PCK for introductory mechanics pre-service teachers in a conceptual lab

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Abstract. The Physics School Experiments Laboratory (PSE-lab) lab at the University of Vienna aims to enhance pre-service teachers’ pedagogical content knowledge (PCK). In this paper we present a design-based research (DBR)-project which we use to develop and evaluate the mechanics section of this lab course. Attendees of the PSE-lab are pre-service physics teachers in the 4th semester of their studies for a Bachelor of Education. Within this lab course pre-service physics teachers learn introductory mechanics with a non-traditional teaching-learning sequence, starting with two-dimensional dynamics. The present project keeps track of pre-service teachers’ conceptions and explores their growth in terms of PCK during four units, 90 minutes each, of PSE-lab. The hypothesis is that, while following the new content structure for introductory mechanics, pre-service teachers will develop a deeper understanding of Newton’s laws on the one hand and on the other hand they will gain insights on how to implement such a structure into their own future teaching. Qualitative analysis of pre-service teachers’ interviews is used to characterize pathways of PCK-development. Despite this short intervention of six hours we have seen clear evidence in pre-service teachers’ early PCK development.

1. Introduction
Pedagogical content knowledge (PCK) has received much attention in recent years due to teachers’ impact on students’ learning (Lipowsky 2006). By putting more emphases on pre-service teachers and their courses at university level, the opportunity is given to increase teachers’ PCK before starting as practitioners. However, there are few research projects describing early stages of pre-service teachers’ developing PCK. Although pre-service teachers’ PCK is assessed professionally with tests and inventories, learning opportunities during their university studies are rarely documented in detail. The present paper describes the development of such a learning opportunity for pre-service teachers within the Physics School Experiments lab course (PSE-lab).

2. Theoretical background
Pre-service physics teachers are to learn not only physics and pedagogy, but also develop a variety of skills and aspects of pedagogical content knowledge (PCK). “Teaching is demanding and difficult mental and physical work that only the most well-educated and mentored professionals can accomplish. PCK is an attribute that teachers develop, and it cannot be found among mere subject matter experts or among those who are ‘good with kids’” (Shulman 2015). Nearly 30 years ago Shulman conceptualized a teacher’s knowledge base as complex and broad-ranging, comprised of subject matter knowledge, curricular knowledge and subject matter for teaching, consisting of seven distinct bases (Shulman 1987, p. 8). Numerous further conceptualizations have been found in the meantime as Gess-Newsome (2001) describes systematically in her book. Implications for science education are discussed (Gess-Newsome & Lederman 2001), at the same time as conceptualization of teacher’s
knowledge bases went on. Lee (2007) similarly found seven categories through which experienced teachers’ PCK could be described. Researchers are convinced that PCK is not only experimental knowledge acquired through classroom teaching but also an “integrated set of knowledge, conceptions, beliefs, values which teachers develop in the context of teaching situation” (Lee et al. 2007). The present project deals with pre-service physics teachers and not with practitioners. We conceptualized a pre-service teacher’s knowledge base for physics teaching comprising six main parts (see Krumphals 2017):

1. General knowledge of learning processes (e.g. motivation, context, nature of science);
2. Knowledge about evaluating learning processes (e.g. cognitive levels of pupils’ answers, diagnosis of learning difficulties);
3. Knowledge about how to plan learning processes (e.g. choosing adequate content);
4. Knowledge about the general framework (e.g. goals of physics learning, curriculum);
5. Knowledge of pupils’ learning processes (e.g. pupils’ beliefs, content specific learning difficulties, motivational factors);
6. Knowledge about implementing experiments (e.g. role of classroom experiments, demonstration and learning effectiveness of experiments).

Within the PSE-lab we want to facilitate only two bases, number three and number six in the latter numeration. Pre-service physics teachers are to learn about how to plan learning processes and they shall gain knowledge about implementing experiments in such a way as to enhance their future middle school students’ learning.

Educational Reconstruction for Teacher Education

Pre-service teachers retain their own beliefs about their future students’ preconceptions, representations of subject matter and perception of teaching. Van Dijk presented a research model to study science teachers’ PCK (Van Dijk & Kattmann 2007). Within her Educational Reconstruction for Teacher Education (ERTE) framework, teachers’ knowledge is related to developing learning activities for students (pupils) which includes the design of teaching-learning sequences, the study of students’ pre-scientific conceptions, and subject matter analysis.

These three main parts are all subject to research: 1) the learner’s perspective, 2) the content to be learned, and 3) the learning environment itself. Our idea is the development of a learning environment on the bases of learners’ perspective (beliefs and difficulties with a specific physics content) and expert’s opinion on subject matter (content) which should be learnt. At the University of Vienna, we didn’t develop a learning environment for pupils, but on a higher level, we started designing a university course for pre-service teachers, the Conceptual Lab in Introductory Mechanics.

Educational Ideas for a Conceptual Lab

Fig. 1. Educational Reconstruction of pre-service physics teachers’ Conceptual Lab in Introductory Mechanics
Fig. 1 shows on the learners’ side (right), pre-service teachers’ beliefs about teaching and pedagogical content knowledge. This first edge of the triangle was investigated by Krumphals (2017) in her Ph.D. studies. On the content side (left), there is a Mechanics Curriculum (Wiesner et al.) for pupils, which was evaluated in Germany (Tobias, 2010). Future teachers shall know about empirically evaluated curricula and the specific structure of content matter, this is seen as one part of their PCK. Therefore this Mechanics Curriculum for pupils, represented in a booklet (Hopf et al. 2011), was elected to represent the learning content for physics pre-service teachers. On the top, the third edge of the ERTE framework triangle, there is the developing learning environment, which is represented by the Physics School Experiments laboratory and especially four units called the Conceptual Lab in Introductory Mechanics. Our hypothesis is that, while following the new content structure for introductory mechanics with this booklet, physics pre-service teachers will develop a deeper understanding of Newton’s laws on the one hand and they will gain insights on how to implement such a structure into their own future teaching on the other hand. We investigate the influence of this new learning opportunity on pre-service teachers’ PCK.

3. Method

Design Based Research
The present design based research project (DBR Collective, 2003) focuses on pre-service teachers’ development of PCK and takes their conceptual understanding in mechanics into account. This project keeps track of pre-service teachers’ conceptions (written protocols, Force Concept Inventory (FCI)) and explores pre-service teachers’ gain on PCK (interviews) during an six hour teaching-learning sequence in introductory mechanics (four units of Introductory Mechanics).

Following this method several cycles of design, enactment and study were undertaken in order to find proto-theories of learning.

Initial research plan
Using the framework of ERTE we related research from our group about pre-service physics teachers’ ideas and beliefs during their studies at University of Vienna (Krumphals & Hopf 2012) to a Mechanics Curriculum (Hopf et al. 2010). Built upon these results a new teaching-learning sequence for pre-service teachers was implemented in the conceptual lab (see Fig. 1). We intend to describe parts of pre-service teachers’ PCK and their learning strategies in the conceptual lab.

Conceptual Lab for Physics School Experiments
Physics School Experiments (PSE) lab encloses a number of units and topics on teaching physics at secondary school. It aims at enhancing pre-service teachers’ PCK as getting conceptual understanding in mechanics especially for school classes. Pre-service teachers will get an experimental perspective on physics concepts and come to recognize that experiments performed in the classroom generally have a different purpose than those performed in conducting scientific research. Pre-service teachers are expected to be familiar with the national high school curriculum for physics. Prior to the lab session they have to select relevant school experiments. In the lab, these experiments are conducted with typical school apparatus. During the lab, pre-service teachers reflect together with supervisors on the function of their selected experiments for middle and high school physics teaching. At the same time teaching goals and the Austrian science education standards play a major role. A deeper reflection on learning efficacy of school experiments is done in a seminar afterwards. Fig. 2 gives an overview about each unit of the PSE lab and summarizes crucial goals of each part of the lab like, preparation work, experimental work and writing exercises.
Fig. 2. Design of each unit within the Physics School Experiments lab. The term “pre-scientific concepts” means, that pre-service teachers describe misconceptions their future students will likely hold.

Introductory Mechanics – Description of the Design

At the University of Vienna pre-service physics teachers attend the Physics School Experiments Laboratory, PSE-lab in the 4th semester of their Bachelor studies. During this PSE-lab, they engage themselves with a non-traditional teaching-learning sequence in introductory mechanics (Hopf et al. 2010). This alternative content structure includes the key idea of starting with two-dimensional dynamics, for a better understanding of Newtonian mechanics (Tobias 2010).

Four units, 90 minutes each, are to be attended chronologically:

- M1 Description of motion
- M2 Newton’s first law
- M3 Newton’s second law
- M4 Newton’s third law

Pre-service teachers use a mechanics booklet (Hopf et al. 2011), initially designed for (10-12 year old) students in introductory mechanics.

In Design Cycle 2 a compulsory activity was added: Three writing activities to reflect on the mechanics curriculum and the material (Mechanics Booklet).

Lab journal entries, so-called protocols are written after each unit (M1-M4) to prepare for future experimental classroom activities.

Goals within the four units of PSE Lab

The main goals are that pre-service teachers learn about the content structure of this teaching-learning sequence as well as knowing how to implement experiments to enhance their students’ learning. Our hypothesis is that, while strictly following the new content structure for introductory mechanics, pre-service teachers will develop a deeper understanding of Newton’s laws as well as gain a better perception of how to implement such a structure into their own teaching. In short, we expect that learning to use a proven teaching experiment (‘recipe’) will help the pre-service teachers to gain PCK effectively.

Design Cycles

As the project is a DBR project, it aims at gaining proto-theories of learning. Our question is: How do pre-service physics teachers at the University of Vienna acquire PCK in PSE lab?

Continuous cycles of design, implementation and analysis are needed to give an answer to this question (see Fig. 3). After each cycle relevant implications for teaching in the PSE lab are communicated with instructors and feedback is given by pre-service teachers. This process allows an evaluation of the design in this authentic framework of a lab.
Fig. 3. Timeline of DBR Cycles: winter semester (WiSe) 2014, summer semester (SuSe) 2015 and winter semester 2015. Numbers represent pre-service teachers which were interviewed, usually there are around 20 pre-service teachers in each lab course

Design Cycle 1.
In winter semester 2014 first cycle started with one main research question: How do pre-service teachers work with the Mechanics Booklet? Experiments were documented by each pre-service teacher in a laboratory journal (protocol). To assess the development of PCK, the author 1) analyzed these journals, 2) observed the pre-service teachers in class during the four mechanics units, and 3) conducted guided interviews with three pairs of pre-service teachers before and after the lab and analyzed interviews with qualitative content analysis. The details and results of this assessment are reported in Wolny & Hopf, 2016.

Design Cycle 2.
First change was implemented in summer semester 2015, pre-service teachers handed in their protocols in pairs, having written a protocol collaboratively. Guided interviews (two groups of two pre-service teachers) before and after the lab were conducted and analyzed with qualitative content analysis. A new question arose: What helps physics pre-service teachers to reflect more on the Mechanics Booklet?

Design Cycle 3.
In winter semester 2015 two pairs of pre-service physics teachers worked together in teams (two pairs of pre-service teachers together) during the lab. Reflective questions about the Mechanics Booklet and about the mechanics curriculum had to be answered before attending the lab. Pre-service teachers handed in their protocols in pairs, having written a protocol collaboratively. Guided interviews (each pre-service teacher on his/ her own) before and after the lab were conducted and analyzed with qualitative content analysis.

Interview analysis
Within the interview guideline pre-service teachers were not only asked to describe a possible learning path for mechanics (concept map) but also to reflect on fictitious classroom activities. In the interview before the lab there was only one prompt (see Fig. 4 on the left.), whereas after attending the lab interviewees were given two different prompts to comment on differences.
As not all of the pre-service teachers finished all parts of the conceptual lab (M1-M4) in sequence, and the interviews were conducted voluntarily, the number of actual analyzable interviews varied each semester. In winter semester 2014 there were 6 out of 17 pre-service teachers interviewed, in summer semester only 4. During the main study in winter semester 2015 pre and post interviews with 14 out of 22 pre-service teachers were conducted (see Fig. 3).

4. Results
The first study of pre-service teachers’ developing pedagogical content knowledge was conducted in 2014 (Wolny & Hopf, 2016), followed by a redesign of the teaching-learning sequence (four units on introductory mechanics of Physics School Experiments laboratory (PSE-lab)) and a second study in 2015. Depending on pre-service teachers’ prior teaching-experiences and commitment during the PSE-lab, they describe learning settings in a more professional way after the lab, using terminology, physics concepts and correct descriptions in their interviews. Knowledge about implementing and arranging learning-settings is broadened, whereas the conceptual understanding is only slightly enhanced, shown with a Hake’s gain of 0.2 on FCI.

Development of PCK
In interviews before attending PSE-lab pre-service teachers recognized only a mathematical approach and the importance of language for teaching sequences. They very rarely formulated alternative learning setups, but wanted to look into the physics textbook and read the curriculum. Often interviewees mentioned acceleration and forces as concepts to start teaching introductory mechanics.

In post-interviews pre-service teachers recognized the importance of starting introductory mechanics with time and position and elucidating a concept of velocity as a term for speed and direction. Scaffolding in introductory mechanics was described with concrete examples of experimental setups. Some pre-service teachers already mentioned students’ views and problems and combined teaching sequences with examples from everyday life.

The material used in the four introductory mechanics units, especially the Mechanics Booklet, is highly appreciated. Pre-service teachers like to get an insight in how implementation in teaching-sequences is arranged. It seems that they have a better guideline, time management and orientation to design experimental activities for a given context and physics topic. Design Cycle 1 showed that at this early stage of studies (4th semester of Bachelor studies) pre-service teachers weren’t able to reflect on the materials independently. Design Cycle 2, underwent a smaller change due to changing instructors in the PSE-lab. Pre-service teachers were working on protocols collaboratively. This collaborative work in pairs was maintained and even elaborated in the following design cycles.
In Design Cycle 3 mandatory reading exercises and reflecting questions were added to the former design of the lab-units (Feedback from Cycle 1). Two pairs of pre-service teachers worked together on one unit as this supported discussion and reflection on possible student-prior knowledge (pupils’ pre-scientific concepts) and key ideas of the curriculum (Feedback from Cycle 2). The collaborative work on each unit is favored by pre-service teachers, but the learning progress is still dependent on the individual dedication to work in the PSE-lab.

5. Discussion & conclusions

Due to changes in the University Curriculum and changing instructors in the PSE-lab, many important factors for successful learning are also under constant change. But there seem to be at least three facts supporting a positive early development of PCK.

- The Mechanics Booklet (middle school students’ version) is a helpful tool for pre-service physics teachers to plan learning processes for their future students
- Collaborative work in teams (four pre-service teachers) enhances discussion and reflection on pre-scientific conceptions
- Knowledge of mechanics curriculum helps pre-service physics teachers to implement experiments in a teaching-learning sequence

Taking content knowledge into account, pre-service teachers’ knowledge base at the beginning of the 4th semester varies a lot. The four units of introductory mechanics showed a gain in conceptual thinking in mechanics but an even higher impact on PCK, according to the concepts of how to plan learning processes in introductory mechanics and how to implement experiments, which supports our hypothesis.

The four units M1 to M4 should be done chronologically which is not always possible within the lab setup. We cannot make an assumption about learning outcomes in other settings so far. We observed, that leaving out the guiding set of reflection questions, leads to experimenting pre-service teachers without thinking during their lab work. While reading through protocols, supervisors can tell which pre-service teacher did prepare for reflection questions or not.

Further analysis is needed to combine findings of interview-analysis with written protocols of each pre-service physics teacher.

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