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Effective factors of a teacher training concerning the implementation of interdisciplinary STEM-modelling projects

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The modelling of the functional principle of a Segway requires an understanding of physical, technical and mathematical concepts, which are usually taught at university level. Nevertheless, the focus of two two-day-teacher trainings lied in the preparation of 11 teachers and 3 teacher students, such that they can implement interdisciplinary STEM-modelling projects with their students of Grade 10 to 12. Since 5 school projects were implemented by 7 teachers and 3 teacher students during summer 2018 we focus on the detection of effective factors and obstacles of the teacher training, concerning the implementation of the modelling projects. This paper describes the design of a one-year-study, especially the concept of the two-day teacher training and the resulting school projects. We also present first results of a qualitative study focusing on the effective factors of the teacher training based on guided interviews, which were conducted with all participants.

Keywords: Teacher training, STEM-modelling projects, interview study.

Introduction

The question of a pilot school project (Lantau, 2016) with 12 students of Grade 12 was if a STEM-modelling project concerning the functional principle of a Segway can be implemented at school. The comprehension of the functional principle of a Segway requires knowledge about modelling a Segway as an inverted pendulum to detect physical forces and energies leading to a mathematical model of a linear state space system. This system is controllable and therefore stabilizable by feedback- or PID-control which can be implemented practically to control a Lego Mindstorms[®] Segway (Lantau, 2017). The students in the pilot project learned many mathematical and physical concepts, mostly at university level, which are used in practice to control a Segway. Furthermore, we received the feedback of the supervising teachers that this kind of STEM-modelling-project shows their students the important role of mathematics in real-life-problems, *but* that they are not able to supervise such a STEM-modelling project on their own. This observation lead to the research question of a PhD-project, of how teachers have to be trained such that they are able to supervise this kind of STEM-modelling project on their own or in a teacher team. By this mean, in 2017 two two-day teacher trainings were offered for 9 teachers. The teacher trainings content was designed to follow the modelling cycle of Blum and Leiss (2007) and will be described in the section teacher training. Based on the teacher training, four school projects were implemented with students of Grade 12 (Lantau, 2017). Three of four school projects concentrated on the comprehension of the functional principle of a Segway, so the students learned how to use the PD-control theoretically and practically to counteract tangential forces to stabilize a Segway. The essence of the first year's PhD-project was that the design of the teacher training was successful in a way that teachers are able to supervise STEM-modelling projects with their students. Therefore, we focus on the analysis of effective factors and obstacles of the teacher training concerning the implementation of STEM-modelling projects at school with students of Grade 10 to 12 by teachers and teacher students.

Research focus

In recent years some projects and research studies concentrated on the professional development of teachers concerning the teaching of mathematical modelling in regular lessons. In their work, Blum and Borromeo-Ferri (2011) stresses that teachers need to be aware of an optimal balance between the maximal independence of the students and the minimal help of teachers. In addition, the results of the LEMA project show that a professional development course has a positive effect on self-efficacy and on pedagogical content knowledge of teachers (Maaß & Gurlitt, 2011). Gastón and Lawrence (2015, p. 9) investigated in their work that “the research does not reveal one perfect method or set of techniques that can prepare each individual teacher to effectively teach mathematical modelling as a transferable process”. Nevertheless, most of the professional development courses for mathematical modelling concentrate on teaching teachers to use mathematical modelling processes in regular lessons or small tasks. For despite, the long tradition of mathematical modelling in Kaiserslautern focuses on interdisciplinary and real-life STEM-problems which students usually investigate in project-based learning environments such as modelling days and weeks (Bock & Bracke, 2015) it was not clear how a teacher training has to be designed such that teachers are able to supervise interdisciplinary STEM-modelling projects. Since one first approach of a teacher training concerning the mathematical modelling of a Segway seemed to be successful (Lantau, 2017), the research focus was set on the detection of effective factors and obstacles of the teacher training. In our work we refer to the model of Lipowsky, in which he describes factors and constraints to explain the effectiveness of teacher training courses (Lipowsky, 2010). Quite similar to Lipowsky’s model, Wilson (2013) and Desimone et al. (2002) investigated 5 core features for professional developments, namely the content focus, an active learning process, a collective participation, coherence and a significant duration of the teacher training.

Nevertheless, since it exists only few research results concerning teacher trainings for interdisciplinary STEM-modelling projects our research question is to explore the effective factors of the teacher training such that interdisciplinary STEM-modelling projects can be implemented at school. We want to answer our question by the help of a qualitative study in which we used guided interviews based on Lipowsky’s model. At first, the participants were asked to reflect their meaning and experiences towards STEM- modelling projects and later the interview focuses on effective factors of the teacher training which encourages teachers to implement this STEM-modelling-project. Furthermore, teachers were asked to describe obstacles during the teacher training. The participants (11 teachers and 3 teacher students) of the teacher training were interviewed after the training and those who implemented their modelling project as a result of the teacher training in summer 2018 (7 teachers and 3 teacher students) were interviewed again after their projects to detect successful factors after the transfer process of the teacher training. The interviews will be analyzed by the method of content-structured analysis (Kuckartz, 2018). Figure 1 shows the design of the one-year-project.



Figure 1: The study design

Teacher training

The teacher training followed the intention that teachers learn the modelling process concerning the understanding of the functional principle of a Segway actively. Therefore, the training started by an experimental phase in which the teachers got the opportunity to drive with a Ninebot Mini Street to get aware of a Segway's functional principle. After the teachers made their driving experiences, the control process of a Ninebot Mini Street and a Lego Mindstorms® Segway were compared. Based on their own experiences and observations of the control process, the teachers set up a model for the functional principle of the Segway. During this phase, the teacher recognized that they are in their students' role while modelling a Segway, so they reflected what kind of modelling approaches can students have when they model the functional principle of a Segway. In a following phase the teachers considered possible questions which they can implement with their students concerning the context Segway. For example, such a question could be the exploration of a shortest and fastest driving of a Segway in a given course. Further contexts are to investigate the effect of the center of mass' location for the control process or to calculate an optimal route for a Segway tourist tour. The collection of possible project ideas gave the teachers the opportunity to think about possible interdisciplinary modelling projects for their students. After further project ideas were collected, the focus of the teacher training was set on the control principle of a Segway, which is described in Figure 2.

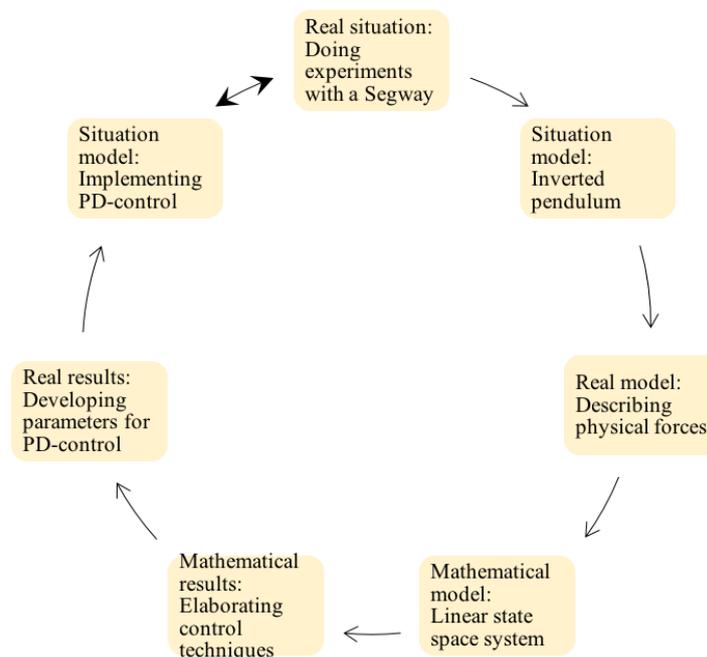


Figure 2: The design of the teacher training

Figure 2 shows that the design of the teacher training followed the modelling cycle of Blum and Leiss (2007), in which each step is connected to a module, which has either a physical, technical, or mathematical focus. By this design, a bilateral learning approach was offered: First, teachers experienced an interdisciplinary STEM-modelling process on their own (active learning) and secondly, they reflected on each module, whether it can be transferred into their school projects,

based on the knowledge of their students (coherence). The different modules are described in the following.

Physics module: Situation and real model

A first model for the control process of a Segway is set up by an inverted pendulum, which contains two mass-centers, one for the wheel axis M and one for the center of mass of the Segway m . The mass centers are connected with a massless pole of length l . The aim of the control principle is to counteract acting tangential forces by a motor force u of the Segway. One can describe the inverted pendulum by two approaches. Once, by analysing acting tangential forces, leading to a nonlinear, inhomogeneous ordinary differential equation of second order: $mg \sin \varphi - ml\ddot{\varphi} = u$

The second approach is done by describing the movement of the inverted pendulum by the *Euler-Lagrange-formalism* (Goldstein, 1980) in which the Lagrange function (difference of kinetic and potential energy) for the generalized coordinates *position* x and *angle* φ is set up:

$$\mathcal{L} = \frac{1}{2}(M + m)\dot{x}^2 + \frac{1}{2}m\dot{\varphi}^2\ell^2 + ml \cos(\varphi)\dot{x}\dot{\varphi} - mgl \cos(\varphi) + ux$$

In a second step the *Euler-Lagrange equation* is calculated for both generalized coordinates:

$$\frac{d}{dt} \frac{\delta \mathcal{L}}{\delta \dot{\varphi}} - \frac{\delta \mathcal{L}}{\delta \varphi} = 0 \wedge \frac{d}{dt} \frac{\delta \mathcal{L}}{\delta \dot{x}} - \frac{\delta \mathcal{L}}{\delta x} = 0$$

This process leads to two equations, one describing horizontal forces and the other describing tangential forces of an inverted pendulum:

$$0 = (M + m)\ddot{x} + ml\ddot{\varphi} \cos(\varphi) - ml\dot{\varphi}^2 \sin(\varphi) - u \wedge 0 = ml^2\ddot{\varphi} + ml \cos(\varphi)\ddot{x} - mgl \sin(\varphi)$$

Mathematics module: Mathematical model and results

A mathematical model for the inverted pendulum is generated of the physical model by applying Taylor-series-approximations of first order around $\mathbf{x}^T = (x \ \dot{x} \ \varphi \ \dot{\varphi})^T = (0 \ 0 \ 0 \ 0)^T$

which leads to the linear state space system $\dot{\mathbf{x}} = A \cdot \mathbf{x} + b \cdot u$

$$\dot{\mathbf{x}} = \begin{pmatrix} \dot{x} \\ \ddot{x} \\ \dot{\varphi} \\ \ddot{\varphi} \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{-mg}{M} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & \frac{g \cdot (M+m)}{M \cdot \ell} & 0 \end{pmatrix} \cdot \begin{pmatrix} x \\ \dot{x} \\ \varphi \\ \dot{\varphi} \end{pmatrix} + \begin{pmatrix} 0 \\ \frac{1}{M} \\ 0 \\ \frac{-1}{M \cdot \ell} \end{pmatrix} \cdot u$$

In order to stabilize the linear state space system a first control technique, the PID-control (Sontag, 1998) can be applied, in which the motor force u is chosen as a weighted sum of the generalized coordinates (proportional control), its time-integral (integral control) and its time-derivative (derivative control). The parameters for the P-, I-, D-control part are usually determined experimentally regarding some conditions that have to be fulfilled to generate asymptotic stable solutions for the linearized system. Based on the *PD-control approach*, one can analytically solve a linear differential equation of second order to elaborate constraints for the control parameters k_P and k_D in order to stabilize the Segway. Furthermore, an explicit Euler-method visualizes the control process of a Segway, which was implemented in GeoGebra.

Technics module: Real results and situation model

Even though the implementation of a simulation in GeoGebra is some kind of a technical product, a more ambitious technical approach is to combine the theoretical results with a practical control of a Lego Mindstorms® Segway. This can either be done by using preconceived Lego Mindstorms® robots and balancing programs (Valk, 2014), or by developing a practical control in Lego Mindstorms®

School projects

As a result of the two-day teacher training 5 school projects took place in summer 2018. The structure and content focus of each project was different based on the learning group, the supervision and the time framework of the project days. The following table summarizes the school projects briefly:

<i>School and time framework</i>	<i>Participating students</i>	<i>Supervisors</i>	<i>Content focus</i>
2 days at a grammar school in Bolanden	24 students (4 female, 20 male) of Grade 10 and 11	1 teacher and 1 teacher student, as well as the teacher trainer	<ul style="list-style-type: none"> a) PD-control b) Functional principle of a gyroscope c) Video analysis of Segway movements
2 days at a vocational school in Wissen	16 students (7 female and 9 male) of Grade 12	2 teachers and the teacher trainer	Video analysis of a fastest Segway tour through a given course
3 days in a grammar school in Mainz	17 female students of Grade 12	1 teacher, 1 colleague and the teacher trainer	<ul style="list-style-type: none"> a) PD-control b) Taylor-approximations c) “Modern curve sketching” by using video analysis of Segway movements d) Shortest paths for Segway tourist tours in Mainz
3 days in a vocational school in Kusel	18 students (2 female and 16 male) of Grade 12 and 13	1 teacher, 1 colleague and the teacher trainer	<ul style="list-style-type: none"> a) PD-control b) Explicit-Euler-method in GeoGebra c) Control of a Lego Mindstorms-Segway
3 days in a grammar school in Daun	13 students (5 female and 8 male) of Grade 12	2 teachers, 2 teacher students, 1 colleague and the teacher trainer	<ul style="list-style-type: none"> a) PD-control b) Explicit-Euler-method in GeoGebra c) Euler-Lagrange-formalism

Table 1: The resulting 5 school projects

Preliminary results

In our point of view, considering the brief exposition of the resulting school projects, one can assess the design of the teacher training successful concerning the implementation of *different* interdisciplinary STEM-modelling projects by teachers and teacher students. The focus of research is set on the investigation of effective factors and obstacles of the teacher training (i), as well as of the school projects (ii), such that this quite ambitious modelling project can be implemented at school. Therefore, the participants were interviewed individually after the teacher training and after their school projects. The process of content-structuring qualitative content analysis has started by analyzing all interviews along the main categories of effective factors, obstacles and assessment of the teacher training and school projects, as well as along school dependent factors, or the meaning and experience towards modelling projects by teachers in their daily life work. In this section we will give an insight into preliminary results, mainly considering effective factors and obstacles.

Effective factors

The analysis of effective factors was done by analyzing once theoretical core features of professional development like the content focus of the training, the active learning during the teacher training, the coherence, and the collective participation (Desimone et al., 2002; Lipowsky, 2010; Wilson, 2013) and secondly indicate effective factors inductively by elaborating sub categories during the analysis of the interviews. The first results hint that most of the teachers who wanted to implement a STEM-modelling project with their students reported that it is very helpful for them that they know that the teacher trainer will support them during the project days. By this fact they know that they can ask the teacher trainer for support if they feel unsure in supervising the project. Furthermore, the teachers indicated that the mathematical and physical background of the STEM-modelling project is very profound, so that their students get an insight where mathematical concepts are used in real-life situations (content focus). On the other hand, based on the teacher training, they feel sure when elaborating the physical and mathematical concepts with their students (active learning). Some of the teachers reported that they had a lot of fun during the teacher training to learn mathematical and physical concepts of university level (content focus). Beside the theoretical background of the functional principle of a Segway, many teachers reported that the simulation of the functional principle in GeoGebra is very useful for their students, so that they get a better understanding of the mathematical background, when they can compare their theoretical results with a simulation (coherence). The most important factor concerning the implementation of a STEM-modelling project however is, that teachers have seen a concrete project concept for an authentic real-life context, which can be described by mathematical concepts, which their students are able to learn with their knowledge (content focus). Finally, teachers indicate that it was very helpful for them to explore a specific modelling project, which can be implemented at school (content focus).

Obstacles

Since the implementation of this STEM-modelling projects requires a profound mathematical, physical and technical knowledge, most of the teacher reported that this project is very ambitious and complex to implement with students of Grade 10 to 12. As the description of the physical and

mathematical modules show, it does not surprise that teachers indicate that the advanced level of the project is an obstacle for them and their students. Furthermore, some teachers indicated that they don't have any experience concerning the work with Lego Mindstorms[®]. Since the teacher training was designed with phases in which the teacher could work on their own ideas, they got an insight in technical and theoretical obstacles during the working phase. In addition to that fact, almost every teacher reflected that it is quite hard to prepare the modelling project, since the possible questions, that students might ask themselves in the project can't be foreseen.

Discussion and Outlook

The short description of the school projects and the section of the preliminary results point out that interdisciplinary STEM-modelling-projects can be implemented by teachers after a respective training. Although the analysis process of the interviews by the method of qualitative content analysis has not been finished yet, there are some hints that some of the theoretical effective factors for professional development, namely content focus, active learning, collective participation and coherence (Desimone et al., 2002; Lipowsky, 2010; Wilson, 2013), were also effective factors for the implementation of interdisciplinary STEM-modelling-projects. The first results of the analysis show that main effective factors for the implementation of interdisciplinary STEM-modelling-projects are the collective participation at the teacher training and the following collaborative supervision (i), the possibility of implementing different projects based on the context Segway (ii), the exposition of a concrete modelling-project (iii), the motivating product of a Segway (iv) and the support of the teacher trainer during the school projects (v). Furthermore, the teachers indicated that the teacher training was a necessary condition for the implementation of their school projects. The participants of the teacher training reported the deep mathematical and physical knowledge, which is necessary to supervise the project (i) as the main obstacle. The main obstacles during their implementations were the supervision of open-structured project lessons (ii) and a non-fitting learning group for the interdisciplinary school project (iii). Besides the first analysis of effective factors and obstacles of the teacher training, one main open question still is how to support teachers such that they are confident enough to implement STEM-modelling projects on their own. In order to answer this question, we asked teachers during the interviews to report us necessary conditions to implement further STEM-modelling projects in future. Fortunately, almost every teacher who successfully implemented their project reported that he or she has the principle intention to implement further STEM-modelling projects in future. First hints for necessary conditions for the implementation of further STEM-modelling projects are the collective support of colleagues during the project days and the external support, for example by offering specific teacher trainings, or the external support during the project days. Finally, it has to be stressed that the focus of this work is not on the implementation of modelling activities in *regular lessons*, since from our experience this complex and interdisciplinary STEM-modelling project is recommended to be implemented in project days.

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