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EXPERIENCING AND TEACHING TECHNOLOGY – INTEGRATING STEM TEACHING-STUDENTS IN INTERDISCIPLINARY DESIGN TEAMS

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ABSTRACT
One reason for a lack of engineers lies in pupils' little knowledge of an engineer's work. Thus, STEM (Science, Technology, Engineering and Mathematics) teachers should be able to convey this knowledge in order to promote pupils' enthusiasm for engineering**.** To qualify those teachers for this task, they need to experience the work of an engineer themselves. At Karlsruhe Institute of Technology (KIT) a new course integrates STEM teaching-students in a mechatronics course using project-based learning to address this need. A study was conducted to answer the questions, (A) what STEM teaching students know about aspects of systematic engineering design before taking part in the course and (B) whether they can learn about those aspects by taking part in this interdisciplinary design course. Semi-structured interviews were conducted with the students at the beginning and the end of the semester, transcribed and analysed qualitatively. Results show, that the students had little knowledge on systematic engineering design before taking part in the course. Also, all of them showed considerable learning at the end of semester, especially knowledge on validation and testing. So at this point, it seems the right way to integrate STEM teaching students in design teams in order to qualify them for conveying knowledge of an engineer's work to school.

Keywords: STEM-Fields, teaching-students, Interdisciplinary Design, Project-based learning

1 INTRODUCTION

Engineering is the backbone of German industry, which results in substantial need for qualified engineers. But only 15% of German pupils consider studying in STEM fields [1] and only a fraction of this percentage has an interest in engineering. So it seems like the majority of pupils is already in school lost for a career in engineering. One aspect of this problem is, that pupils have little knowledge of the engineering profession and especially of engineering design [2]. In order to promote the enthusiasm of pupils for engineering, STEM teachers need to convey this knowledge in school. Thus, STEM teachers need to be qualified in teacher training for this task. This is why teacher training should be looked at more closely when dealing with this matter.

1.1 STEM teacher training

Since 2007, "Naturwissenschaft and Technik", in the following called STEM, is one core subject in high schools of a federal state in southern Germany. It includes topics from natural sciences and from engineering. In project-based lessons, the pupils work on tasks by using their knowledge from natural sciences in a technical context [3]. One goal of this subject is to promote pupils' enthusiasm for technical professions.

Starting in winter term 2010/11, STEM teacher training was established at KIT. ***Figure 1*** illustrates the progression of STEM teacher training at KIT. The students start in their studies with basic science qualifications in biology, chemistry and physics. In the following, they can choose two out of three profiles that contain basic lectures in mechanical, electrical and civil engineering as well as information technology. Afterwards the students selected two specialisations in the engineering fields. There they attended engineering lectures, which are part of the B.Sc.-studies in Engineering. The teacher training is accompanied by lectures to technical didactics for all teaching-students at KIT. [4]

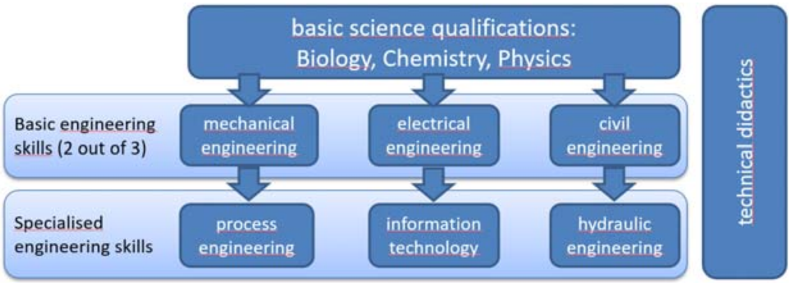

Figure 1. Illustration of STEM teachers training at KIT

The students mainly attend basic lectures without project work. There are also no exams, which link contents of different fields. It is visible that STEM teacher training at this point does not sufficiently address the actual work in engineering design [5], especially project work, which enables practical experience in this field, is missing. There are three other universities that offer teacher training in this field. Two of those universities provide courses containing project work, which address didactics by practical work with pupils or professional competencies by technical projects on a smaller scale. To get the students in touch with the actual work in technical fields one of the universities provides internships in production. At KIT the main goal is to teach STEM teaching-students, what it is like to be an engineer. Thus, the new approach is to qualify teaching-students by letting them experience engineering design themselves *together with engineering students*.

1.2 Integrating STEM teaching-students in a mechatronics course

In the module “Experiencing and teaching technology”, STEM teaching-students take part in a mechatronics course using project-based learning to gain experience in engineering design. In the course, student teams develop mechatronic systems to fulfil a given task. Figure 2 shows impressions of the course’s project work. The STEM teaching-students are part of the teams and experience the whole product development process from finding a concept over developing and validating prototypes to presenting the final product. Their role in the teams is to support the project work methodically. A lecture supports all students of the course by providing different aspects of systematic engineering design, the corresponding methods and professional basics. [6]
By experiencing the whole process of developing a technical product from the perspective of an engineer, the students get to know more aspects of what it means to work as an engineer. This enables them to convey a more differentiated picture of the engineering profession in which the pupils can find themselves, which influences the pupils’ choice of study.

Figure 2. Impressions of project work and prototypes

1.3 Systematic engineering design

By taking part in the before described mechatronics course, STEM teaching-students get the possibility to experience the systematic way of thinking and problem solving in engineering design. Pahl and Beitz describe a systematic approach on engineering design which contains guidelines for the whole product development process [7]. The mechatronics course emphasizes some aspects of this systematic engineering design. Those aspects are named and described in the following to set categories for knowledge that can be acquired by taking part in the mechatronics course:
Structured process. Developing a new product in engineering design happens within a process. This process contains different phases from planning over conceptual and embodiment design to detail design of the product [7].

Problem solving with systems. Engineering designers solve technical problems by creation of technical systems. In order to solve the technical problem, it is split up in sub-problems, which are solved by finding suitable subsystems. Those subsystems are then combined to a full system, which embodies the solution of the technical problem [8]. While combining multiple subsystems, it is necessary to consider all inter-relationships including environmental influences.
Validation and testing. In many cases, it is necessary to develop prototypes or partial prototypes from an early stage on in order to clarify fundamental questions [7] or to test the developed system's functions and sub functions. In addition, it is necessary to ensure, that the developed system fulfils the intended purpose by validation [9] preferably in all phases of development.
Iterative design. Iterations are often necessary when designing technical systems, because the interrelationships between subsystems are too complex to be designed in a single step. Although necessary, those iteration loops should be as small as possible for an efficient design process. [7]
These aspects can also be applied to other technical professions. For example, the aspect "structured process" is reflected in every form of project work, "problem solving with systems" can also be transferred to the IT sector.
In winter-term 2017, STEM teaching-students took part in the mechatronics course for the first time. The main goal of integrating them in the described course was to teach them systematic engineering design so they can convey this knowledge in school and promote pupils' enthusiasm for engineering design. To this point it was unclear, what the students actually learned by taking part in the course. This raises two questions. (A): What do STEM teaching-students know about aspects of systematic engineering design before they take part in the course? And (B): Can they learn about these aspects by taking part in the presented interdisciplinary design course? By conducting a study that compares the knowledge of STEM teaching-students before and after taking part in the course these questions will be answered in the following.

2 MATERIALS & METHODS

This section presents the conducted study's design and describes the analysis of the collected data. The study contained semi-structured interviews with multiple STEM teaching-students who all took part in the first run of "experiencing and teaching technology". Following Yin's classification of basic types of designs for case studies [10], it was an embedded single case study. Five STEM teaching-students took part in this study, four of them in their 9^{th} semester and one in the 7^{th} semester. One main goal of the study was to identify what those students knew about systematic engineering design before taking part in the course. To get detailed information about the students' knowledge, a semi-structured interview was conducted with every participant at the beginning of the semester. The questions addressed, directly and indirectly, the before presented aspects of systematic engineering design.
Beginning interview structure. When conducting an interview, it is important to create a tolerant and permissive atmosphere in which the interviewee can answer freely and without fear of being sanctioned [11]. That is why the semi-structured interview contained the following four stages:
1) Collecting personal data to assign corresponding data to the participant and to give the participants an easy start. 2) Asking about the participants' expectations for the course in order to get to the topic and to make them more comfortable with the interview. 3) Direct questions on a design engineer's work in general and challenges of the field to get some direct answers on the topic. 4) The participants should describe how they would structure an engineering design project for pupils in school. This aimed at identifying whether the students could transfer their knowledge to another context that was suited for teachers. To find out about the participants' knowledge about *validation and testing*, they should also describe, how they would ensure a functioning product for the pupils. Research question (B) addresses, what the participants learned by taking part in the course. Conducting a second interview at the end of semester provided information on their knowledge at the end of semester.
End interview structure. The general structure of the interview at the end of the semester was similar to the one at the beginning. But the participants were asked about their experiences in stage 2) instead of expectations. Also, some queries to given answers from the starting interview were added in all stages to address the participants' development. A direct question in which part of the course they learned most during the semester had the goal to make the most important part of the course in the students' eyes visible.
Data Analysis. The interview transcripts of beginning and end interview were analysed qualitatively by two persons independently. According to Yin [10] it is helpful to have an analytic strategy when

analysing qualitative data. In this case, the strategy was to find statements in the interviews' transcripts that were linked to the before identified aspects of systematic engineering design. Each investigator sorted the found statements and used the above named four aspects of systematic engineering design as categories. By discussing and comparing the found statements of both investigators for the participants' knowledge, it was possible to identify a number of key statements. In a next step, corresponding answers of beginning and end interview were matched together for each participant separately – if possible – to make identifying the participants' key learnings easier. It was also recorded in which part of the course the participants had learned the most according to their own statements.

3 RESULTS

This section presents the results of the transcripts' qualitative analysis. Table 1 shows the identified key statements sorted by aspects of systematic engineering design as category (most left column) for the two representative participants P1 and P3.

Structured process. The results show (see Table 1) that before and after the course, students named multiple phases as a structure for the development process. In addition to that, they mentioned "setting goals" and "milestones" as elements of the process.

Problem solving with systems. At the beginning of semester, three out of five participants gave no statements, which addressed systematic problem solving. At the end interview in four out of five cases statements about splitting up problems or systems to find a solution could be found.

Table 1. Interviews' key statements sorted by aspects of systematic engineering design[1]

Cate-gory	Parti-cipant	Beginning Interview	End Interview
structured process	**P1**	Phases of idea generation, then building... that means construction phases, [....] then building phases and then definitely test phases.	first present the concept idea, then why one takes this concept, [...] then prototypes, Subsystems
	P3	Problem phase, the…um…the solution phase, test phase, construction phase, reflection phase	what phases there are, what project phases, profile determination, idea generation, concept development, prototype and so on
problem solving with systems	**P1**	*No statements*	so the basic functions should be tested at an early stage,[...] And then whether they also work in the overall game with the others.
	P3	splitting up the problem [...] where are the…uh… components? I'm looking at the subsystem, and then I'm trying to find a solution.	To assess the long-term consequences of their decisions, i. e. that not only develop a subsystem without the inclusion of the other Systems [...] Where does my subsystem have intersections?
validation and testing	**P1**	to build the whole thing, test it and then improve it once more.	[testing] should happen as soon as possible […] should already happen from the first subsystems onwards.
	P3	you try to find the good prototype, then construct it, that is, that you really have the final product and it is then evaluated, tested.	prototype is always quickly made out of paper, cardboard, the faster you test the more you end up with success.
iterative design	**P1**	*No statements*	Testing. So basically testing, validation, again and again
	P3	*No statements*	although these iterations take time and so, um, it's important to make them once to see how often you actually need to improve the product and what you need to improve.

Validation and testing. Before taking the course, all participants named testing as an instrument to ensure a functioning product at the end of development. After the course, there were more statements about testing and prototypes in general and the students placed testing and validation at the beginning of the process, too. Also, paper prototypes were named (see Table 1, "validation and testing"). In

[1] All Interviews conducted in German. Key statements were translated for this paper

addition to Table 1, participant P2 changed from the view, that high numbers of prototypes are the key to success, to the insight, that the significance of the conducted tests is most important.
Iterative design. In the beginning interview only one out of five participants described an iterative setting that could be linked to this category. It stated you had to start over, if your system did not work, so it described big iterations. At the end of semester, four participants described iterations as necessary when designing technical systems.
According to their self-assessment, four out of five participants learned the most in the course's project work. All of those four underlined the importance of experiencing the product development directly as part of the team. The remaining participant rated the lecture as important as the project work but also found it necessary to have both to maximize learnings.

4 DISCUSSION

As introduced, the main goals of the conducted study were to find out, (A) what STEM teaching-students knew about systematic engineering design before taking part in the course and (B) what they could learn about these aspects by taking part in the presented design course. By interpreting the given results in the light of systematic engineering design, this section answers those questions.

4.1 Knowledge of STEM teaching students before the course

Structured process. The participants described designing a technical product in phases that include planning, testing and setting milestones to control progress (see ***Table 1***, "structured process"). This shows they knew, that it is a process that needs to be structured. But the use of uncommon terms like "building phase" (see ***Table 1***, "structured process") implicate, that they simply describe what they imagine as product development process and followed no plan.
Problem solving with systems/iterative design. The missing statements in the categories "problem solving with systems" and "iterative design" (see ***Table 1***, column "Beginning interview") implicate, that the participants had only little knowledge of those aspects of systematic engineering design before taking part in the course.
Validation and testing. Results show, that all participating students see testing as an important matter and some of them named prototypes as instrument to identify, if a system works or not. But testing was placed as last activity in the process, e.g. "you try to find the good prototype, […] that you really have the final product and it is then evaluated, tested" (see ***Table 1***, "validation and testing"). In addition to often not concise descriptions, it seems the students did not know when and what to test. Descriptions like "the good prototype" (see Table 1, "validation and testing") support the view, that they had no consistent picture of what a prototype actually is.
Conclusion for question (A). Before taking part in the course STEM teaching-students had some general knowledge on the product development process and were aware that testing is essential, but in the categories *problem solving with systems* and *iterative design* they showed little to no knowledge.

4.2 Learnings through the course

Structured process. Compared to the beginning interview, the participants put the phases of development in the right order and used more appropriate terms to describe them (see ***Table 1***, "structured process"). They also stressed the importance of setting goals and milestones as very important.
Problem solving with systems. One key learning of the students in this category was that you have to split your system in development up into subsystems to find solutions and combine them to fulfil an overall function. Another was, that when combining subsystems, you have to take all inter-relationships including environmental influences into account and test the full system again. Especially P1 developed from no statement in this category to the view, that early testing and integration of sub functions is crucial. (See Table 1 "problem solving with systems")
Validation and testing. This category seems to be the one, where STEM teaching-students learned the most. They deepened their knowledge in many ways, what a higher number of statements shows (see Results). They underlined how important early testing is, e.g. "should happen as soon as possible" (see ***Table 1***, "validation and testing") and described how paper prototypes support early testing. They also described, that the environment needs to be considered while testing and that significance of tests plays an important role (see Results). All those aspects show a deeper understanding of validation and testing compared to the beginning interview.

Iterative design. The increasing number of identified statements shows, that the study's participants became an insight in iterative design. Some of them described the necessity of iterations in engineering design to optimise (see ***Table 1***, "iterative design") the product.
Conclusion for question (B). Most of the STEM teaching-students showed a development in all investigated categories of systematic engineering approach. Especially in the categories *problem solving with systems* and *iterative design* their learning was clearly visible due to an increased number of statements. In the category *validation and testing* they clearly deepened their knowledge and gained new insights. All in all the participants' statements showed a more sophisticated view on the topic.
Together with the participants' self-assessment that they learned the most in the course's project work, it seems the right way to integrate STEM teaching-students in interdisciplinary design teams to teach them aspects of systematic engineering design. This enables them to convey their knowledge in their future work in school.

4.3 Limitations and Outlook

Due to the small number of participants, the presented results can only give a rough picture of knowledge and learning of STEM teaching-students in general. Nevertheless compared with around 12-15 students per year in STEM teaching at KIT, the number of investigated participants is quite high. STEM is currently being taught in Baden-Württemberg by teachers of the natural sciences without training in engineering. The findings of the study are intended to contribute to the further training of these teachers. Another limitation lies in the focused view on only four aspects of systematic engineering design to make investigation possible. Additionally the interview transcripts were the only data used for analysis. For further studies, there should be more sources to make triangulating the data possible. To strengthen the study's findings further investigation is advised. The results of the evaluation of the course among the engineering students showed, that they saw great added value in the participation of the teacher training students, which indicates good integration.

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