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PROBLEM SOLVING AND ENGINEERING DESIGN: INTRODUCING STUDENTS TO ENGINEERING WORK IN THE FIRST PHASE OF THE BACHELOR OF ENGINEERING AT K.U. LEUVEN

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ABSTRACT
A new engineering curriculum was introduced at K.U.Leuven together with the transition to the bachelor-master system. The students take a new course 'Problem Solving and Engineering Design' to introduce them from the first semester onwards into real engineering practice and teamwork. Throughout the three semesters of the first phase of the bachelor, a gradual transition from solving closed engineering problems to working on open-end design projects is implemented. The teamwork is much more coached and monitored in the first semester than in the third semester. The new course was introduced in September 2003 and was taken by all 420 freshman engineering students. Formal student feedback was obtained at the end of the first semester. The overall feedback was very positive. Only few student teams had to be catalogued as performing rather poorly. The vast majority of the students appreciated this new course and commented that they had learned more in a team than when they had to do the same tasks alone. The integration of the team assignments with the other regular courses will be improved before the start of the next academic year.

Keywords: Bachelor of engineering, small group collaborative project based instruction

1 INTRODUCTION

It is generally recognized that the paradigms of engineering education are changing. On the one hand, students have to master an ever increasing body of basic mathematical and scientific courses, as well as technological courses. On the other hand, engineers must possess a set of skills and professional attitudes allowing them to function in a team and preparing them for life long learning [1,2,3]. The Engineering Faculty of Katholieke Universiteit Leuven has followed this international trend and has introduced a new curriculum together with the transition to the bachelor-master system in the academic year 2003-2004.

The first phase of the new bachelor program lasts three semesters, and is common for all engineering disciplines with the exception of the study leading to the degree in architecture. The courses are subdivided into three groups: mathematics, energy and material science, information and communication science. In addition to the regular coursework, the students take a new course called 'Problem Solving and Engineering Design' (acronym P&O in Dutch), in which they are made familiar with characteristic elements of the engineering profession. The P&O course has been introduced in September 2003, and the concept was drawn by a working group that started its activities in autumn of 2001.

The aim of this course is to teach the students that solving real life engineering problems requires the integration of different courses, which is supplemented with skills such as mastering information and communication tools, simulation tools, sketching and visualization tools, experimental work, teamwork, critical attitude, systematic approach to problem solving and engineering design. The student assignments relate to one technological area, in 2003-2004 this area was aerospace engineering.

Throughout the first three semesters of the bachelor, a gradual transition from solving closed engineering problems to working on open-end design projects is implemented. The teamwork is also much more coached and monitored in the first semester than in the third semester. This paper will report on the implementation of this small group collaborative problem based instruction concept and the feedback that has been obtained by systematic questioning of the students.

2 IMPLEMENTATION

2.1 First semester (four ECTS study points out of 30 for 'P&O')

Because of the variety of aims and objectives that are claimed for this new course, several didactic methods are integrated into it:

- introductory seminars (week 1 until 5),
- instruction seminars and exercises (week 1 until 5),
- teamwork (week 7 until 13).

The introductory seminars explain the concept of the course and the evaluation system. Two further sessions of two hours are used to introduce the students to the technological area of aerospace engineering. There is also a one-hour seminar about group functioning.

There are two series of instruction seminars: (i) manual sketching techniques and (ii) tools for simulation, information and communication, on which the students spend a total of 48 hours.

The team assignments are made in teams of eight students; 15 teams are present in the seminar room at the same time. Students are assigned at random to a team and have a design studio at their disposal during seven sessions of four hours. Each studio has a meeting table and four personal computers (Figure 1). Three tutors and two course specialists are present to assist the students in their teamwork. The paperwork result of each team is kept in a portfolio, the computer files are stored on a file server. The final deliverable for each team at the end of the first semester is a website that demonstrates the application of the courses that the students take in the first semester (calculus, algebra, engineering mechanics, chemistry) in some selected problems related to aerospace engineering. The teamwork in the first semester is monitored closely by the tutors, subassignments and subteams are imposed.

It is generally recognised that the assessment of project work in an objective way is a difficult task [4]. The student evaluation is based upon a combination of their individual result for the instruction seminars and exercises (evaluated through individual assignments) and a mark for the teamwork (team mark given by the tutors, individual fine tuning based upon tutor feedback and peer assessment).

2.2 Second semester (three ECTS study points out of 30 for ‘P&O’)

In the second semester introductory seminars explain about design methodology and project planning [5]. Instruction seminars make the students familiar with the basics of computer aided design and the design of control systems with finite state machines. Introductory seminars and instruction seminars are scheduled in the first four weeks. The team assignment (still teams of eight students, but changed team composition) consists of designing a water rocket, and using it to reach a target that will be put at a certain distance and elevation from a launching platform. The team first simulates the rocket flight and thrust production, and then compares the measured flight with the simulation. The team has much more responsibility in the second semester, i.e. they have to develop their own project planning, create subteams and subassignments, and produce a final report and a presentation about their work.

2.3 Third semester (five ECTS study points out of 30 for ‘P&O’)

Teams of six students will be formed in the third semester (starting in September 2004). The overall course structure will be maintained, consisting of seminars and teamwork. Here the students work on an open-end design project, selected from a list proposed by the different technical departments of the Faculty of Engineering at K.U.Leuven. The end result is much more open than in the preceding semesters, and the students are expected to design a solution, to create and to evaluate a prototype and report in a written way and by means of a small exhibition on a fair-like event.

3 RESULTS

3.1 STUDENT ACTIVITIES IN SEMESTERS 1 AND 2

Introductory seminars

An introductory seminar on space technology has been delivered by Frank De Winne, Belgian ESA astronaut during a Soyuz flight in October 2002. This seminar was highly motivating for the students, since the lecturer is well known to them through media coverage. At the beginning of the second semester, an introductory seminar presented the basics of project planning since the team project in the second semester requires much more independence from the student teams in planning their own activities and monitoring their own progress.

Instruction seminars

The instruction seminars have provided the students with engineering drawing skills and plan reading skills, as well as the basic information and communication technology competencies. In the second semester, the instruction seminars dealt with basics of computer aided design and with the design of control systems using the state machine approach.

Teamwork

The teamwork in the first semester progressed smoothly. The strategy to work with closed and rather well defined engineering problems in the first semester worked well and allowed the students to combine mastering teamwork skills with achieving satisfactory results in solving the technological problems. The first assignment was to use a mind mapping technique for analysing the problem ‘launching of a rocket to put a communication satellite in an orbit around the earth’. In the second assignment the students were asked to study the orbit of the International Space Station and to analyse the flight paths of the Texus and Maxus rockets used by ESA for microgravity research. The third assignment focused on the generation of propulsive forces in aerospace by combining elements from chemistry and thermodynamics with elements from mechanics (conservation of momentum). A specially designed experiment to measure the propulsive force generated by the exhaust of water and caused by a chemical reaction was integrated into this assignment (Figure 2). In the fourth and final assignment of the first semester the student teams made an animation film of a rocket launch. During this fourth phase the students were less guided and made more responsible for their own project planning in order to prepare them for the teamwork of the second semester. The deliverables were a portfolio with the paperwork and a website that demonstrated how the student teams had solved the assignments and how they had used the basic courses of the first semester to achieve this.

Figure 1: Studio available to a team with a meeting and working table, and four computers.

Figure 2: Preparation of the experiment to measure propulsive force generated by a chemical reaction and exhaust of water.

The teamwork in the second semester consists of one main project: to launch a water rocket from a platform in such a way that it passes a target as close as possible at the highest possible speed. The target will be appr. 10 m above the launching location and at a distance of appr. 15 m. The teams have spent one afternoon in analyzing this task and defining their project planning for the rest of the semester. The project activities encompass designing and building the water rocket and the launching platform. An experiment to measure the drag characteristics of the team's water rocket using Doppler theory had to be incorporated into their project. Particular attention is paid to critical comparison between experimental data and simulation results. Demonstrations of the water rocket launching events are scheduled in week 8 of their project, the oral presentations of the teamwork are scheduled in week 9 in three parallel sessions.

3.2 STUDENT FEEDBACK

Student feedback has been obtained at the end of the team assignments of the first semester by means of a questionnaire [6]. At the end of the first semester, the questionnaire was filled out by appr. 400 engineering students who participated in the teamwork.

The questionnaire related to the project group as a whole (8 students) and it comprised 9 existing scales measuring different aspects of the quality of group functioning together with four ad hoc constructed scales. The 9 existing scales were: 'Interaction' ([7]; 7 items), 'Equal contribution' ([8]; 10 items), 'Discussion Quality' ([8]; 3 items), 'Dominance' ([8]; 2 items), 'Affect' ([9]; 6 items), 'Fairness of Equal Scores' ([9]; 2 items), 'Fairness of Contribution' ([9]; 3 items), 'Waste of Time' ([9]; 1 item) and 'Surplus Value of Group Work' ([9]; 6 items). The four ad hoc constructed scales were: 'Illusion of Productivity' (5 items), 'Free Riding' (3 items), 'Downward Comparison' (4 items) and 'Within group communication' (5 items).

A few examples of questions are: 'I am satisfied with how group members interact with each other'; 'I feel we have good communication among group members'; 'Every member of our group deserves the same final grade'. All 57 items were scored on a common six-point scale (1=*strongly disagree*; 6=*strongly agree*).

Missing values were substituted with the average score of all students. A factor analysis confirmed the existence of the 13 (9+4) scales. A subsequent item analysis endorses the reliability of these scales.

To detect like patterns of socio emotive quality of group functioning over subjects, a cluster analysis (Ward's method; squared Euclidian distances) was performed. The analysis clearly categorizes perceptions of students in two distinct clusters. One 'cluster' or 'class' consists of 270 students who indicated their group was doing well (the 'functional' cluster). A second 'cluster' contains 113 students who indicated that they were rather dissatisfied with their group and the way it was functioning during the preceding period of group work (the 'dysfunctional' cluster). Figure 3 shows the estimated marginal mean scores for both clusters on each of the 13 scales.

Students in the 'functional' cluster perceived their group as a coherent and harmonious entity and indicated that they performed more efficiently than if there were no groups. They believed that their interactions resulted in decisions of good quality. Group-work was not perceived as a waste of time and students were satisfied with both the final result of the group work and with the way group members interacted with each other. Students had the perception that all group members contributed evenly, that there were no distinctly dominant group members or free riders. They judged it as fair that everyone in their group would receive the same score. Students in the 'dysfunctional' cluster show the reverse pattern.

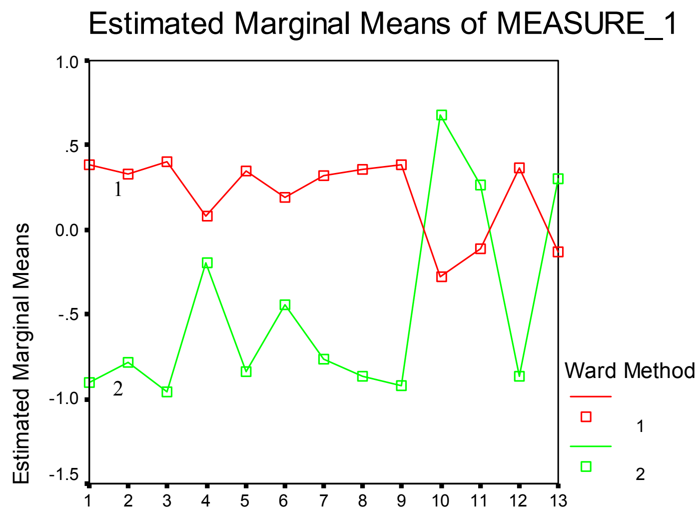

Figure 3: The results of the cluster analysis for the different scales. Cluster 1 is the 'functional' cluster. For the 'negative' scales such as '10. free riding' and '13. waste of time', the 'dysfunctional' cluster scores higher than the 'functional'.

Next, the relative number of students in the 'functional' cluster was used as an (arbitrary) index of the perceived quality of socio-emotive quality of a group. If the majority of students within one group belongs to the 'functional' cluster, then it was decided to classify that the group as a whole was 'functional'. If on the other hand only a minority of student within one group belongs to the 'functional' cluster, then it was decided to classify that group as a 'dysfunctional' one. Using this criterion, 7 out of the 47 teams (i.e. 15 percent of the teams) were classified as 'dysfunctional'.

4 DISCUSSION AND FUTURE WORK

At the start of the second semester the team composition was changed. Although a majority of the teams expressed their wish to continue with the same team as in the first semester, we believed that by changing the teams the students get a new chance of refining their teamwork skills.

Compared to other experiences with problem based learning and team assignments, we have opted for a gradual approach in confronting the students with teamwork skills. In the first semester, the team assignments are well defined, with a limited freedom for the teams to define and schedule their own work. The focus is on problem solving combined with basic skills of teamwork (discussion leadership, creation of subteams, reporting back to the team, …). In the second semester, the problems are less closed, and considerably more freedom is given to the teams to schedule their project. This gradual approach is appreciated by the teams and a low percentage of poorly performing teams was identified in the first semester. Also in the now ongoing second semester, the vast majority of teams work properly in a constructive atmosphere.

The course 'Problem Solving and Engineering Design' was approved by the Faculty of Engineering of K.U.Leuven in March 2003. Everything had to be prepared for a start with approximately 400 students in September 2003. From March 2003 onwards, a team of appr. ten coworkers has worked intensively to prepare all assignments and to design and prepare the experiments. The core of the didactic team could build upon a couple of years of experience with project based engineering instruction in the former second year of the engineering curriculum at K.U.Leuven [10]. This has in some sense facilitated the preparation and allowed that an operational concept was ready after only six months of real preparation. The team activities are coached by three tutors and three course specialists per fifteen student teams. This seems to be an absolute minimum for a proper functioning of the teams. From the student feedback, it is clear that they appreciate the overall concept of the new course, and hence this will be maintained in the next years. The integration of the team assignments with the individual courses however needs further attention and refinement. This will be the focus of our activities in the summer of 2004, in preparation of the academic year 2004-2005. The progress in teamwork skills of the individual students and the teams will be monitored and compared with our strategy of gradual increase in complexity of team assignments.
A commission, appointed for a visitation of the educational programme of the bachelor phase and the mechanical engineering programme, commented in March 2004 in a very positive way about the Problem Solving and Engineering Design concept and its implementation. This too is reassuring to continue along the lines that were defined at the start.

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