universal as both projects include some form of design optimization and taking measurements using electronic equipment which means that students groups compete with each other for the best design. On average some 300 students take this course in groups of 8-10 students.

As this number is somewhat impossible to staff by faculty members alone extensive use is made of senior students as tutors. Each tutor has two groups of 8-10 students in their care and also serves as a mentor during the first year. The tutors are trained beforehand on tutoring and counseling and are in close contact with faculty staff. The tutors make a recommendation on the grade the individual student gets, but the lecturer determines the final grade.

Figure 1: The result of the first year project: a satellite box in its test rig (photo courtesy of Ir. A.W.H. Klompé)

During the second year there are two projects on the subjects of the design of a multi component control mechanism of an aircraft or satellite and the simulation of the flight path of an air- or spacecraft. Each project has a study load of 12 hours a week and lasts 7 weeks.

The main learning objectives of these projects are[3]:

- Practicing team effort in designing a multi-component mechanism fulfilling a given set of design requirements (project 1).

- Acquiring basic problem-based programming experience applied to a multi component simulation program describing an aircraft or spacecraft mission whilst working together as a group (project 2).

Again the projects are closely linked with the lectures given in the second year.

The first project can be classified as a hybrid form between an assignment and a subject project. Although the subject, the design of a mechanism is set, as well as the design requirements the design freedom within the project is rather limited by the lecturers for fear of students running out of time or coming up with unfeasible designs. Additional laboratory exercises are also part of this project to give students the necessary feel for the introduction of forces in structures. The group size is 8-9 students.

The second project can be classified as a subject project. The choice of methods is restricted by the knowledge gained in lectures and the programming environment. Also students have a set time to complete the project in. Integrated with the second project is a course in Technical Writing and Business communication. All reports produced during the project are also assignments for this course this ensuring student motivation and dedication to take part in a course which is regarded as ‘soft’ by many students. The group size is 6-8 students and the groups are of different make up than the first project, as students must learn to work together with anyone.

Again for both project extensive use is made of student-tutors. Although each group has a staff member acting as a client, a tutor is present for every two groups. The selection of those tutors is stricter as the tutors do not only guide the group process but must also have enough subject knowledge to deal with first line questions. Extra training in tutoring and on subject matter is given.

In the final (fourth) period of the third year the final project of the Bachelor program takes place. The Design Synthesis Exercise lasts 10 weeks and is only accessible for students who have completed the first two years of the curriculum. Students work in groups of 10 students on a design topic chosen from a selection of topics. Each disciplinary group in the faculty is asked to provide one or two principle tutor who must write a multi-disciplinary design assignment suitable this level of students. The project can therefore be classed as a problem project.

The objectives of the design synthesis exercise are to enhance the student’s skills in[6]:

- Designing
- Application of knowledge
- Communication (discussion, presentation, reporting)
- Working as a team
- Sustainable development

Integrated with the exercise are courses on non-technical topics such as Sustainable development, Systems Engineering & Project Management and Oral Presentations. The assignments for those courses are incorporated in the exercise, e.g. students must discuss the sustainability as an aspect of their design, all reviews are also graded on their oral presentation skill level, and the project plan is graded for system engineering and project management. Also a library user course is given to allow students to use the library more effectively.

The design synthesis exercise can be divided into different parts:

- Organization & Planning
- Requirements analysis
- Conceptual Design Phase
- Refined Conceptual Design Phase
- Analysis and Evaluation
- Detailed Design Phase
- Reporting

Each team is assigned one principal tutor and two auxiliary tutors. Each tutor is a faculty staff member and comes from a different disciplinary group within the faculty to ensure a multi-disciplinary tutoring team.

During the exercises there are two major reviews, one half way and one at the end of the exercise. The exercise is concluded with a one-day symposium at which all groups present their work to their peers and parents. A Professional Jury awards a prize to the best group of the day. The Faculty publishes all abstracts of the reports in a yearly book[6].

Project facilities

The faculty has 22 project rooms of 5 by 10 m dedicated to project education. Each room is fitted out with 5 PCs, a whiteboard, a cupboard, a meeting table and chairs. During the scheduled hours students have access to these rooms. Additionally, for the first year aerodynamics project 3 small wind tunnels (TecQuipment "AF10 Airflow Bench") are available and for the structures project a dedicated workshop is set up to manufacture their designs. For design reference purposes the faculty has a 800 m^2 aircraft and spacecraft parts collection enabling students to see design solutions of past and present to help them with their designs as well as an extensive library in the faculty building which is part of the university library which is considered to be the largest technical library in Europe.

Observations

From the start the projects have been subject to strict evaluations to guard and ensure their quality. As students at the university tend to be very vocal about the level of our education we are generally not short of response (on average 95% response). These observations are based on internal evaluations carried out in the year 2002.

In the first year students indicate when asked if the project motivated them for Aerospace Engineering, 52% indicated that it enhanced their motivation for their studies, 35% was neutral and 17% did not feel it motivated them. When asked about their improvement in skills in working in teams: 47% said they increased their skills a lot, 39% indicated it improved and 14% indicated that it contributed very little to their skills. When asked if the project gave them a better insight into the degree of aerospace engineering and their future work as an engineer 35%

indicated they had a much better idea, 43 % indicated they had a better idea 22% indicated it did little to give them a better insight.

Although these numbers in itself are very satisfying at first glance, they also raise questions: Why is there such a large number of students who are in the middle when asked about their motivation, their team workings kills and their perspective on the future. Are those skills already present or are our projects not fit for purpose? To answers such questions more research is necessary.

We asked our students in the second year to grade themselves on several key areas of the project both before and after the project on a scale of 1 – 10, with 10 points being the highest score. In the table below we can see the increase in points during the project

Project/Skill	Team skills	Design skills	Problem solution	CAD skills	Programming	Accompanying lectures
Year 2 pt 1	0.95	2.2	1.25	2.0	-	2.3
Year 2 pt 2	0.65	-	1.2	-	4.5	1.5

Table 1: Improvement of team working skills according to students based on surveys in the year 2002.

From the table it can be observed that there is only a slight increase in team working skills as perceived by the students. Again the question can be posed as to the reasons why. Is the first year project effective enough or do we need to look at other factors involved? Also the improvement in problem solving skills is not very large from a students' point-of-view. Again more research into the reasons behind this observation is necessary.

In the third year students are asked to indicate to what extent the exercise contributes:

- To a better understanding of aerospace engineering,
- To a better understanding of the relationship between the different branches within aerospace engineering,
- To better design skills and
- To better team working skills.

Students give a mean score of 0.6, 0.67, 0.61 and 0.70 respectively on a –1 to 1 scale, which can be interpreted as a rather positive contribution, with a score of –1 being negative and +1 extremely positive.

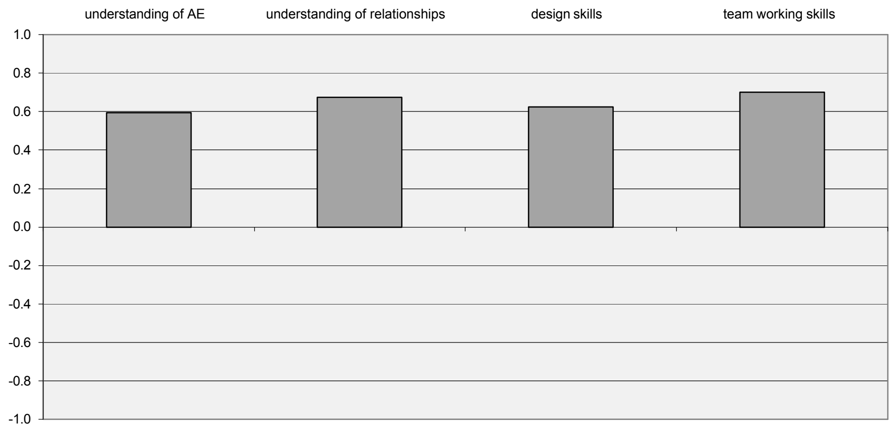

Figure 2: The contribution of the exercise to achieving several learning objectives during the project.

This exercise seems to achieve its objectives far more successfully from a student point-of-view, than the projects in the earlier years, which can be explained from the fact that this project is a typical problem project with high student independence and design freedom. A second reason is that students see being allowed to participate in this project as a major milestone in their study and it allows them to choose the MSc. Stream in which they will continue. The motivation when taking part is high, team spirit is great even among lecturers even resulting in a project soccer competition including the lecturers!

Conclusions

Engineering students need to acquire more competencies than just engineering skills, Professional knowledge, society abilities, organizational and management skills as well as communicative and social skills are just as important. In order to comply with these new demands on graduating engineers, the Faculty of Aerospace engineering has adapted her program by implementing projects in the first three years. Although the regular evaluations indicate that students perceive these projects as a success, it remains unclear what they learn exactly through the project work. The authors are engaged in a research project with the objective of effectively measuring what students really acquire in terms of non-engineering skills at an academic institute and what part of that is being acquired elsewhere, for instance in student life, or even outside the academic world.

Appendix: Faculty of Aerospace Engineering at Delft University of Technology

The degree of Aerospace Engineering[7] at Delft University of Technology[8] exists since 1940 and Aerospace Engineering has been an independent faculty since 1975. It currently has some 1600 students enrolled in their 5 year combined Bachelor and Masters programme. Students graduate with a Master of Science degree in Aerospace Engineering, which is internationally recognised (ABET).

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