INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
6 & 7 SEPTEMBER 2012, ARTESIS UNIVERSITY COLLEGE, ANTWERP, BELGIUM

STUDENTS RESPONSE TO OPEN-ENDED PROBLEMS IN AN ENGINEERING DESIGN PROJECT

Markus VOSS
DHBW Baden-Wuerttemberg Cooperative State University, Mannheim, Germany

ABSTRACT
Engineering Design is not teachable without letting students explore the design process on their own. Therefore students are often confronted with open-ended problems in Engineering Design projects. The paper outlines a course concept for such a project that is based on a strengthened employment of project management methods, formalises roles of students and faculty, tries to engage students in working scientifically with literature, and lets students participate in the evaluation of their work. The students' response to the course concept was collected in a comparative study. The effect of the concept was measured in a statistical survey by comparing the answers of students working with that concept with others from parallel classes that do not. The results indicate that students particularly perceive that the presented course concept shortens feedback loops, intensifies communication between students and faculty about the learning outcome and affords useful insights into design projects. The drawn conclusions from this study may serve as reference for other lecturers reorganising their project-based Engineering Design courses.

Keywords: Engineering design education, guided self-study, open-ended problems, problem-based learning (PBL), comparative study

1 COURSE DESCRIPTION

In Engineering Design education, projects help students to acquire a 'broader picture' of the design process. One of such an Engineering Design project course and its anchoring in the Mechanical Engineering curriculum are described in the following.

1.1 Cooperative concept of studies

Baden-Wuerttemberg Cooperative State University (DHBW) pioneered the cooperative tertiary education system in Germany. 'Cooperative' (or 'dual') refers to integrating academic studies and workplace training which are alternating in three monthly intervals in the curriculum, see Figure 1. At DHBW, lectures are held by university teachers and skilled professionals. The DHBW bachelor programmes are accredited with 210 ECTS credits. For that reason, the programmes are considered as intensive programmes and demand a high rate of self-study from students.

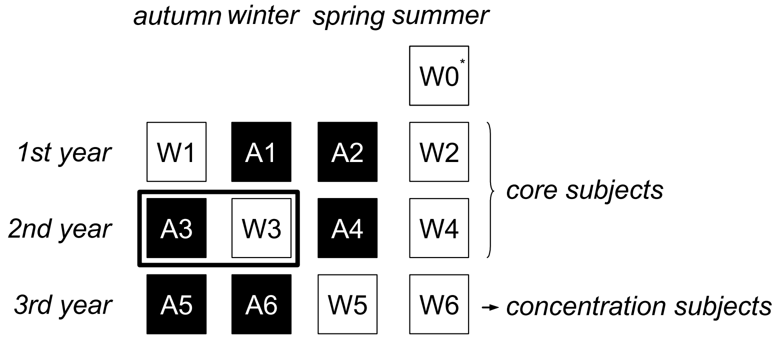


Figure 1. Mechanical Engineering curriculum:
A *academic studies,* W *workplace training,* 1-6 *semester,* * *voluntary*

1.2 Engineering Design in the Mechanical Engineering Curriculum

Measured by its student workload, Engineering Design is the most important course in Mechanical Engineering education at DHBW. From first to fourth semester, students attend 240 class hours of Engineering Design courses in total. Lectures with integrated exercises are held in 168 class hours. The Engineering Design courses are supplemented by Engineering Design projects supervised in 72 class hours of attendance. Additionally, students are held to work 160 hours on their own in these projects.

1.3 Guided Self-Study

For enabling efficient learning, modern didactics in (tertiary) education advocates a blend of teaching and learning methods. 'Traditional' *frontal teaching* and *self-study* are considered to complement each other. When faculty staff is partly present to coach students we speak of *guided self-study* (or *semi-autonomous learning*). In total absence of faculty staff, we speak of *individual self-study* (*or autonomous learning*) [1,p.6f.]. A common best-practice recommendation [2,p.13f] is an approximate proportion of: 40 % frontal teaching, 40 % guided self-study and 20 % individual self-study [3,p.101]. Research in Educational Psychology shows that self-regulatory learning is teachable and increases students' motivation and achievement, although 'few teachers effectively prepare students to learn on their own' [4,p.69].

1.4 New course concept

So that confronting students with open-ended problems from 'real life' does not end up in frustration, Engineering Design projects need a structure that facilitates learning. Therefore, a new concept for the third semester (A3 and W3 in Figure 1) has been developed and implemented in three classes in Autumn Semester 2011 where the students had to design the worm gear of a hand mixer. The basic difference to individual assignments in parallel classes is that the presented concept emphasises

- project management
- role play
- teamwork
- literature research
- self-assessment and peer review

Project management. The students had to plan their project in accordance with a milestone plan. The project starts in the academic third semester in university and the students continue it during their workplace training in industry.

Role play. Students are working as members of a project team on a development project. Faculty staff assumes the role of the ordering party, the steering committee and experts, see Figure 2.

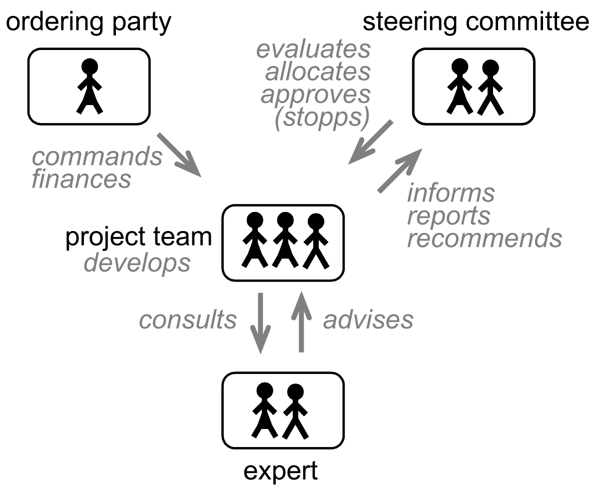


Figure 2. Project roles and responsibilities

Teamwork. Students work on the problem in groups of three or four. The team composition is drawn by lot. In order to facilitate communication among students as well as between students and faculty, the new course concept intensively used Moodle (Modular Object-Oriented Dynamic Learning

Environment) as Virtual Learning Environment (VLE). Questions have been posted and answered in a news forum, students uploaded their project results, and project material was graded online.
Literature research. Not every subject that the students need to know for their project is covered in the accompanying Engineering Design lecture. Thus, students had to explore suitable types of gears, principles of power transmission and gear materials in a literature research.
Self-assessment and peer review. Students were invited to self-assess their own course achievement and should review two final reports of peer groups.

1.5 Course objectives

Based on research on good teaching and learning [5,p.3], [6,p.10ff] and own experience, we derived the following objectives for the new course concept: The course should especially

- spark communication between students and faculty
- develop cooperation among students
- activate learning
- enable effective learning
- shorten feedback loops
- help students developing engineering judgement

2 RESEARCH QUESTIONS

Presenting *open-ended problems* (also called *ill-defined problems*) has a long tradition in Engineering Design education [7,p.425]. Engineering Design projects are considered to be ‘an engineering adaptation of problem-based learning approaches’ [8,p.268]. But it is often blindly assumed that the combination of real-life problems and peer collaboration ‘will positively influence students’ autonomy and achievement goals’ [9,p.376]. Recent publications on new learning environments in Engineering Design courses conclude that collaborative, problem-based learning does not ‘automatically foster the development of expertise’, but ‘must be considered in light of learner characteristics, particularly their interest’ [9,p.390]. The goal of this study is to find out what students learn by solving open-ended problems in Engineering Design projects. To be more precise, the study investigates what students perceive to learn.
Research question 1 (existence): Do students differentially perceive their learning outcome depending on whether they worked with the new course concept or with more traditional teaching?
Research question 2 (identification): Which are the learning outcomes that students perceive differently?

3 METHOD OF EVALUATION

3.1 Participants

The study group comprised $n = 143$ third semester BEng students in Mechanical Engineering, divided in seven classes. Three classes ($n_A = 57$) have been instructed by the author and worked with the new course concept. The four parallel classes have been instructed by other lecturers and acted as control group ($n_P = 86$). In analogy to clinical studies, the new course concept is denominated active treatment (index A), the control group is said to receive a placebo treatment (index P).

3.2 Procedure

Data were collected by means of a questionnaire. The students filled in the questionnaire in class, after a short intervention explaining the study. Luckily, the study obtained a response rate of 100 % of the distributed questionnaires.

3.3 Measurement

The questionnaire contained eleven items (listed in Tables 1 and 2) to which the respondents should assert their degree of agreement or disagreement respectively. For this purpose a Likert-type scale was used, reaching from ‘strong agreement’ (value 1) to ‘strong disagreement’ (value 5), with a neutral intermediate value ‘neither agreement nor disagreement’ (value 3). Of course, the risk of presenting statements in a uniform way is that ‘respondents are […] less likely to read the statements carefully when all the statements are framed positively’ [10,p.497].

3.4 Statistical evaluation

The formulation of the null hypothesis H_0 typically represents the opposite of what we are hoping to demonstrate [11,p.103f]. In our case, we want to compare expected values with unknown variances [12,p.458]. The null hypothesis H_0 expresses that there is no difference in the answers given by both groups:

$$H_0\text{: } \delta_\mu = \mu_P - \mu_A = 0 \tag{1}$$

The (unidirectional) alternative hypothesis examines how large the observed difference between the treatments is:

$$H_1\text{: } \delta_\mu = \mu_P - \mu_A > 0 \tag{2}$$

For testing our hypotheses for each item at the 5% significance level (significance threshold $\alpha = 0.05$ in Student's t-distribution) we can calculate a critical value $C \approx 0{,}3$. The decisional rule in this one-tailed test states that

$$H_0 \text{ is rejected (and } H_1 \text{ accepted) if } \delta_\mu = \mu_P - \mu_A > 0.3 \geq C \tag{3}$$

4 RESULTS

For each item of the questionnaire, the results are presented in a uniform way, see Figure 3. Histograms show the distribution of answers given within the two groups. The squares between the two histograms indicate the arithmetic means μ of the samples, the length of the bars marks the standard deviation σ.

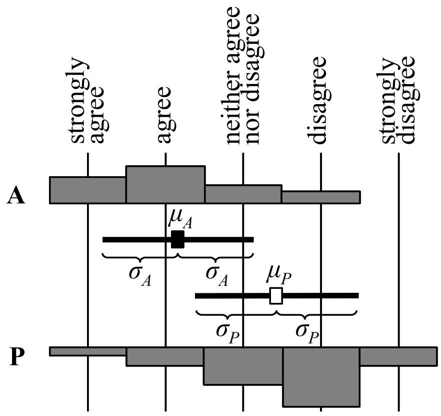


Figure 3. Graphical analysis: A *active 'treatment',* P *control group ('placebo' treatment)*

A first rough examination shows that the average of students following the presented course concept perceives the learning outcome systematically better than their fellow students in the parallel classes. In the following tables, the items are ordered by descending differences $\mu_P - \mu_A$. Table 1 lists the items satisfying the alternative hypothesis H_1 in Equation (3), i.e. those where the presented course concept is susceptible of having a positive influence on the students' perception of their learning outcome.

The most evident difference ($\mu_P - \mu_A = 1.27$) is in the regularity in which students state having received feedback from the lecturer. This might be explained by the chosen role model. The lecturer did not only give advice in his role as consultant but is also deemed to act as a steering committee for the student project teams in the new course concept. Assuming these roles helped to foster a continuous discussion about what the lecturer expects from the students and how the students perform.

Compared to their fellow students, participants working with the presented course concept are also significantly more affirmative when being asked if they gained insights in design projects ($\mu_P - \mu_A = 0.85$) or if they learned how to structure projects ($\mu_P - \mu_A = 0.44$). It seems likely that this is due to the strong focus on project management methods in the presented course concept.

Other studies show that 'students are rarely asked to […] evaluate their work' [4,p.69] or the work of others. The results of this study indicate that involving students into the evaluation process (by self-assessment or peer reviews) also makes them more sensitive to the criteria according to which their course achievement will be assessed ($\mu_P - \mu_A = 0.64$).

According to the rest of the items, see Table 2, the 'treatment' (= chosen learning methods) impacts the results remarkably but not significantly ($\mu_P - \mu_A \approx 0.3$), only barely noticeably ($0 < \mu_P - \mu_A << 0.3$) or even inversely ($\mu_P - \mu_A < 0$).

Table 1. Items satisfying the alternative hypothesis H_1

	$\mu_P - \mu_A$
I received regular feedback from the lecturer	1.27
I gained useful insights in design projects from the course	0.85
I know according to which criteria my course achievement will be assessed	0.64
I learned how to structure design tasks from the course	0.44

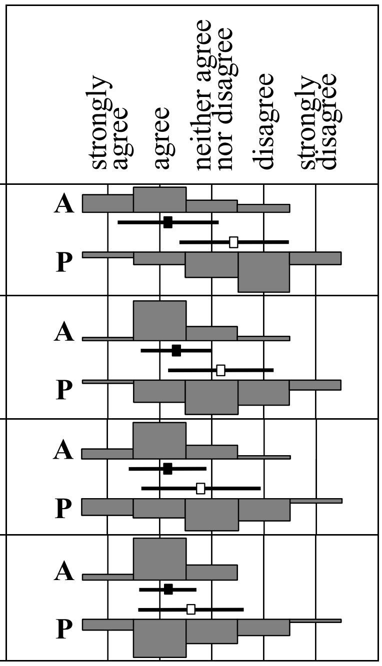
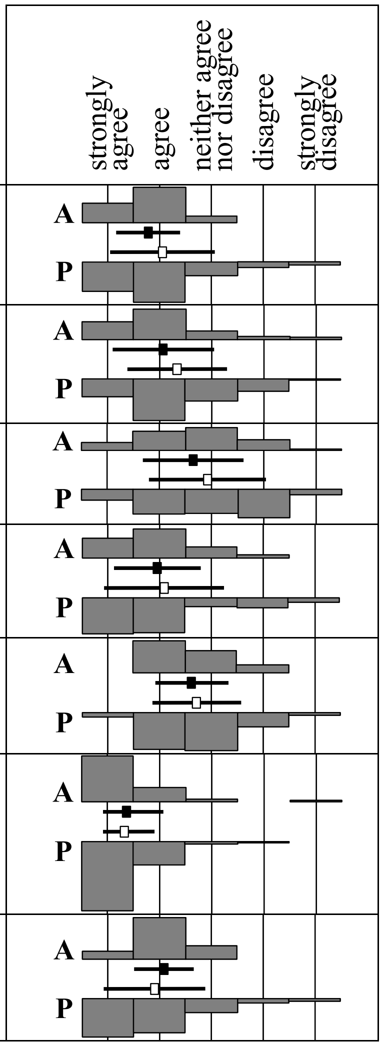


Table 2. Items not satisfying the alternative hypothesis H_1

	$\mu_P - \mu_A$
I cooperated intensively with fellow students in solving the posed problem	0.27
The structure of the course promoted regular cooperation with fellow students in solving the posed problem	0.27
I acquired important knowledge on the treated subjects from own literature research	0.27
I contributed own ideas to solve the problem	0.12
In the course I learned from my own failings	0.10
The posed problem calls for extensive work	–0.04
The posed problem has practical relevance	–0.18



5 DISCUSSION AND CONCLUSION

The evaluation gives valuable insights in what learning outcomes students perceive in an Engineering Design project. The answers of students that worked with the new course concept significantly differed from their peers in parallel classes *(answer to research question 1)*. It could be shown that the presented course concept shortened feedback-loops and made assessments more transparent. Students also say to have gained more insights in design projects and have better learned to structure their tasks through the new course concept. But that concept did not impact all learning outcomes equally *(answer to research question 2)*. Some but no significant differences could be observed in the perceived intensity of cooperation between the students and in the perceived quality of a literature research.

Of course, a questionnaire-based evaluation is just a first step. It was used to identify the levers that have an influence on the students' perception of the learning outcome. In future, more systematic evaluation is needed. Especially, the actual design outcomes [13] and team interaction [14] should be compared in a comparative study. In future studies, research methodology should be improved, e.g. using non-participant [15] or participant observation [16]. Also the impact of direct collaboration with industry [17] – which is a particular strength of the DHBW cooperative education system – should be investigated more deeply.

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