Teacher students’ beliefs about teaching physics and their teacher education

IKrumphals1, M Hopf2 and C Haagen-Schützenhöfer3
1University of Graz, Department of Physics Education, Austria
2University of Vienna, Austrian Educational Competence Centre Physics (AECCP), Austria

Abstract. It is beyond doubt that teacher education plays a crucial role in the development of the educational system. Following the educational reconstruction for teacher education model [1], a clarification of teacher students’ beliefs seems mandatory in order to improve the education of future physics teachers. The main aim of this research project was to determine beliefs of physics teacher students about high quality physics instruction at school. Therefore, interviews with 23 physics teacher students and an additional case study with six teacher students were conducted. Several beliefs of teacher students’ such as experiments rise students’ interest and with the help of experiments physical contents can be memorized better were found.

1 Introduction
It is undisputed that teachers’ pedagogical content knowledge (PCK) plays an essential role in the creation of a successful and fruitful learning environment. One of the first empirical hints about the relevance of PCK was given by the COACTIV study in mathematics education, in which researchers found that teachers’ distinct PCK influences pupils’ achievements to a high degree [2]. A transfer of these research outcomes to the area of physics cannot be done without empirical evidence. Although different projects have worked on replicating these results, it seems that in physics classes processes are different than in mathematics classes (see e. g. [3, 4]). Therefore, it appears to be of great importance to investigate how this basis of professional knowledge can be fostered in teacher education.

Following the model of didactical reconstruction [5], structure of content and learner perspectives have to be taken into account when designing learning environments. Prerequisites for designing a learning environment in teacher education for physics didactics are firstly, knowledge about the design of learning environments for school and, secondly, knowledge about the learners’ perspective (in this case future teachers’ perspective). Latter is the focus of the presented study: Interviews with 23 students at the University of Vienna (Austria) were conducted to find out more about teacher students’ beliefs about teaching physics and their teacher education. Another objective of our study was to investigate student teachers’ beliefs about experiments as well as changes of their beliefs during their teacher education. Therefore, six focus interviews with physics teacher students were conducted at the beginning of and three years into their studies. Within the study a broad category system of physics teacher students’ beliefs was developed as basis for further development of physics didactics courses within tertiary education [6]. This paper focuses on presenting physics teacher students’ beliefs about their teacher education and about experiments in physics classes.
2 Theoretical Background

In the last two decades teachers’ professional knowledge has come more and more into research focus. The discussion about teachers’ knowledge and its components was initialized by Shulman [7, 8] who first mentioned the importance of teachers’ professional knowledge. Additionally, he was the first who described PCK as a separate essential knowledge domain of teachers. Shulman originally established seven categories of teachers’ knowledge. In science education, content knowledge (CK), pedagogical knowledge (PK) and pedagogical content knowledge (PCK) are seen as main domains of teachers’ professional knowledge [9].

Besides knowledge teachers need profound competences for teaching. According to Riese [10], who based his model on the concept of competence by Weinert [11], teachers’ professional action competences consist of two main parts: teachers’ professional knowledge (divided into CK, PK and PCK) and motivational, volitional and social dispositions and capabilities (separated in beliefs systems and motivational orientations). Another indication of the potential role of beliefs in classroom is given by Gess-Newsome’s model of teacher professional knowledge and skill (TPK&S) [12]. In this model teachers’ personal PCK is seen as generated in classroom practice. Therefore, subject specific pedagogical knowledge (TSPK) – knowledge about teaching a specific topic – must be transformed into teachers personal PCK for the use in classroom. While several attempts haven been made to measure TSPK, there are no procedures for measuring personal PCK because it is generated directly within classroom intervention. The transformation of TSPK into personal PCK is complex and it is assumed that within this process teacher beliefs, orientations, prior knowledge and context act as amplifiers and filters for personal PCK. Hence, this shows that other aspects connected to teachers’ professional knowledge must be taken into account for further discussion about teacher education.

An aim of this study is a contribution to an enhancement of physics teacher education on the level of designing physics didactics courses. The ERTE Model (Educational Reconstruction for Teacher Education Model) of Van Dijk and Kattmann [1] forms a main basis of our study. This model describes a didactical reconstruction of second order. The design of learning environments (for school) and PCK-studies (knowledge about learners’ perspectives) play a major role in the educational construction of teacher education. Van Dijk and Kattmann [1] assume, “that the content for teacher education needs to be ‘reconstructed’ for teaching’”. Learners’ preconditions must be taken into consideration for reconstructing learning environments in physics didactics. Thus, beliefs about teaching and learning must be taken into account for the design of learning environments in teacher education.

The term beliefs frequently occurs in research. However, there is no consensus on the definition and the concept of beliefs is often used vaguely [13]. According to Smith and Siegel [14], knowledge and beliefs are separated constructs which interact and can not be isolated from each other. Knowledge is based on objective facts accepted as scientific knowledge and beliefs are naive ideas based on subjective valuation and judgement [15]. Moreover, beliefs are presumed to drive a person’s actions [15, 16]. Beliefs are derived from a cognitive process and/or from personal observation [17]. In contrast to knowledge, beliefs influence the way an individual deals with tasks and problems [16]. Therefore, teachers make decisions and act in classrooms influenced by their beliefs [18]. Thus, it seems necessary to investigate beliefs of future physics teacher students and support future teachers’ professional development within teacher education.

The investigation of teacher students’ beliefs which may play a further role in instruction in teacher education is purpose of this study. Following this objective we use a very broad definition of beliefs and follow the definition of Markic [19] who defines beliefs as followed: “Beliefs are separated from knowledge and refer to all mental representations that teachers or student teachers hold (consciously and unconsciously) in their minds that influence, to a certain extent, their (potential) behavior as teachers of Science. From this perspective, all beliefs are personal constructs influenced by experience, knowledge,
Previous research about beliefs about teaching and learning already identifies various categories of beliefs. Kember [20] indicated several categories of beliefs about teaching found in 13 studies. He categorized the beliefs in two levels, the two higher level beliefs being ‘teacher-centered/content-oriented’ and ‘student-centered/learning-orientated’. Among these two main categories, sub-categories like imparting information and transmitting structured knowledge refer to teacher-centered/content-oriented beliefs. Facilitating understanding, conceptual change and intellectual development are counted as student-centered/learning-orientated beliefs. The two higher level beliefs are considered as firmly established and a transition between them is regarded to require a fundamental change. In between the sub-categories of teacher-centered and student-centered beliefs the recognition of a necessary student teacher interaction/apprenticeship is identified as separate sub-category [20]. In terms of physics classes, studies about beliefs about experiments in physics classes (e.g. [21–23]) uncovered e.g. that experiments are seen as interesting for students [21], a connection between theory and practice [23] and important for physics instruction [22]. Therefore, several beliefs were identified, but the question how these beliefs may change during teacher education still remains unanswered.

The presented study aims at uncovering several beliefs which pre-service-teachers have concerning physics education (limited to the University of Vienna, Austria), in order to use this broad information about common beliefs which potentially influences the process of knowledge acquisition of our students, in physics didactics courses. The knowledge of our physics teacher students’ beliefs forms the basis for the future development of learning opportunities in physics didactics. Additionally, we were interested to deeper investigate teacher students’ beliefs. Therefore, a second focus of our study lies on the investigation of beliefs concerning experiments in physics classes and their changes during physics teacher training at the university. Thereby, we follow the objectives to investigate how static these beliefs are and to collect hints about possible influencing factors for changes in beliefs.

The focus on beliefs about experiments in physics classes was chosen for two main reasons: First, the results of the main study showed a gap between teacher students’ beliefs and the scientific view of educational research on experiments in physics classes. Second, we assumed that physics didactics courses might change these beliefs.

3 Research Design

In this section we describe the design of the study, followed by the description of the sample and the developed category system.

3.1 Design of the study

As mentioned above, the design of physics didactics courses requires knowledge about the subject matter (in this case physics education) and about the learners’ perspectives (here physics teacher students) [1]. This study focused on getting a broader and deeper insight into physics teacher students’ beliefs at the University of Vienna (Austria). As the whole study is very broad and the space of this paper is limited, we will focus on the following research questions (RQ) in this article:

1a) Which beliefs do physics teacher students have about high-quality physics instruction at school?

1b) Which wishes do physics teacher students have concerning their teacher education?

The study consists of one main study and a focus study. The main interview study was conducted first to get an overview of teacher students’ beliefs. This was followed by a second phase, a focus study, to get deeper insight into teacher students’ beliefs. The aim was to extract factors for the future improvement of physics didactics courses. Consequently, the main study was a cross-sectional study conducting semi-structured interviews with 23 teacher students of all semesters to detect teacher students’ general beliefs concerning teaching and learning of physics as well as their wishes regarding their teacher education. The
interviews lasted approximately 50 minutes, were transcribed and qualitative content analysis was done [24]. Within this study, the aim was to create a category system covering all found beliefs. Several indications of the first phase, especially unwanted students’ beliefs about experiments, led to the research emphasis of the focus study in which the research question was:

2) Which beliefs do physics teacher students hold a) concerning the role of experiments in physics classes and b) the learning effectiveness of experiments?

More precisely, we were interested in beliefs regarding functions, learning efficacy, implementation and objectives of experiments in physics classes. To get insight into changes of physics teacher students’ beliefs during their studies a further research question was added:

2c) Which differences (concerning physics teacher students’ beliefs about experiments) can be detected after six semesters of their studies?

Consequently, six case studies were conducted within the focus study. The main purpose was the investigation of physics teacher students’ beliefs of experiments in physics classes. Six teacher students were interviewed at the beginning of their teacher education and then again approximately three years later (with nearly the same interview guideline) to detect differences in their beliefs. Data analysis followed the same procedure as in the main study. The interviews of the focus study were transcribed and analyzed by the means of qualitative content analysis.

3.2 Sample
The main study was conducted with $n = 23$ ($♀ = 11, ♂ = 12$) physics teacher students. On average the students were in their 5.09 ($σ = 3.19$) semester. Hence, a broad distribution over the students’ progress in studies was reached. Additionally, the interviewed students exhibited a great variety of their second subject of teacher education, all in all 10 different subjects were stated. Mathematics ($n = 8$) was the most combined subject with physics. The focus study included six teacher students ($♀ = 4, ♂ = 2$) first interviewed at the beginning of their studies (1st semester) and then 2.5-3 years later. All participating students in the main and the focus study took part voluntarily.

3.3 The category system
The category system in the main study consisted of 7 sections, according to the topics of the interview guideline (beliefs about: 1) the teaching profession, 2) physics classes in general, 3) experiments in physics classes, 4) wishes for the pre-service teacher training, 5) difficulties concerning physics teaching, 6) physics didactics in general, 7) importance of CK, PCK and PK within their studies and for their future teaching). These 7 sections consist of 28 main categories and 148 sub-categories. Within the focus study 23 sub-categories were added. The reliability of the category system was checked by coding at least 15 per cent of citations by a second expert. The overall intercoder-reliability is $κ = 0.86$ ($κ > 0.7$ in terms of each sub-category). Additionally, the intracoder-reliability was calculated (between first and second data analysis two years passed). The Cohens-kappa for the intracoder-reliability is $κ = 0.93$. According to Landis and Koch [25] values between 0.61 and 0.80 show a moderate level of agreement and values between 0.80 and 1.00 indicate a very strong level of agreement. Therefore, the category system is seen as reliable.

Within this paper we will present selected results addressing the above mentioned research questions. Therefore, the following sub-categories of the sections – found in the main study and in the focus study – will be presented (see Table 1).

| Table 1: Physics teacher students’ beliefs – presented main categories in this article |
|-----------------------------------|-----------------------------------|------------------|
| Section (number of main categories) | Presented main category (number of subcategories) | Addressed RQ |
| 2 (4) | Beliefs about high quality physics instruction (13) | RQ 1a |
In terms of RQ 1b, we additionally report the most important sub-categories of other main categories of section 3 in order to broadly address our research question. Therefore, we report about students’ experiences with experiments in school and their beliefs about the use of experiments in physics classes.

4 Results

In this section we present selected results of the main and the longitudinal case study. Mainly we focus on presenting results in terms of physics teacher students’ beliefs about high quality physics instruction, physics teacher students’ wishes for their didactics courses in physics teacher education, their beliefs about the role of experiments and about the learning effectiveness of experiments.

Starting with results about beliefs of high-quality physics instruction, addressing RQ 1a, gives an overview of the found sub-categories. General beliefs of physics teacher students about high quality physics instructions are, for example, ’arouses interest’, ’refers to everyday life’ and ’contains experiments’. Less mentioned are aspects about learning e.g. ’is a phase of effective learning’ is mentioned just by three students.

Concerning RQ 1b the identified sub-categories of physics teacher students’ wishes for their didactics courses are shown in Figure 2. The most frequently mentioned wishes are ’input covering best practice examples, practical advice, guidelines’ (19/23), ’more teaching experience/role playing/micro-teaching’ (17/19), and ’learning opportunities for gaining knowledge about theories on physics instruction and lesson planning’ (17/23). Additionally, it is very important for physics teacher students to recognize any relevance for their future teaching in covered contents within their courses (13/23). Furthermore, knowledge about several teaching methods seem to also be very important for teacher students. Eleven students mentioned that they want to get to know various teaching methods for their future teaching. In the main study no differences between first year students and their colleagues in higher semesters were detected.
Figure 1. Physics teacher students' beliefs about high quality physics instruction (n = 23) (13 sub-categories of one main category of section 2)
Figure 2. Physics teacher students’ wishes for their physics didactics courses (n = 23) (15 sub-categories of one main category of section 4)

In the focus study the investigation of beliefs concerning experiments in physics class was emphasized. Within the six case studies the following 12 sub-categories of beliefs about the role of experiments in physics classes were found (addressing RQ 2a):

Experiments…
a) create a wow-effect
b) are for illustration of a content
c) link theory and everyday life
d) link theory and practice
e) rise interest
f) rise motivation  

g) activate students during physics class  

h) foster autonomous learning  

i) are part of physics  

j) attract students’ attention  

k) are a variation in teaching methods  

l) enhance precise and scientific working

An interesting fact is that students hardly mention experiments in combination with knowledge gain or learning processes. The interviewed physics teacher students seem to think that experiments automatically have an impact on interest and motivation. When addressing the learning effectiveness of experiments the students express the following beliefs: 'experiments (automatically) have a positive effect on students’ learning outcomes’, 'students learning by simply watching' and 'doing experiments’ and 'experiments support deeper understanding through interlinking of content knowledge'. Additionally, the students think that experiments exert 'automatically', 'through simply watching', 'through simply doing' a long-term memorizing effect on content knowledge. The students mentioned positive aspects of 'teacher-centered’ as well as 'student-centered’ experiments concerning learning effectiveness. Besides, we found that students think that experiments are a good method for addressing different types of learners (it is strongly assumed that the students mean learning types conferring to Vester [26]).

Furthermore, contradictions within students’ beliefs and their perception of experiments in school were found. On the one hand four students mentioned that they learned a lot through experiments they conducted in school and that these experiments helped them to memorize the content better than without experiments. On the other hand, the same four students could hardly remember anything about their experiences with experiments in school or they mentioned at another point within the interview something along the lines of ‘didn’t learn much in school while experimenting’.

Results of the longitudinal study reveal that especially the belief that experiments exert a long-term memorizing effect on content knowledge and about the learning type theory are particularly resilient. All students mentioned the better memorizing effect and still stuck to that belief 3 years later. Likewise, the four students who mentioned the learning types in the first interview showed the same belief in the second interview.

In terms of beliefs about the usage of experiments in physics classes, four students show a slight shift of their beliefs. One student mentioned more functions of experiments in physics class and the three others determined that the pupils must have some knowledge gain while conducting experiments. Furthermore, they said, that the results of the experiments must be discussed to ensure a better learning outcome. In terms of learning effectiveness of experiments, the beliefs of four students changed slightly. One student extended his view that as a teacher he is responsible for making sure that knowledge gained through experiments is more sustainable. Another student shifted his view from experiments conducted by students always being good for their learning processes, to the opinion that strongly guided experiments do not help to foster understanding of physics concepts. The student argued that just following a recipe will not support learning processes. Additionally, one student concluded that just conducting many experiments does not help students learn about concepts in physics (in the first interview she was confident about a positive effect of experiments). The beliefs of two students concerning experiments remained unchanged between their first and second interview.

All in all, indications can be found that changes in beliefs of four students were at least slightly influenced by physics teacher education. Either the students mentioned that they thought differently because of their knowledge gained through their studies or it obviously could be detected that students used concepts (like students’ conceptions) covered in didactics courses in their argumentation. Still, just
slight changes could be found and profound beliefs (e.g. the learning type theory and the memorizing effect on content knowledge) stayed within the students’ beliefs system.

5 Conclusion and Discussion

The general aim of teacher education is to foster teachers’ professional competence, especially focusing on the development of CK, PK and PCK. One of the most important goals of physics didactics courses is to foster the development of physics teacher students’ PCK. In order to provide high quality instruction in physics didactics, educational reconstruction of teacher education [1] is necessary. Following the model of didactical reconstruction, the structure of content as well as the learners’ perspectives must be considered for the design of a learning environment. Therefore, knowledge about learners’ beliefs is needed (see chapter 2). Previous research shows that high quality instruction is seen by teacher students rather as a receptive learning process than a constructive one [21, 27, 28]. Furthermore, Kagan [29] found out that the ideas about good physics instruction stay unchanged throughout physics teacher students’ studies and that these ideas were taken into teaching practice.

In our study, we conducted a first broad cross-sectional interview study (n=23) to detect a broad range of physics teacher students’ beliefs. The derived category system of beliefs forms a basis for the development of learning environments in physics didactics. Additionally, a deeper insight into beliefs of physics teacher students about experiments and the change of these beliefs over the course of teacher education was facilitated. Six students were interviewed at the beginning of their studies and about three years later.

Referring to ¡Error! No se encuentra el origen de la referencia., the results of the main study show that major physics teacher student’ beliefs about high quality physics instruction are, ‘good instruction arouses interest’, ‘refers to everyday life’ and ‘involves experiments’. Within the focus study we found various beliefs about experiments in physics class. Beliefs concerning the role of an experiment in physics class are, among others, that an experiment supports the rise of interest, the rise of motivation and increases the students’ attention etc. Experiments play no or only a minor role in the statements of the students when it comes to supporting students in understanding physics concepts. Our results are in accordance with results of previous studies conducted by Fischler [21], Jonas-Ahrend [22] and Nivalainen et al. [23] who also investigated teachers’ or student teachers’ beliefs about experiments.

Furthermore, our longitudinal-study gives an insight into a possible change of beliefs of physics teacher students. Some beliefs of physics teacher students about experiments seem to be very stable. The learning effectiveness of experiments, especially the attribution of a better memorizing effect of physics concepts, stays resilient over teacher education. Latter appears within a contradiction, since students who mention that they conducted experiments in school cannot remember much or even nothing about them. This underpins the framework theory [30], where beliefs can be independent, do not have to be internally logical and can exist as fragments. Furthermore, we found hints that teacher education influences the changes in beliefs at least to a little extent. Four of our six cases in the longitudinal study showed hints of this influence. As beliefs act as amplifiers and filters [12] within the transformation process of TSPK to personal PCK, beliefs which do not align with scientific knowledge will most likely lead to unwanted results in teachers’ actions. Therefore, didactics courses must support a change of beliefs or a development of adequate and fruitful beliefs for this transformation process.

However, limitations of our study must be considered when interpreting our data. Firstly, we may have dealt in our sample with a positive selection of interviewed students since they took part in the study voluntarily. Secondly, our study was conducted at one university in Austria and results may be different at other teacher training institutions. Thirdly, we only had a small sample especially in the focus study. All evidence we found must be interpreted against the background of these limitations.

Nevertheless, the developed system of categories of physics teacher students’ beliefs provides a profound basis for a didactical reconstruction [1] of future courses in physics teacher education. Teacher
students’ wishes about their studies, e.g. pointing out the relevance of the taught content to their future profession as a teacher, must be addressed in the courses. Finally, in our opinion, teacher education must play a larger role in change of beliefs, since beliefs influence an individual’s actions [16] and, therefore, teachers’ personal PCK and their actions in classroom are influenced through their beliefs [12].

References

[1] Van Dijk E M and Kattmann U 2007 A research model for the study of science teachers’ PCK and improving teacher education Teaching and Teacher Education 23 885–97
[2] Neubrand M and Jordan A 2007 Mathematikbezogenes Lehrerwissen: Konzepte und Ergebnisse aus der COACTIV-Studie Beiträge zum Mathematikunterricht Vorträge auf der 41. Tagung für Didaktik der Mathematik in Berlin (Hildesheim: Franzbecker)
[3] Vogelsang C 2014 Validierung eines Instruments zur Erfassung der professionellen Handlungskompetenz von Physiklehrkräften - Zusammenhangsanalysen zwischen Lehrerkompetenz und Lehrerperformanz (Berlin: Logos Verl.)
[4] Ergönenç J, Neumann K and Fischer H E 2014 The Impact of Pedagogical Content Knowledge on Cognitive Activation and Student Learning. Quality of Instruction in Physics: Comparing Finland, Switzerland and Germany vol 1, ed H E Fischer et al (Münster, New York: Waxmann Verlag GmbH) pp 145–59
[5] Kattmann U, Duit R, Gropengießer H and Komorek M 1997 Das Modell der didaktischen Rekonstruktion: Ein Rahmen für naturwissenschaftsdidaktische Forschung und Entwicklung Zeitschrift für Didaktik der Naturwissenschaften 3 3–18
[6] Krumphals I 2017 Vorstellungen von Physiklehrerinnen und Lehrer über das Fach Physik: Wie lehren sie Physik? (Berlin: Logos Verlag)
[7] Shulman L S 1986 Those Who Understand: Knowledge Growth in Teaching Educational Researcher 15 2 4–14
[8] Shulman L S 1987 Knowledge and Teaching: Foundations of the New Reform Harvard Educational Review 57 1 1–22
[9] Fischer H E, Borowski A and Tepner O 2012 Professional Knowledge of Science Teachers Second international handbook of science education vol 1, ed B J Fraser et al (Dordrecht: Springer) pp 435–48
[10] Riese J 2009 Professionelles Wissen und professionelle Handlungskompetenz von (angehenden) Physiklehrkräften (Berlin: Logos Verl.)
[11] Weinert F E 2001 Concept of Competence: A Conceptual Clarification Defining and Selecting Key Competencies ed D S Rychen and L Salganik (Göttingen: Hogrefe) pp 45–66
[12] Gess-Newsome J 2015 A model of teacher professional knowledge and skill including PCK: Results of the thinking from the PCK Summit Re-examining pedagogical content knowledge in science education ed A Berry et al (New York: Routledge) pp 28–42
[13] Borg M 2001 Key Concepts in ELT - Teachers' beliefs ELT Journal 55 2 186–8
[14] Smith M U and Siegel H 2004 Knowing, Believing, and Understanding: What Goals for Science Education? Sci & Educ 23 6 553–82
[15] Pajares M F 1992 Teachers’ Beliefs and Educational Research: Cleaning Up a Messy Construct Review of Educational Research 62 3 307–32
[16] Bryan L A 2012 Research on Science Teacher Beliefs Second international handbook of science education vol 1, ed B J Fraser et al (Dordrecht: Springer) pp. 477–95
[17] Khader, Fakri, R. 2012 Teachers’ Pedagogical Beliefs and Actual Classroom Practices in Social Studies Instruction. American International Journal of Contemporary Research 2 1 73–92
[18] Richards J C, Lockhart C 1994 Reflective teaching in second language classrooms (Cambridge: Cambridge University Press)
[19] Markic S and Eilks I 2008 A case study on German first year chemistry student teachers
beliefs about chemistry teaching, and their comparison with student teachers from other
science teaching domains Chem. Educ. Res. Pract. 9 1 25–34
[20] Kember D 1997 A reconceptualisation of the research into university academics conceptions
of teaching Learning and Instruction 7 3 255–75
[21] Fischler H 2000 Über den Einfluß von Unterrichtserfahrungen auf die Vorstellungen vom
Lehren und Lernen bei Lehrerstudenten der Physik: Teil 2: Ergebnisse der Untersuchung
Zeitschrift für Didaktik der Naturwissenschaften 6 79–95
[22] Jonas-Ahrend G 2004 Physiklehrervorstellungen zum Experiment im Physikunterricht (Berlin:
Logos Verl.)
[23] Nivalainen V, Asikainen M A and Hirvonen P E 2013 Preservice teachers’ objectives and
their experience of practical work Physical Review Special Topics - Physics Education
Research 9 1 1–17
[24] Mayring P 2010 Qualitative Inhaltsanalyse: Grundlagen und Techniken. vol 11 (Weinheim:
Beltz)
[25] Landis J R and Koch G G 1977 The Measurement of Observer Agreement for Categorical
Data Biometrics 33 1 159–74
[26] Vester F 2001 Denken, Lernen, Vergessen: was geht in unserem Kopf vor, wie lernt das
Gehirn und wann lässt es uns im Stich? (München: Deutscher Taschenbuch Verlag)
[27] Markic S and Eilks I 2007 Vorstellungen von Lehramtsstudierenden der Physik über
Physikunterricht zu Beginn ihres Studiums und ihre Einordnung Physik und Didaktik in
Schule und Hochschule 2 6 31–42
[28] Aguirre J M, Haggerty S M and Linder C J 1990 Student teachers' conceptions of science,
teaching and learning: A case study in preservice science education. International Journal
of Science Education 12 4 381–90
[29] Kagan D M 1992 Professional Growth Among Preservice and Beginning Teachers Review of
Educational Research 62 2 129–69
[30] Vosniadou S 2013 The Framework Theory Approach. International handbook of research on
conceptual change ed S Vosniadou (New York: Routledge/Taylor & Francis Group)
pp 11–30