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MAKE YOUR BED AND LIE IN IT! LEARNING TO TAKE THE CONSEQUENCES OF DESIGN DECISIONS IN AN ENGINEERING DESIGN PROJECT

Markus VOß, Hulusi BOZKURT and Thorsten SAUER
DHBW Baden-Württemberg Cooperative State University, Germany

ABSTRACT
In many design assignments engineering students do a lot of paperwork. But on very rare occasions during their studies they should also build and test the appliances, products or machines they have planned. In this paper, the authors report on a project-oriented 'design-build-test' learning experience that accompanies lectures on Engineering Design during the third semester of a Bachelor degree programme in Mechanical Engineering. In the past academic year, students at *DHBW Baden-Württemberg Cooperative State University* were asked to design a winch for launching non-motorised model aeroplanes (gliders). The ground-based winch should be powered by a cordless drill. Instead of designing everything 'from the scratch', the parts for the winches should be entirely selected from a comprehensive supply parts catalogue, meeting a given budget. This allowed to go through all development phases from conception to functional testing within only six weeks without causing major capacity constraints to the faculty's laboratory. For practising communication skills, students from three different classes and two campuses were teamed up in groups. The project also involved new techniques for classroom assessment. For example, students partially got graded for easily accessible design-related parameters, like cost and assembly time. For determining the latter, the students shot an uncut digital film ('video selfie') which they uploaded on the virtual learning environment *Moodle*. The actual launching of the gliders will be organised outside the course in form of a competition next summer.

Keywords: Design-build-test experience, student projects, engineering design, problem-based learning, orientation on competences, communications skills.

1 MOTIVATION AND AIMS

In contemporary engineering education Crawley [1] observes 'a seemingly irreconcilable tension between… the ever increasing body of technical knowledge that… graduating students must command... [and the] wide array of personal, interpersonal, and system building knowledge and skills that will allow them to function in real engineering teams.' In response to this shortcoming, the *CDIO* initiative – an international educational network – formulates that the chief concern for engineering faculties should be to form students that are able to 'conceive, design, implement and operate real-world systems and products'. In other words, 'tinkering' [2] becomes 'academically acceptable' again and regains its significance in engineering education.
In this paper, the authors

- report on their concept of a student design project that they have developed and refined over the last five years
- comment on promising outcomes and point out current deficiencies
- want to share the experiences made in this design-build-test-oriented project course with other (passionate) lecturers

1.1 Projects that dig deeper

Design assignments often are pure paperwork – even when real-world problems are studied (problem-based learning). Within the field of engineering design many problems rest hidden under the surface. Especially for novice designers, many of these problems must be experienced. For example, from technical drawings it is not obvious for beginners how much effort it can take to assemble an ‘oddly-executed’ design.

1.2 The role of lecturers: Keepers of the Holy Grail or facilitators for learning?

Even though the generation of students that enters tertiary education nowadays has grown up with project-oriented learning, some students still ‘cultivate’ archaic and simplistic reasoning about what an assignment should look like. Many lecturers will recognise this mental model about teaching and learning that they encounter nearly daily. However, often students assume that their lecturer gives them problems, where he perfectly knows the answer, like a paper chase game (hare and hounds) for long solved problems. In this restricted view, the assignment just serves as a test if the student has paid attention in the lectures about what the teacher thinks the right answer is. One of the hardest lessons in design-related subjects is: There is no (absolute) right or wrong design. Solutions only tend to be better or worse (with respect to given conditions).

1.3 Developing engineering responsibility

Coming from a school environment where passing exams is the measure of achievement, undergraduates often still have a vague concept of ‘professionalism’ [3]. Student projects can be a crucial point in the curriculum where students develop a ‘deeper understanding of a basis for decision making’. Thus, determining the transmission ratio is not just an abstract number in a student report that is buried in the files but becomes a strategic question for students that decides whether the own design performs better than that of other teams or not. Design-build-test experiences are also a good opportunity for studying the consequences of own design decisions and for learning to feel responsible for these. Having experienced this mechanism once deeply (at a complex but still surveyable scale) is the critical step over the doorsill for scrutinising the own responsibility and duties in the larger context of ‘engineering ethics’.

2 COURSE DESCRIPTION AND DESIGN BRIEF

Over the last five years the authors have developed and refined a project course at *DHBW Baden-Württemberg Cooperative State University*. The student project accompanies a lecture on Engineering Design in the third semester of a Bachelor degree programme in Mechanical Engineering.

A good (problem-based) assignment fits on less than a page: In the past academic year, the students were asked to design a winch for launching non-motorised model aeroplanes (gliders). The ground-based winch should be powered by a cordless drill.

2.1 Immersive character

The main goal of the course is to ‘fence in a playground’ where the students should forget about the academic laboratory conditions in which they are acting and instead immerse totally in the project. Letting teams compete for the best solutions helps to blur the boundaries between academic studies and real-world problems [4, 5].

2.2 Against the clock

Another key element of the project course is its timeline. It allows the future engineers to experience the whole product development process in fast-motion. Within the extremely short period of six weeks, the students pass through all stages from requirements analysis, conception, the actual design, over the purchase of the parts to the assembly and testing of *their* product, cf. the project plan in Figure 1.

2.3 Configuring standard parts, instead of designing everything from the scratch

A deeply distressing experience for the students was when they were told that not everything should be designed ‘from the scratch’. Instead, the parts for the winches should be entirely selected from a supply parts catalogue (Figure 2) with more than 4,000 pages. Although even turned shafts could be ordered readily by a part number, many students reacted with the feeling that their design freedom has been curtailed considerably. It sounds trivial to order parts by a part number from a catalogue, but up to 12 % of the items in the parts lists were not correctly indicated by the teams. A pedagogically particularly valuable detail is, that it was not the lecturer but a sales representative who pointed out the mistake to the students.

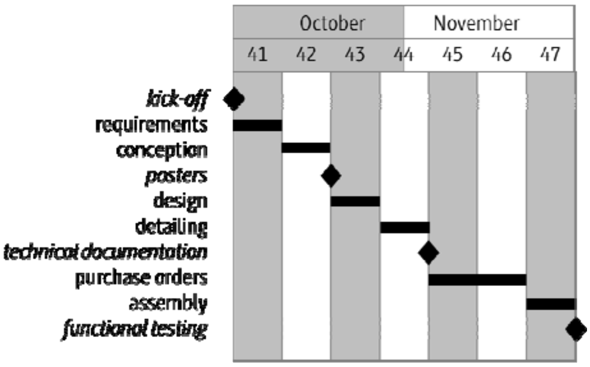

Figure 1. Project plan

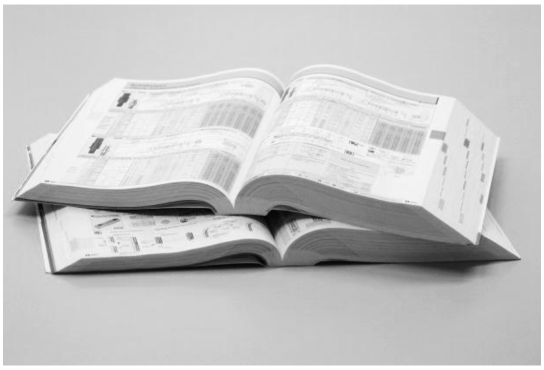

Figure 2. Supply parts catalogue

Figure 3 exemplarily shows a concept of a student team using a simplified graphical representation for kinematics as specified by ISO standard 3952 [6]. Figure 4 reproduces an assembly drawing of a ‘configured’ design. The short delivery times (that range between two days for standardised parts and eight days for machined parts) allowed to continue seamlessly with the building phase, cf. Figure 6, without major capacity constraints in the faculty’s laboratory.

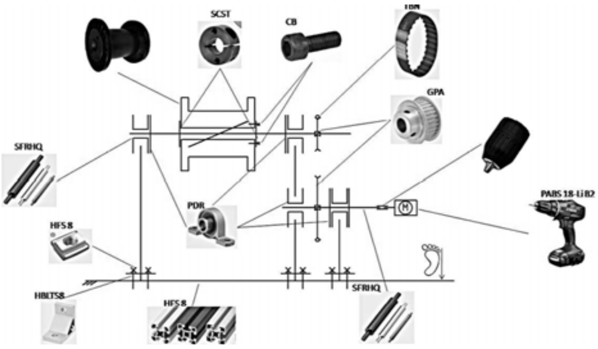

Figure 3. Drive concept of a student team

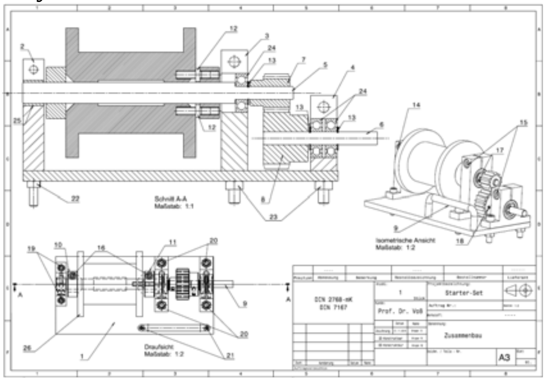

Figure 4. Technical drawing of a student team

2.4 Fixed budget

Exactly as in real-world projects, the budget in the student project was restricted. But for keeping it simple and easy to verify, only the costs for buying parts were accounted. Every team disposed of a budget of € 250 (gross amount).

3 COMMUNICATION

One of the major abilities that engineers need in real-world situations is communicating with others.

3.1 Distance communication

For practising these skills, students from three different classes and two campuses were teamed up in twelve groups of six to seven. The classes did not know students from the other classes before. The distance between the campuses is 215 km as the crow flies. In the course of the project, students at one site met regularly face-to-face, between both sites purely distance telecommunication (group meetings with Skype, e-mail, telephone) was used. As expected, in conflict situations (e. g. when own expectations were not met) students complained mutually about their teammates, especially about those from the other campus. In a similar interregional and international collaboration project, Advani, Frost et al. [7] also describe a negative impact on group dynamics that they attribute to the predominant use of asynchronous modes of communication.

3.2 Virtual Learning Environment

The project course used the open source web-application *Moodle* as a communication platform. All announcements concerning the project course were made in the news forum section. The students had to upload all submissions on *Moodle*. This made it easy for the teaching staff to control deadlines. The teaching staff also tested alternative techniques for classroom assessment. While assembling and testing their winches, the students shot an uncut digital film (‘video selfie’), cf. Figure 5, which they uploaded on the virtual learning environment *Moodle*. The assembly time was marked on basis of that video. In order to prove that the winch is operative, the teams knotted a light object (a glove or a pencil case) at the end of the bobbin and pulled it over some meters on the floor. The technical side of handling large-sized files did not cause any problems to the generation of ‘digital natives’.

Figure 5. Assembly video of a student team

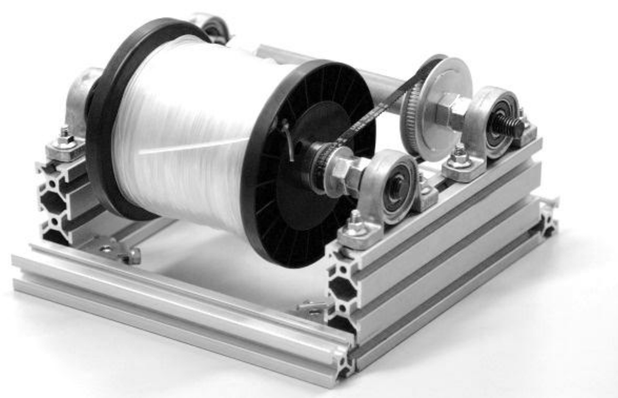

Figure 6. Example of an assembled winch

4 COURSE ACHIEVEMENTS

Overall, the students obtained excellent results in the project and surpassed the lecturer’s expectations by far. Through the new setup of the project, the students seemed to be motivated in a high degree and always handed in the due documentation on time. Compared to earlier cohorts, also the technical drawings were much clearer.

4.1 Rebound effect on performance

One of the aims for restructuring this project course has been to give the students a quicker feedback on the results they have produced. In the past, the students worked independently on their project during the semester and wrote a comprehensive final report that was due five weeks after the end of the semester. The reports often were exuberant and imprecise in style and therefore hard to read and correct for the lecturers. The dialogue between the class and the lecturer mostly engaged in the post-exam reviews and degenerated into a haggling for better marks which did not permit a qualitative feedback. And when the class and the lecturer met again in the next semester, everything was forgotten and they had other things in mind. Therefore, a number of milestones were introduced where the students must hand in partial results, as an order list or an assembly drawing for example. Thus, it is easier to outline for the lecturers what they actually want their students to work on while the students do not get constrained in their design freedom.
For marking the students’ performance in the module *Engineering Design* in the third semester, the project mark is balanced with the written examination on the lecture using a half-half weighting. Unexpectedly, the overall performance of the current cohort in the module suffered from a strong rebound effect. Since the students got an instant and detailed feedback on their performance in the project, seemingly many of them felt (too) ‘safe’ for the written examination and did not revise properly. The outcome of the written examination dropped in unimagined depths. More than half of the students fail to reach 50 percent of the maximum score in the written examination, cf. Figure 7. The usual share in this unit is 10 to 15 percent. Of course, the challenge for optimising the project will be about how to give detailed qualitative feedback without inducing a counterproductive behavioural response.

4.2 Cart horses and free riders

As Goodhew [8] portrays it well, ‘the issue of assessing individual performance during group or team work excites a lot of debate at meetings of academic engineers’. Inevitably, the question also arises among the teaching staff in this project course. The common dilemma in group assessment becomes manifest in the observation that groups quickly establish an informal ‘work hierarchy’: The ‘cart horses’ among the group members pull off the project while the free riders contribute little but finally

want to benefit from the assigned group mark. In the present project course, a group mark is assigned to every member of the group. A good cure against free rider behaviour is to include a separate oral submission in the form of a short presentation that allows to verify if every student is fully (or at least well) informed about what has been done in the group. But especially for larger classes, this also rises the effort considerably. Another way would be to moderate group marks based on observations of the peer groups [8]. However, other authors, like Kouliavtsev [9], object that 'students in groups systematically and substantially overstate their own contribution to a group project'.
After a long discussion whether to modify the group marks individually or not, a look on the obtained marks, made the teaching staff maintain the 'simple' marking model without a change. The reason for the decision is that the results show a 'self-adjusting' effect: For the best of each group (represented by the filled dots in Figure 7), there is a good positive correlation between the mark in the written examination and the project mark, see Figure 7, except for some 'outliers' that have been put in brackets. For those with the lowest mark within a group, there is almost a negative trend. But this effect is less pronounced.

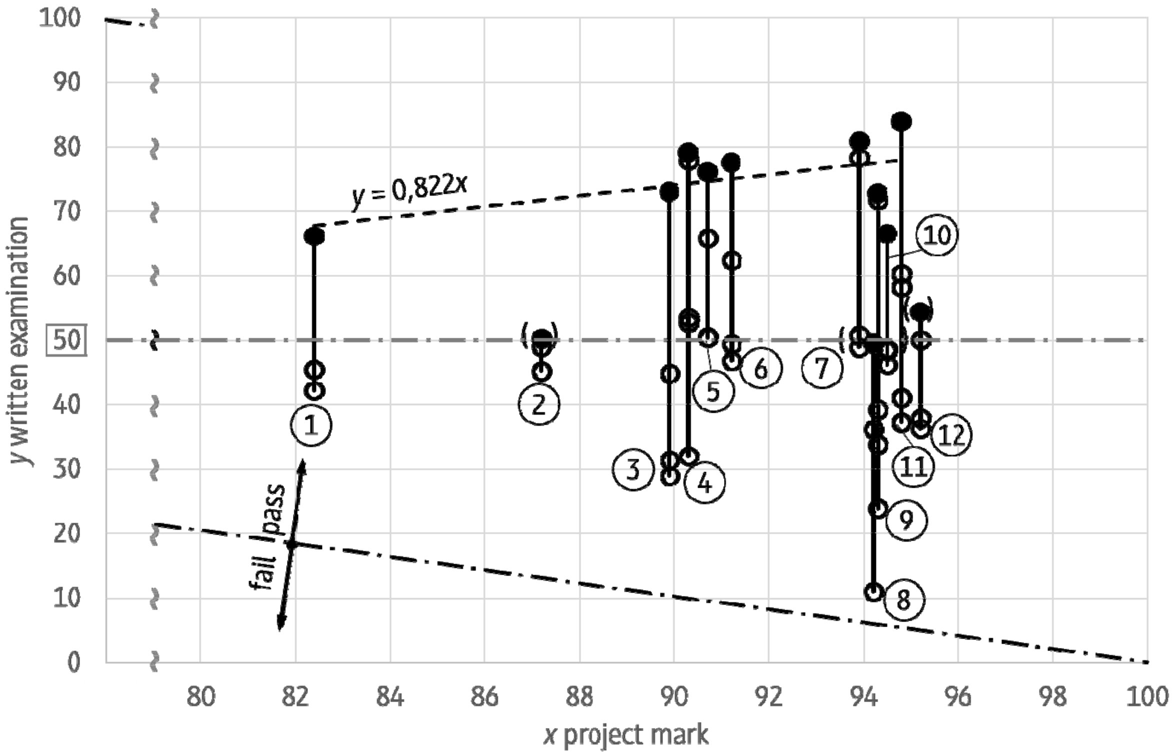

Figure 7. Correlation between the project grading and the written examination

5 ECONOMY OF TEACHING

Doubtlessly, it would totally overload a curriculum if design-build-test experiences were implemented in all modules of a study programme according to the 'watering-can principle'. Such a uniform implementation also would soon leave traces of weariness behind. Design-build-test experiences should rather occupy prominent spots in the curriculum. Capstone projects at the end of an academic programme offer perfect conditions for this type of deep learning experience, but take an enormous effort for both – learners and tutors.
Engineering Design projects – like this one – have a long tradition in Mechanical Engineering programmes. But especially when teaching large classes, teaching staff often gets 'immobilised' by the project assignment. Tutoring groups, manufacturing parts, marking reports – all this seems incompatible with large classes, cf. [10]. One of the contributions of this paper should be to focus on the 'economy of teaching'. The presented project course tries to reconcile large classrooms and individual experiences.
Owing to the exclusive use of supplied parts, the effort for the faculty's laboratory drops dramatically. The labour expended is reduced to the time needed for compiling the order lists and the actual

purchasing of the parts. The number of participants has been N=84 in the present project course, but can easily be scaled to larger populations.

The monetary costs for purchasing the parts in this project course amount to a maximum share of € 42.50 (VAT included) per student (working in groups of six to seven). As the groups did not fully exhaust their budget, every student needed € 31.13 on average in the present course. When being reused over an amortisation period of five years, the cordless power drills add approximately € 2.00 per student.

Compared to traditional chalk-and-talk teaching, project courses usually are a loss making-operation for the teaching staff in terms of the teaching load conceded. In this case, the three professors involved in the project receive eleven contact hours each and the same amount for preparation and wrap-up. In the first years when the project course has been set up, this was not even sufficient for reading and marking the reports. But investing more time for harmonising the classroom activities in a project plan led to less effort for assessing the results. For example, it did not take more than one hour for examining the assembly and testing videos– a 'frontloading' that definitely pays off!

6 OUTLOOK

In a project course like this, still more things can be optimised. In future, the authors will concentrate on the following measures:

- The student reception and perception need to be studied closer
- Team-forming meetings have to be introduced for permitting the group members to work more efficiently and with less friction from the beginning
- The qualitative feedback on the results of the groups given by the teaching staff should not allow to conclude 'sharply' on the project marking (before the written examination) in order to avoid the observed rebound effect on student performance

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