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ETH FOCUS PROJECTS – SUCCESSFUL APPROACHES FOR PROJECT-BASED EDUCATION IN ENGINEERING DESIGN

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ABSTRACT
In the third year of the mechanical engineering bachelor programme, ETH Zurich offers so called Focus Projects as an integrative and intensive project-based learning course in product development. In this course type, interdisciplinary teams of typically 5 to 10 students in mechanical and electrical engineering and industrial design develop a product from the market profile to a tested prototype. From ten years of running Focus Projects and refining the course concept, three valuable approaches in coaching have been derived to increase learning and team performance. The presented reasons underlying the three approaches shall help engineering educators understand the importance of these approaches and give guidance in applying them on their own projects.
The first approach is factual and experienced feedback through extensive testing, which enhances the learning experience. The physical experience of the working of the own design adds meaning to the theoretical knowledge and thus leads to its manifestation. The second approach is value-based coaching, focussing on the values responsibility, transparency and open feedback. This helps the students grow not only on a knowledge level but as a person as they build self-confidence and learn collaborative behaviour. The third approach is the application of a question-driven stage-gate process. It gives the student teams the freedom to experiment and still enough orientation to reach a successful project outcome.

Keywords: Project-based learning, testing, stage-gate process, coaching by values

1 INTRODUCTION

Project-based learning is well-established in engineering education (see e.g. [1], [2], [3]). It trains the students in transferring theoretical knowledge to engineering practice, in soft-skills and in skills and knowledge like project management, presentation technique and technical documentation – skills that are not or little taught in other courses. A critical factor for the learning impact of a student design project is the coaching by the academic staff [4]. However literature specifically on the coaching aspect of project-based learning is scarce. The challenge is how to do the coaching to give the students orientation but still enough freedom to make their own experience, to try, fail and learn. In this context a big question for the coaching is, where to put the emphasis of what to discuss with the team and what to require from the team.
In the context of the Focus Projects we have developed three complementary approaches to coaching student teams towards intensive and comprehensive learning outcomes: Factual and experienced feedback through testing, value-based coaching and a question-driven stage-gate process. These approaches are not visible in Pembridge's extensive study [5]. They are applied in combination and proved to be successful with regard to both, the students' learning experience and also the technical project outcome.
We suggest these approaches to engineering educators running advanced design projects. To lay stress on the respective aspects of coaching requires consciousness for their importance. This consciousness is best raised when teachers understand the reasons why and the mechanisms how these approaches are valuable. To share these reasons is the goal of this paper.
The paper continues with an introduction to the history and the boundary conditions of Focus Projects at ETH Zurich. In the main part in Section 3 the three approaches are described together with the theoretical insights that underlie their application. Section 4 presents the conclusions.

2 FOCUS PROJECTS AT ETH ZURICH

The concept of Focus Projects was introduced at ETH Zurich in 2004 by Markus Meier, professor of product development at the Department of Mechanical and Process Engineering. The intention is to let the students apply their theoretical knowledge from lectures, combine it with a practical assignment and to experience the challenge of a real product development in a supportive learning environment.

2.1 General course setup

Since 2012 the Focus Project is an official course type that any professor in the mechanical engineering department can offer to mechanical engineering students in their 3rd year of bachelor studies. Some of the common characteristics are:

- 2 semester duration in the 5th and 6th term of BSc in Mechanical Engineering programme
- 14 ECTS for the project itself plus 6 ECTS for complementary courses
- Teams of 3 to 8 students of mechanical engineering plus students of other programmes

The general framework for Focus Projects also defines a list of common learning objectives [6].

2.2 Project diversity

Differences between the projects sponsored by different professors lie especially in the foci regarding

- the character of the project tasks, from technology demonstrators [7] over projects with industry partners [8] to world record attempts [9],
- the organization of the projects, like the teaching staff involved and the funding, and
- the emphasis and depth of coaching support (technical, process-oriented, methods) for the teams.

This year, 2013/14, twelve different projects have been offered by eight professors. Some projects are initiated from student ideas. The course allows including students from other faculties such as electrical engineering and also faculties of other universities such as industrial design. Additionally students from a business school cooperate loosely to conceive business cases based on the project outcomes.

2.3 Teaching and coaching structure

For the students doing a Focus Project, supportive courses are offered. One is a three day "base camp" at the beginning of the project for the students aiming at accelerating the team building process, catalysing the development of a project vision and introducing design thinking tools.
Two "practice courses", of which the students can choose one, accompany the project through the first semester, one on project management, the other one on advanced CAD, PDM and FEM.
For the coaches, which are in most cases a team of PhD students and a master student who did a Focus Project earlier, a "coach-the-coaches training" is offered.
The organisation of most Focus Projects includes intermediate reviews and a final review. At these reviews the students present their project state, preliminary results and plan how to proceed in front of faculty staff and often also financial sponsors.

2.4 Focus Projects at pd|z

Due to the large diversity of the Focus Projects at ETH Zurich it would go beyond the scope of this paper to describe all variations. Therefore this paper focuses on projects sponsored by pd|z Product Development Group Zurich. pd|z sees humans in the central roles of product development, human users and human developers. Therefore it consciously observes roles and relations in the focus projects and strives for continuous improvement. In this context we have identified three successful approaches to coaching student teams that go beyond common coaching practice at universities.

3 THREE COACHING APPROACHES

In this section the three complementary approaches to coaching an interdisciplinary design project are described and explained. Examples base on the 2012/13 project "Ship Inspection Robot". The project task was to develop a remote controlled rover that can move through the ballast tanks of cargo ships to take pictures for visual inspection of the ship. To that purpose the robot has to be compact, be able to drive on vertical surfaces or even upside down on the ceiling and also be able to overcome stiffening structures of different shapes (see Figure 1, Figure 2 and [10]).

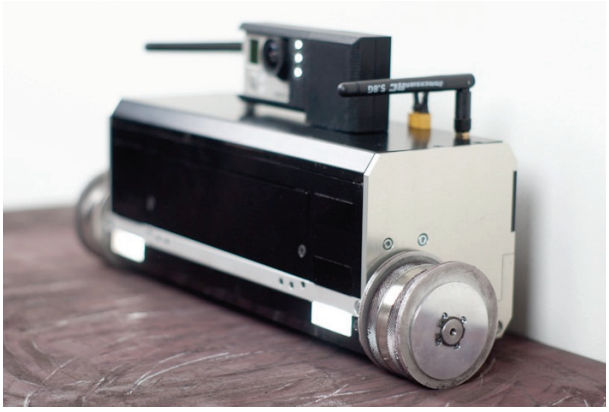

Figure 1. Final prototype of the exemplary project Ship Inspection Robot

3.1 Extensive and systematic testing

No product development is finished with a CAD model delivered and no serious company would start selling an untested product. Testing is an integral aspect of product development [11] and what is more it is a valuable source of feedback to the students. Therefore pd|z puts strong emphasis on the testing of the students' systems (see also [12]). While many publications about student projects mention prototypes or testing (e.g. [13], [14], [15], and [16]) it remains unclear to a reader in what form and depth it is done and with what motivation it is promoted by the project coaches. The testing of the example project comprised many verification tests of single functions like wireless data transmission, correct and precise position control of single wheels or the defined turning of the camera. The most important test on system level was the passing of all defined obstacle shapes in four different directions to gravity (see Figure 1).

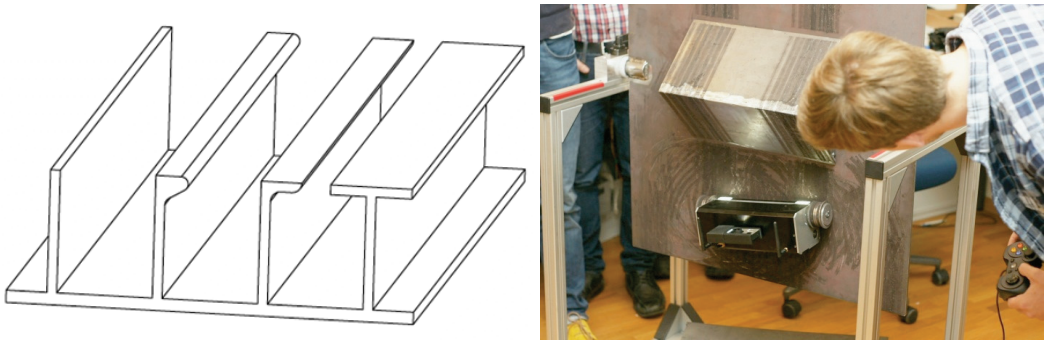

Figure 2. Defined profiles for the robot to climb (left) and the turnable test rig, with which all relevant obstacle features can be simulated with variable direction of gravity (right)

3.1.1 Factual and experienced feedback

In education students usually get feedback on their work from their teachers based on the teacher's experience and opinion. Extensive and systematic testing can provide the students self-generated factual feedback in which no teacher opinion is involved: The students design and build a system, the students test it and the system does or does not what it was intended to do. The result of a test leads generate direct feedback on the students' assumptions and design decisions.

Important in addition to the factual component of testing is the experience component. When the students do the assembly they haptically experience how tight a chosen fitting is. And when they see the robot flip around a profile edge, and fear for a second that it would fall down, they can link the abstract idea of an instability point to an experienced situation. This physical experience helps the students give their theoretical knowledge more meaning and the emotional component of an experience leads to more intense and durable learnings. On the other hand testing helps the students to understand "the difference between theory and actuality" [17].

3.1.2 Implementation and reflection

Most important towards implementation is probably the appreciation of testing by the coaches in general, leading to early questions about the plans how to test and late questions about the results of

the tests, as well as support in developing the test plan. More technical preconditions are that the teams have sufficient resources to build high fidelity prototypes and test environments and that the project definition allows for reaching a sufficient project maturity to be able to test the system.
For the learning effect it is also important that the students feel committed to the requirements that are tested. If the requirements come from the teaching team or a corporate partner, it is important that the students understand the reason behind them and adopt the requirements as their own. In our observation, projects pushed towards extensive testing achieved higher project maturity at the end of the project.

3.2 Coaching by values

In long-duration student projects that include an intense coaching by teaching staff, the input and the attitude of the coaches have an impact on the students' motivation and behaviour throughout the entire project. By trying to get the best benefit for the students, we are focussing especially on the process, how methods and approaches are taught, how the interaction occurs and how beneficiary mindsets can be passed on to the students. This can be done effectively through communicating and exemplifying values, which help the students, grow, not only on a knowledge level and for the current project, but also as a person for future challenges. Adopting these values further helps the students improve their collaborative skills.

3.2.1 Open feedback culture

In an environment of young motivated students and engineers, the willingness for learning new things and for personal development is very high. The feedback from teammates and coaches is highly valuable for the reflection process. Therefore it is important to demonstrate the value of open feedback culture to the students. This is firstly done by giving feedback to the students in a constructive and positive way, so that the image of giving feedback is attractive and positive. Especially the feedback framework "I like, I wish" – consisting of positive observations and constructive suggestions – enables a positive view on feedback, which is in our culture often but misleadingly put on a level with negative criticism. Secondly an openness to give and receive feedback is presented and regular feedback sessions are organized.

3.2.2 Taking on responsibility

For students in the 3rd Bachelor year with little project and teamwork experience, it is an important aspect to build up self-confidence in their own abilities as a future engineer. We believe that this can be achieved by giving them many rights and freedom for their decisions on goals, requirements and the way of achieving them. As coaches we encourage them to take on responsibility by, for example, defining the deliverables expected from each team member in his respective role. Major decisions are left to the team and help is just offered for example by working out the pros and cons for a decision together, but never by deciding for the students.

3.2.3 Transparency – no hidden agenda

In our opinion the ideal role of a coach, how he is recognized by the students, is an engineer with some more project and product development experience compared to the students and who gives helpful input and hints whenever possible. To support the team effectively, the coach should have insight in the technical aspects of the projects and the team dynamics. The students will only grant this insight, if they do not perceive a coach as a judge or as someone having a hidden agenda. For helping the students accept this role, the underlying goals and ambitions need to be communicated clearly and transparently. It is important to be open about the fact that the coaches are not experts in everything. In this context it helps to talk about the coaches' careers to the students to help them judge how well-founded an input from a coach is. Transparency between coaches and team should also lead to the same openness within the team among the students. This ideal of "no hidden agenda", of as much transparency as possible, is addressed openly and directly from the beginning.

3.2.4 Implementation

After the selection process for students wishing to attend the Focus Project course, the project starts with a kick-off event together with both students and coaches. The goal of this event is to manage each other's expectations for the upcoming year and learn about the respective roles. The coaches present the values of pd|z and also their values in coaching, such as transparency, trust, responsibility, open

feedback and willingness to learn. They make examples on how those values express in daily routine and what consequences they have for the coaching relation. In the weekly coaching sessions the coaches are very careful to act according to the values and sometimes refer to them, to continuously make the students aware of what motivates their actions.

3.3 Question-driven stage-gate process

It is common practice to divide projects into multiple phases and to define milestones when certain tasks have to be completed. This also applies to education projects. When the milestones do not only define a deadline but a decision point, they are rather referred to as gates [18]. Often in such processes in education the milestones are deliverable-driven (e.g. [19]). This approach has three traps:
Firstly, every development process is unique and characterized by specific challenges [20]. Fixedly defined deliverables based on certain tools, like an FMEA analysis or a critical function prototype [17], or with a specified result, like a market segmentation [18], are often not apt to solve the effective challenge at a current project stage. Secondly, engineering education should not aim at educating "executors" but at educating actively thinking team members and "leaders" in engineering. Thus it is desired that the students reflect on the product development process itself. Fixed deliverables do not foster this reflection. And thirdly, rather openly defined deliverables like a "product profile" [16] run the risk of not answering the relevant questions for a gate decision.
To reduce the risk of stepping into one of these traps we promote a question-driven stage-gate process.

3.3.1 Question-driven approach

Instead of fixed deliverables the framework given to the students defines what questions have to be answered at the gate to support a well-founded decision. But it does not define *how* these questions should be answered. Examples for such questions are: "Are the selection decisions coherent and well-founded?" (standard question at all gates) or "Are the technological risks known and the critical functions identified" (gate 2: "product concept"). Thus the team can define for themselves what they plan to do to answer the gate questions. As a suggestion, "typical" tasks and methods for every stage are provided, however it is not compulsory for the students to use them.

3.3.2 Compromise between orientation and self-direction

We believe that a question-driven stage-gate process is a good compromise. On the one hand the gate questions give orientation to the development team. The answering of the gate questions forms an intermediate goal. To be successful in answering the critical questions at the gate also helps to reduce the risk of big mistakes provoking big and thus "expensive" cross-gate iterations [20].
On the other hand the question-based framework leaves great freedom to the development team, in what form to answer the gate questions. Especially it allows to experiment and to adjust the choice of methods to the specific characteristics of the project, for example the knowledge base from which the development starts and the resources available for the project.

3.3.3 Gate scheduling

In contrast to common corporate reality the Focus Project teams are given the freedom to schedule the gates, and thus the stage duration, on their own. In case the plan looks completely unrealistic the coaches can give feedback to the planning. What is more important, however, is the experienced feedback the students get on their planning from how well they manage to follow it. This is again a factual and experienced feedback like the one obtained from testing (see Sec. 3.1).

3.3.4 Implementation and reflection

The board deciding whether a gate can be passed consists of the direct coaches and the professor. The meeting is prepared by the students with a two page summary of the project state and the answers to the gate questions. After an informal presentation by the students and additional questions by the board members, the latter decide on whether to let the team continue as planned or to require more or better answers.
It is still a challenge to achieve that all team members and throughout the stages work with the provided framework. In our observation, mainly the students dedicated to project management use the framework document intensely and that mainly when it comes to planning the next stage.

4 CONCLUSION

This paper presents three complementary approaches to coaching a design project in engineering education:

- Systematic and extensive testing to induce factual and experienced feedback,
- coaching by values to train them in responsibility and self-confidence and
- a question-driven stage-gate framework providing flexibility and freedom to experiment.

These three approaches support an intense and genuine learning experience as well as personal growth for the students in the scope of the two semesters Focus Project. The approaches are not unique to project-based education, but it is their explicit and conscious application which makes coaching more valuable. The understanding of the underlying reasons, presented in this paper, helps coaches to implement the complementary approaches consequently and in the coaches' individual style.

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