GRADING ENGINEERING DESIGN PROJECTS – LET PRODUCTS GIVE FEEDBACK!

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ABSTRACT
The article reflects the current practice of grading Engineering Design projects and suggests ways for enabling students to get 'direct feedback' from products. In the current practice, educators often establish a goal system where the assessment criteria are modulated by weighting factors. The inherent problem with this assessment procedure is that quality of the feedback obviously depends on the experience that the educator has obtained in these domains. Figuratively speaking, the educator is the mirror through which the students perceive their learning achievement – with all risks for eventual 'dark spots' on the mirror! 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. The interest of the paper lies in the direct feedback that students receive when they 'design-build-test' products: When students also test the products they have designed, it is the product and not the teacher that tells the students if (or how well) the product works. This also allows to develop easily measurable criteria that assess product performance and to integrate them into a grading scheme. The authors illustrate this assessment paradigm by various examples from teaching an Engineering Design course in a BEng programme.

Keywords: Project-oriented and problem-based learning, grading, learning achievement, feedback.

1 ENGINEERING DESIGN PROJECTS – AN INDISPENSABLE COMPLEMENT FOR LECTURES ON ENGINEERING DESIGN

Engineering Design is not teachable without letting students explore the design process on their own. Presenting open-ended problems (also called ill-defined problems) has a long tradition in Engineering Design education [1]. Engineering Design projects are considered to be 'an engineering adaptation of problem-based learning approaches' [2]. Thus, Engineering Design projects translate the 'fundamental shift from transmitting technical content knowledge to the urgent need for educating for broader competencies which concern students' attitudes and values' [3].

2 WHAT ARE GRADES GOOD FOR?

By assigning grades educators communicate to several stakeholders – to the student, other educators, or prospective employers. The decision that a person reading a grade typically wants to make is complex, since the grade should help to predict the student's <u>future</u> performance. A student for example wants to know if it makes sense to major in that field. Educators are interested if a student is qualified for advanced courses. Potential employers typically try to deduce if a student is apt to solve related problems on-the-job [4].

For students, the informational content of the grade itself (expressed by a numerical value) is very poor. Of course, educators can provide written or oral feedback. But teacher-provided comments always risk to be seen as subjective.

Grades also can be used to give incentives for self-regulated learning. Many engineering programmes schedule regular small assessments 'to encourage students to distribute their efforts more evenly across their studies' [5].

3 CRITERIA FOR GRADING ENGINEERING DESIGN PROJECTS

In order to pass 'from gut feeling to a structured […] assessment' [6] educators often establish a goal system where assessment criteria are modulated by weighting factors. Various examples of how systematic grading procedures should be developed and adapted to special subject areas or types of projects can be found in literature [7, 8, 9, 10, 11].

In an engineering context, the quality of a student design is often assessed by the way the designed product is prepared for important product life cycle phases or deals with other universal virtues. This corresponds to the concerns of Design for X (abbreviated DfX) – an essential branch of design science. The X in DfX may be replaced either by a phase of the product life cycle (among others manufacturing, assembly, testing, service and recycling) or a universal virtue (like quality, cost, risk etc.) [12]. Another dimension of assessing student designs is the conformity with standards, especially concerning the correct representation of parts in the technical documentation.

Perhaps the most holistic way for assessing student work is to focus on learning outcomes. A commonly used set of general criteria for measuring learning outcomes in Engineering Education is articulated by the Accreditation Board for Engineering and Technology [13]: Accordingly, Engineering programmes should prepare their graduates to attain

(a) an ability to apply knowledge on mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyse and interpret data
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate efficiently
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

In view of these ambitious demands the question is legitimate to raise if it is possible at all to teach and assess these professional skills. Undoubtedly, this will cause problems in traditional, and underpins the urgent need for developing new formats of teaching and assessment [14]. Of course, we cannot suppose that all lectures participate uniformly in the development of the students' skills. Skill-oriented assessment must be broken down, so that 'each […] exercise or assignment must be designed with the objective of teaching, practicing, assessing a particular sub-set of skills' [15].

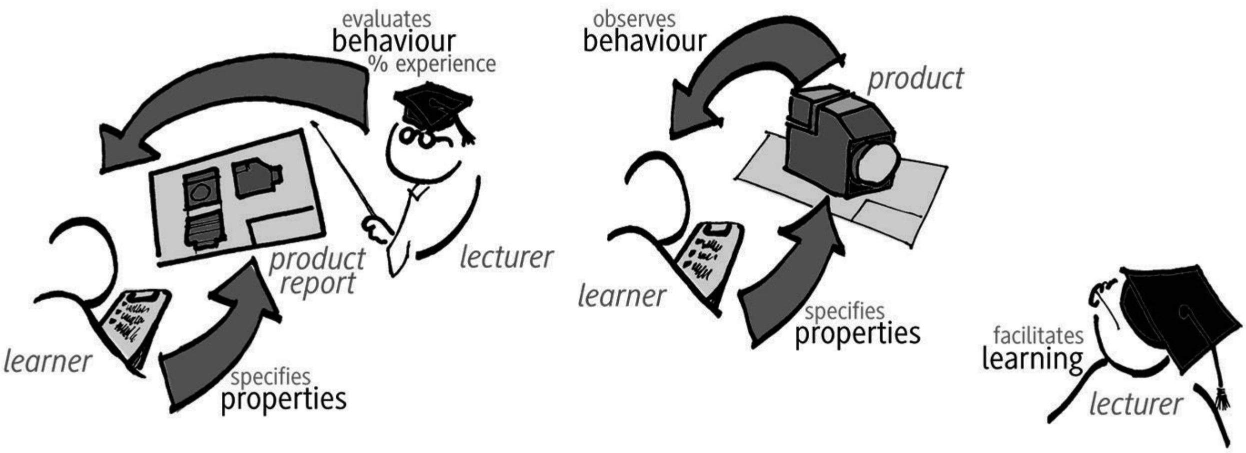
4 CRITICISM TOWARDS 'EDUCATOR-CENTRED GRADING'

Although many faculties have altered their curricula over the last decades and integrated project-oriented and problem-based learning into Engineering Design courses, the assessment of the learning outcomes is often unavoidably still educator-centred. This rather 'traditional' role distribution between learners and educators is illustrated in Figure 1a. Students specify the properties of products and document their results in product reports. Since the result of the students' work is just a virtual representation of the product, students cannot observe how the product physically behaves under real conditions. Usually, educators bridge that gap in the feedback loop and evaluate the products' behaviour in all of its life cycle phases and with respect to all universal virtues. For example, by examining a technical drawing of a machined part, the educator must judge how well the student prepared the part for manufacturing and if there are ways of manufacturing it at a lower cost.

The inherent problem with this assessment procedure is that quality of the feedback obviously depends on the experience that the educator has obtained in these domains. Figuratively speaking, the educator is the mirror through which the students perceive their learning achievements – with all risks for eventual 'dark spots' on the mirror! In addition, the fact of being dependent on a teacher does not encourage self-sufficient learning. Also the timeline is often disadvantageous in this feedback model: The educator's feedback risks to reach the learner too late, i.e. when the learner already devotes the attention to new challenging courses.

5 'PLAN–BUILD–TEST' EXPERIENCES – A DOOR-OPENER FOR DIRECT PRODUCT FEEDBACK

In many Engineering Design assignments, students are 'condemned' to do a lot of paperwork. But on very rare occasions during their studies, they receive the opportunity to build and to test the appliances, products or machines they have planned. In the following, we call this type of projects briefly 'design-build-test experiences'. Indeed, this requires that the products or at least functional prototypes are (physically) built. The fundamental difference with these learning experiences is in the way how students receive feedback when testing their products. This allows them to observe the (real) behaviour of their product (and not just a simulation of it) on their own, see Figure 1b. Briefly expressed, students learn from their product, not from their teacher. Therefore, we speak of direct product feedback. Experience shows that this direct feedback creates strong motivational effects and allows students to develop a deeper understanding (perhaps not only of the problem studied but also) of complex interactions in the design process. There is also an effect on the educator. Since this feedback loop is not centred on the educator, the educator can fully concentrate on his role as 'learning facilitator'.



(a) (b)

Figure 1. Learning feedback (a) *in 'traditional' design projects,* (b) *through design-build-test experiences*

A straightforward thought which suggests itself is to integrate direct product feedback into the practice of assigning grades. An assessment of product performance delivers easily measurable criteria. At first glance, grading the performance of the product that a student has built instead of concentrating on the outcomes of the learning process makes the hair on the neck of an educationalist stand on end. Nevertheless, even critic minds cannot deny the connection. A student cannot raise the performance of the product without having precisely studied the constraints that delimit the design freedom. But the problem for the educator is to find the 'meaningful' indicators that align with specific learning outcomes and to select those that cover the spectrum of expected competencies, knowledge, skills and abilities as broadly as possible.

6 EXAMPLES FOR DIRECT PRODUCT FEEDBACK

Table 1 lists recent projects with a focus on a design-build-test procedure in undergraduate courses on Engineering Design of a BEng Mechanical Engineering programme at the authors' university. In all projects students had to solve typical mechanical transmission problems and all products (except for the mini-quadcopter in project E) are driven by a cordless powerdrill.

Table 1. Recent design-build-test projects at DHBW Cooperative State University

	year	*sem*	#	*product*	*SP*	*AM*
A	2013	3	52	Electrically driven go-kart	X	
B	2014	3	84	Winch for launching non-motorised model aeroplanes [16]	X	
C	2015	3	67	Small helicopter rotor and starting device	X	X
D		4	65	Strain wave gear (Harmonic Drive™) [17]		X
E	2016	2	76	Mini-quadcopter (Flexbot) for transporting matchboxes		X
F		4	72	Centrifugal clutch	X	X

sem semester, # number of participating students, *SP* supply parts, *AM* additive manufacturing

A critical point in design-build-test projects, of course, is the manufacturing of the parts. If the entire project should 'fit' into an 'immovable' semester, experience shows that manufacturing time should not exceed three weeks – an almost unsolvable problem for the capacity of an ordinary laboratory! Therefore, we either ask our students to configure their products entirely with parts from a supply parts catalogue (as in project A and B) or to build their products with help of Additive Manufacturing systems – such as a laser sintering system or fused-deposition modelling 3D-printers – (project D and E), or by combining both (project C and F).
Just as in real-world projects in industry, our students have to complete a number of deliverables according to a fixed project plan along the semester. But not every deliverable is equally suitable for being graded by an indicator derived from direct product feedback. In our design-build-test projects we rather try to carefully balance out direct product feedback (marked DPF) with 'traditional' feedback given by the educator, cf. the scheme in Table 2. For example, the grading of project B where students had to design a winch for launching non-motorised model aeroplanes (see Figure 2) is based on a half-half weighting.

Table 2. Grading scheme from the winch project

	milestone	*document*	*weighting*	*DPF*
1	drive concept	poster	10 %	
2	supply parts	order list	30 %	X
3	costs			X
4	technical documentation	assembly drawing	30 %	
5	assembly time	video	10 %	X
6	operating test	video	10 %	X
7	unique selling propositions	product flyer	10 %	

DPF direct product feedback

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. In order to assess if students already have developed the necessary skills to manage complex technical communication, the relative number of supply parts from the order list that could be delivered without further enquiries was included in the grading. A pedagogically particularly valuable detail is, that it was not the lecturer but a sales representative who pointed out the eventual mistakes to the students. Exactly as in real-world projects, students also had to meet target costs (a budget of 250 € per team). Using the actual costs of the supply parts as an indicator, also the students' ability to handle the trade-off between the technical and economic constraints of their design task were considered in the grading.
While assembling and testing their winches, the students shot an uncut digital film ('video selfie'), cf. Figure 3, which they uploaded on the virtual learning environment Moodle. The assembly time was marked on basis of that video. The large variation of assembly time (between two and a half and more than nine minutes) revealed to the students that they had put different effort on preparing their design for assembly. 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 proper flight tests were organised off the grading records in convivial atmosphere on the last day of the semester on the flying field of a local aeromodelling club.

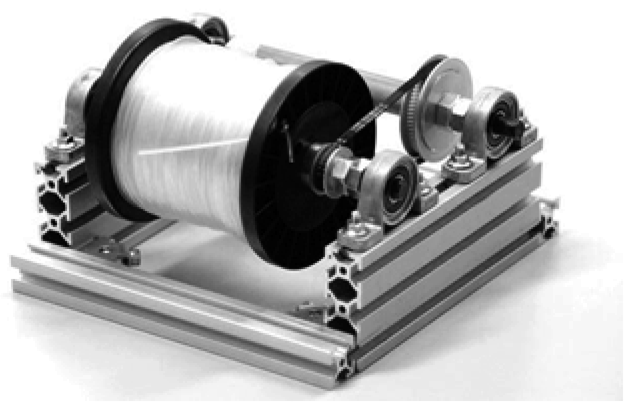


Figure 2. Assembled winch

Figure 3. Assembly video of a student team

7 CONCLUSION

Including direct product feedback offers a simple means for grading projects that students understand easily and accept willingly. Such a transparent and traceable grading process also avoids most complaints (and administrative effort correspondingly). Compared to other grading approaches, we noticed that the number of students who want their grade changed diminished drastically, even vanished.

We argue that it is possible to align direct product feedback with criteria that try to grade learning outcomes. Further research on the mechanisms of this alignment and on its implementation in form of a systematic procedure should be made in future.

A common problem of project-oriented courses is that they are highly demanding in terms of communication between students and staff. As a supporting measure, we currently prepare a series of electronic lectures that delivers the basic instructional content of our course on Engineering Design. This (hopefully) allows to flip the classroom and to use in-class lectures more efficiently for questions on comprehension and also for strengthening the students' design-build-test experiences.

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