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Interplay of secondary pre-service teacher content knowledge (CK), pedagogical content knowledge (PCK), and attitudes regarding scientific inquiry teaching within teacher training

To investigate quantitatively the longitudinal relationship between knowledge and attitudes on scientific inquiry teaching, 121 pre-service teachers for teaching biology at the secondary level in Germany and Switzerland were assessed with respect to their content knowledge (CK), pedagogical content knowledge (PCK) and attitudes on teaching scientific inquiry. As part of the teachers' attitudes we measured cognitive beliefs, affective states and self-efficacy. The assessments were conducted during a training session on peer-coaching as a tool for teacher development and scientific inquiry teaching as a method and activity that leads to the development of scientific knowledge. Data of both knowledge tests were IRT-scaled and combined with the data from the attitude questionnaire. To examine the relationship between the different measurements we applied structure equation modelling. The analysis demonstrates that the PCK acquired after the training on teaching scientific inquiry predicts subsequent attitudes. In contrast, prior CK does not affect subsequent attitudes regarding teaching scientific inquiry. Moreover, prior attitudes do not substantially predict subsequent PCK and CK. In addition, prior teaching experience in biology explains individual differences, and self-efficacy attitudes predict changes in attitudes with respect to teaching scientific inquiry by the end of training. To foster positive attitudes toward scientific inquiry teaching, teaching education programs should be designed to broaden PCK.

Keywords: attitudes, content knowledge, pedagogical content knowledge, pre-service teachers, scientific inquiry

Introduction

Research indicates that pupils who participate in inquiry-based activities achieve increased scores on standardised measures of science learning while exhibiting increased interest in and understanding of the nature of science as a social and cultural practice (Furtak, Seidel, Iverson, & Briggs, 2012; Marshall & Alston, 2014; Schroeder, Scott, Tolson, Huang, & Lee, 2007). According to a literature review by Keys and Bryan (2001), evidence suggests that teacher attitudes toward scientific inquiry teaching have an impact on student science learning. Recent research has also demonstrated that teacher self-efficacy beliefs regarding scientific inquiry teaching are related to student learning (Fogleman, McNeill, & Krajcik, 2011; Lumpe, Czerniak, Haney, & Beltyukova, 2011). However, pre- and in-service teachers often carry limited beliefs of scientific inquiry teaching. P. L. Brown, Abell, Demir, and Schmidt (2006) described such narrow views of inquiry as being completely open ended and student driven. This full and open inquiry understanding reinforces perceived problems with inquiry teaching: that inquiry is unstructured and time consuming. Teachers also wrongly associate, e.g., the laboratory experience with knowledge verification and technical skill development (Gyllenpalm & Wickman, 2011; Tesch & Duit, 2004; Wallace & Kang, 2004). Desirable is a pedagogy that engages students in designing and carrying out investigations and learning subject matter as part of a process that is scaffolded by the teacher (Crawford, 2007). Moreover, there is a lack of consensus regarding a single definition of science inquiry teaching (Hanauer, Hatfull, & Jacobs-Sera, 2009). It is expected that the recent shift from teaching science as an inquiry to teaching science as a practice will help teachers better understand what it means to teach science through inquiry (NGSS Lead States, 2013; Osborne, 2014). Few teaching education programmes foster pre-service teachers who develop effective pedagogies for laboratory settings. In turn, some teachers do not know them well have difficulty understanding the benefit of inquiry activities or are not confident in their capacities to properly support students (Abrahams & Reiss, 2012). Beginning teachers encounter several constraints with respect to scientific inquiry when they begin to teach science (Marshall, Smart, & Alston, 2016). Depending on their prior beliefs, knowledge, and understanding, which may or may not have been reinforced during teaching education programs, these constraints affect their teaching of inquiry (Roehrig & Luft, 2004). To support beginning teachers in the implementation of science as inquiry, induction programs that address these constraints are needed. For example, workshops focused on inquiry-focused teaching strategies may provide pedagogical knowledge for individuals who lack these tools for their preparation programs (Luft, Roehrig, & Patterson, 2003). Our 'KUBeX' bi-national research project examines pre-service teacher knowledge of scientific inquiry teaching as formulated in national standards and their attitudes. Pre-service teacher training modules that combined peer coaching and scientific inquiry lesson planning were delivered and evaluated. Planning comprises an important element of classroom practice and is a component of teacher professional knowledge (Gess-Newsome, 2015), whereas peer-coaching is considered a promising learning tool in teacher education (Britton & Anderson, 2010). Feedback from peers should help pre-service teachers reflect on aspects of scientific inquiry teaching (Burton, 2013). Our research was conducted at four universities of teacher education in Switzerland and Germany. Following a presentation of a theoretical outline, we examine different components of pre-service teachers' attitudes and how these components are interrelated. We discuss the development of these attitudes in response to the training and in relation to prospective teacher knowledge, and provide recommendations on teacher education.

Theoretical Background

Scientific inquiry teaching

Twenty-first century skills and abilities in different scientific disciplines are needed to participate in a knowledge-based society (National Research Council, 2012). The role of K-12 education in helping students learn these skills is a subject of current debate. Science is viewed as a promising case because it not only represents a body of accepted knowledge but also concerns processes that lead to the generation of this knowledge (Hilton, 2010). Engaging students in scientific processes (e.g., discussion, argumentation, modelling, representation, and learning through investigation) builds science proficiency (National Research Council, 2012). Scientific inquiry has not been implemented as widely accepted, in part, because of a lack of a commonly accepted understanding of what it means to teach science through inquiry. Recent reforms in the US have expanded the term scientific inquiry to scientific practices to combine the doing and knowing of science (Osborne, 2014). Scientific inquiry is one form of these practices (Bybee, 2011). In this study, the terms scientific inquiry, scientific inquiry teaching or scientific inquiry activities in the science classroom are used to refer to pedagogical approaches that model the general process of investigation that scientists use as they attempt to answer questions regarding the natural world. Several studies favour student-oriented inquiry teaching approaches (Minner, Levy, & Century, 2010); however, inquiry teaching may also be teacher guided (P. L. Brown et al., 2006). Nevertheless, not all inquiry-focused lessons are effective: Teacher-led inquiry lessons appear to have a more significant effect on student learning compared with lessons that are student-led (Furtak et al., 2012).

Numerous national science standards outline inquiry competency expectations. Currently, in many countries, curriculum initiatives and national science standards are imposed to guide and support science teachers in achieving these aims (Kim, Chu, & Lim, 2015; Neumann, Fischer, & Kauertz, 2010; NGSS Lead States, 2013). As an example and a basis for this research, we will discuss the situation for Switzerland and Germany (Kultusministerkonferenz (KMK), 2005; Swiss Conference of Cantonal Ministers of Education (EDK), 2011). The Swiss 21 national curriculum (Deutschschweizer Erziehungsdirektoren-Konferenz (D-EDK), 2015, p. 13) states that occupation with the nature of science implies that students are able to critically engage with the world and related natural laws. It says that this can be realised e.g., through an explicit approach by discussing and reflecting the processes of scientific knowledge acquisition. This refers to scientific inquiry teaching. Bölsterli, Wilhelm, and Rehm (2015) asked teachers in Switzerland what they expect from schoolbooks with respect to experimentation; they determined that the explicit approach is not currently established in Swiss classrooms. Teachers are primarily concerned with whether textbooks contain real-life, fool-proof experiments that may be used for demonstration purposes (Bölsterli et al., 2015). In this traditional sense, experiments are used to broaden phenomena and subject matter. In Germany, new scientific standards have been added to content knowledge competencies in the field of scientific inquiry (knowledge on scientific inquiry, the nature of science, and experimentation skills) (Kampa & Köller, 2016; Neumann et al., 2010). However, similar to Switzerland, the use of open-ended or inquiry-based experiments remains limited in German science classrooms with respect to quality and quantity according to di Fuccia, Witteck, Markic, and Eilks (2012). They claim that science process skills, such as skills that involve posing questions and hypotheses, controlling variables, planning and conducting experiments, and interpreting data, are rarely focused on.

Teachers may disregard forms of inquiry stressed in science standards because of a lack of content knowledge. For example, in several countries, including Germany, pre-service teacher knowledge regarding central inquiry concepts is not consistent with scientific meanings (Forsthuber, Motiejunaite, & de Almeida Coutinho, 2011; Gunckel, 2010). Pre- and in-service teachers often conflate 'experiments' with 'laboratory tasks'; they view them as product-oriented activities rather than research activities (Gyllenpalm & Wickman, 2011; Wallace & Kang, 2004). The transformation of teacher practices in German speaking countries and worldwide towards education systems that develop student understanding of the canon of scientific knowledge and how science functions is a long-term project that will require significant and sustained investment in the continuous professional development (PD) of teachers based on sound research studies (Osborne & Dillon, 2008).

In German speaking countries, there has been limited empirical examination of teacher training in experimental instruction as part of a quality-development system for learning and instruction (Fischer et al., 2005). However, several new studies are planned or are currently being conducted, e.g., Kotzebue et al. (2015). In response, di Fuccia et al. (2012) stress the need for more projects based on effective, experience-based and continuous professional development models that are used, for example, in collaborative or action research-based models of innovation (Abrahams, Reiss, & Sharpe, 2014; Blanchard, Southerland, & Granger, 2009; Capps & Crawford, 2013a; Elster, 2009; Parchmann et al., 2006). Wilson, Taylor, Kowalski, and Carlson (2010) emphasise the important role of teacher PD in the successful realisation of inquiry-focused lessons. As an integral part of their PD design, participating teachers were required to develop an understanding of curriculum materials and instructional models. Lotter, Harwood, and Bonner (2007) had teachers participate in an inquiry workshop, in which the teachers discussed how they view the learning content as experts and how they may translate their knowledge into practical opportunities that apply inquiry-focused methodologies in pairs. This process involved having teachers think through how they teach and asking them to challenge their common teaching practices. There appears to be evidence that existing short-term and intensive PD may support teachers in enhancing their knowledge and views. Capps and Crawford (2013a) report slight advantages in the development of inquiry understanding for teachers with basic inquiry knowledge. To implement changes in a sustained manner, teachers must employ effective self-reflective practices with assistance from a coach who may provide feedback, support, and advice on ways to incorporate inquiry into class settings (West & Staub, 2003). S. C. Lee, Nugent, Kunz, and Houston (2013) successfully delivered peer-coaching services to attain the aims of a scientific inquiry project. Peer-coaching also serves as a helpful instrument of pre-service teacher education (Britton & Anderson, 2010). Video-supported collaboration with peers may provide the catalyst for change related to inquiry-based instruction according to a case study by Lebak (2016).

Attitudes and knowledge

Teacher attitudes and knowledge are crucial to the implementation of inquiry science teaching practices (Avery & Meyer, 2012; Fazio, Melville, & Bartley, 2010; Minner et al., 2010). The term ‘belief’ refers to an individual’s judgment of the truth or falsity of a proposition (Pajares, 1992, p. 316). Some researchers clearly distinguish between attitudes and beliefs, e.g., Ernest (1989), whereas other researchers view attitudes as substructures of beliefs. Teacher attitudes and beliefs are often interchangeably used (Jones & Leagon, 2014; van Aalderen-Smeets, Walma van der Molen, & Asma, 2011) and, in our study, we share this approach. The cognitive component of attitudes expresses evaluative thoughts and beliefs that a person has about the attitude object while the affective component includes moods and feelings. van Aalderen-Smeets and Walma van der Molen (2013) developed a comprehensive and empirical proven model for measuring primary teachers' attitudes toward teaching science. Their model consists of the two mentioned components (cognitive and affective) next to a third one relating to self-efficacy and context dependency.

The distinction between attitudes and knowledge for PCK in particular is more an analytical tool than that it can strictly be kept up (Jones & Leagon, 2014). Teacher knowledge of and attitudes toward scientific inquiry teaching are expected to affect student learning and interest outcomes (Fogleman et al., 2011; Gess-Newsome, 2015; Keys & Bryan, 2001; Lumpe et al., 2011; Pell & Jarvis, 2003). Both CK and PCK comprise essential components of effective teaching (Abell, 2007; Park & Oliver, 2008). Shulman (1986, 1987) initially understood teacher professional knowledge as a combination of three categories of knowledge: content (CK), pedagogical (PK) and pedagogical content knowledge (PCK). This model has been refined to better specify these categories or adapt them to a specific content (see, e.g., Grossman, 1990; Park & Oliver, 2008). In discussions at a worldwide PCK summit in 2012, an attempt was made to form a general consensus regarding a description and conceptualisation of PCK. The attendees, all of whom had experiential and expert knowledge regarding the construct of PCK, believed PCK was representative of a teacher's knowledge of, reasoning behind, and purposeful planning for teaching a particular topic with a specific approach for enhanced student learning (Gess-Newsome, 2015). In this consensus model, CK is part of the teacher's knowledge base, and it influences and is influenced by the professional knowledge of a particular topic (theoretical PCK). Personal PCK is manifested in the practice of the classroom, e.g., the teacher's lesson planning. Beliefs act as amplifiers or filters to teacher learning and mediate teacher actions.

Most quantitative research on the relationship and the development of CK and PCK is based on mathematics. However, a study by Kaya (2009) looked into the relation of PCK and CK, with regard to the ozone layer depletion, within a sample of Turkish pre-service science teachers. The author reported medium to large correlations between CK and different PCK components. Two larger studies have recently analysed these concepts with respect to the subject of biology. An initial study by Großschedl, Harms, Kleickmann, and Glowinski (2015) that focused on general biology knowledge in pre-service teachers distinguished between CK, PCK and PK. The correlation between CK and PCK was strong (r=.68); however, CK and PK were not significantly related, whereas PCK and PK were related (r=.35). A second study by Jüttner, Boone, Park, and Neuhaus (2013) presented a framework for measuring the CK and PCK of in-service biology teachers as part of the project ProwiN. This study indicated correlations between CK and PCK that were relatively low but significant (r=.22). CK and PCK may have been modelled as different constructs in both of these studies on biology; however, the strength of the correlations appears to be test and/or sample dependent. In studies on mathematics, correlations identified between CK and PCK have predominately been high (Blömeke, Suhl, & Döhrmann, 2012; Kunter et al., 2007); however, the results from a recent study by Blömeke, Buchholtz, Suhl, and Kaiser (2014) based on a longitudinal model also demonstrated low values of approximately r=.22. In this longitudinal study, the authors further disclose that mathematical PCK affects teacher beliefs, whereas prior beliefs do not influence subsequent PCK. The results of a teacher development program in Colorado, US, indicate that science CK, PCK and attitudes interact. Moreover, in university science content courses, teacher self-efficacy beliefs are cultivated in addition to their PCK when discussing the application of course content to classrooms (Swackhamer, Koellner, Basile, & Kimbrough, 2009).

Pre-service teacher knowledge and scientific inquiry teaching attitudes

A synthesis of previous research by Davis, Petish, and Smithey (2006) indicates that numerous pre-service teachers possess unsophisticated understandings of inquiry teaching approaches and related skills, with individual variability. With respect to beliefs on the nature of science, the authors present similar findings of relatively unsophisticated beliefs. Moreover, the definitions of teacher scientific inquiry attitudes vary in the literature; thus, comparisons between results must be made cautiously (van Aalderen-Smeets & Walma van der Molen, 2013).

A study by Lemberger, Hewson, and Park (1999) indicates that secondary school teachers in biology who exited teacher preparation continued to struggle with the conflict between transmission beliefs about teaching and conceptual change teaching. Inquiry-focused teaching practices may be influenced by previous experience. The results from a teacher education project conducted at a public university in the northwest United States suggest that pre-service teacher uses of inquiry teaching approaches in the classroom are most strongly associated with previous research experiences, e.g., gained via working in a research laboratory of a university department, and were less associated with experiences with the training project (Windschitl, 2003). Prospective teachers may thus require access to continuing experiences with inquiry projects throughout their educational careers in conjunction with scientific inquiry courses or via contact with real scientists who may discuss their work practices and how they acquire new knowledge (Lotter et al., 2007; Windschitl, 2003).

Pre-service teachers who present negative attitudes toward scientific inquiry teaching have less self-confidence and self-efficacy related to science teaching (Tosun, 2000b). Problems associated with self-efficacy and self-confidence often appear in primary teachers (Avery & Meyer, 2012; Forbes & Zint, 2010). This issue may be a result of a disregard for student teacher self-confidence during science courses (Appleton, 1995). Experience from science courses and high content knowledge (CK) do not appear to affect student teacher self-efficacy beliefs (Tosun, 2000b). However, inquiry-based science content courses that actively involve primary school student teachers in collaborative processes of learning and discovery may promote a positive change in attitudes, as indicated by Riegle-Crumb et al. (2015). Studies with beginning science teachers indicate that secondary school teachers struggle with inquiry-focused teaching, in part, because of management issues, unmotivated or less capable students, and time constraints, as well as external impediments related to class time, facilities, and/or administration (Crawford, 2007; Wallace & Kang, 2004). Their rather positive beliefs with respect to scientific inquiry teaching practices may differ from the findings of external observers (S. L. Brown & Melear, 2006). Content knowledge does not appear to guarantee the successful implementation of inquiry-based lessons. However, strong (pedagogical) content knowledge combined with student-centred beliefs and a contemporary view on the epistemological underpinnings of science activities and the characteristics of resulting knowledge may increase the likelihood that inquiry will be taught in the classroom (Roehrig & Luft, 2004). Student teachers with insufficient subject-matter knowledge appear to struggle more when teaching inquiry strategies, e.g., when involving students in framing questions or formulating explanations (Crawford, 2007).

Capps, Crawford, and Constas (2012) recommend that studies on inquiry professional development should investigate the connections between the design of professional development, teacher knowledge, changes in teacher beliefs and practice, and student knowledge. With the exception of the last element, our study includes these aspects and assesses the effectiveness of our teacher-training model. Most of these results on the relationship between the scientific inquiry attitudes of pre-service teachers and their knowledge are based on qualitative studies. However, the causal relationships of the knowledge and attitudes must be analysed in longitudinal designs. A limited number of quantitative studies have examined the interplay between CK, PCK and attitudes towards scientific inquiry. Our research questions are designed to further clarify how these important factors affect one another.

Research questions

(1) Are there correlations between pre-service teachers' cognitive, affective and control attitudes regarding scientific inquiry?

(2) Do scientific inquiry attitudes develop during our project? What context factors/personal characteristics affect these developments?

(3) Do pre-service teachers' scientific inquiry attitudes, CK and PCK correlate and do knowledge and attitudes affect each other over time?

Methods

Design

The present study was a component of the Lake of Constance-IBH project 'KUBeX' (Content-focused peer coaching in pre-service teacher education) and was conducted by four teacher education universities across Germany and Switzerland. The project was initiated in 2013 and was conducted over two years. Its design was quasi-experimental and longitudinal (Table 1), and its primary aim was to determine the effects of a pre-service teacher training module on content-focused peer coaching (West & Staub, 2003). However, there were no differences in the CK, PCK and scientific inquiry attitudes (SIA) between the intervention and control groups at all measurement time points. As a consequence, we bundled the control and treatment groups in this study. For the PCK content of the peer coaching session, experimentation was used as a central means of acquiring biological knowledge that involved all forms of scientific inquiry. 'Visual perception' was used as the biological background content (CK) for the facilitation of scientific inquiry. In this respect, a secondary target involved investigating the state of pre-service teacher knowledge and attitudes on scientific inquiry teaching. Teacher professional knowledge (see Gess-Newsome, 2015) in our study consists of CK, PCK and attitudes as shown in Figure 1. A description of the instruments is provided in the following section.

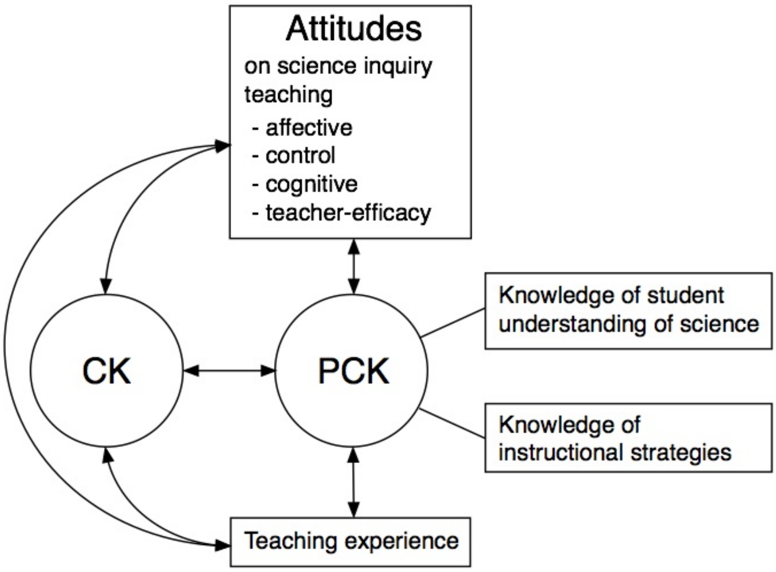

Figure 1: Research model of the presented study

The training consisted of 4 x 2 lessons (90 minutes) and a lesson-planning task followed by peer coaching. The limited amount of time is typical for teacher education; thus, the training is of high ecological validity. Capps and Crawford (2013b) have demonstrated that short-term and intensive PD may enhance knowledge and attitudes. We measured the participants' knowledge and attitudes before delivering the initial 2 x 2 lessons with theoretical PCK input on scientific inquiry to ensure all participants had a similar level of knowledge (Table 1). For example, the first 2 lessons were performed as follows: The training was initiated with a video study of a teacher student conducting an experiment. The video study included a collaborative task, which consisted of hypothetical feedback to the student in the video. These feedbacks were discussed within the class and the input of the teacher educator clarified open questions related to science inquiry. In the subsequent step, we measured the pedagogical content knowledge again and conducted an intervention related to peer-coaching, which is the focus of another study. Pairs of pre-service teachers were subsequently asked to individually prepare a lesson that focused on the process skills of scientific inquiry, e.g., posing questions or hypotheses; planning, conducting, and evaluating experiments; or analysing scientific data. Each pre-service teacher was required to present his or her lesson plans as a sketch to his or her coaching partner. These presentations were videotaped for subsequent analysis. Finally, their knowledge and attitudes were measured again. The entire training service (including the empirical component) lasted for approximately one month and was conducted at each university separately but by the same research team.

Table 1: Research Design (constrained to aspects of this article)

T1 Test & Questionnaire - before training	Input 2 x 2 lessons	T2 Test - after PCK input	Intervention 2 x 2 lessons	Videography open, max. 40 minutes	T3 Test & Questionnaire - after training
Attitudes on scientific inquiry	IG & CG: PCK input teaching scientific inquiry in biology	-	IG: Peer-coaching	Dyadic lesson planning	Attitudes on scientific inquiry
CK / PCK of teaching optics with a focus on scientific inquiry		PCK of teaching optics with a focus on scientific inquiry	CG: Independent science input		CK / PCK of teaching optics with a focus on scientific inquiry

Note: IG = Intervention Group, CG = Control Group

Items

Attitudes.

For the items that measured teacher attitudes towards scientific inquiry, we referred to the DAS Instrument created by van Aalderen-Smeets and Walma van der Molen (2013). Their model consists of three dimensions for measuring attitudes towards science in general that may explain behavioural intentions: cognitive beliefs, affective states and perceived control.

Based on their model, we adapted the items for a more detailed analysis of inquiry, replaced the items on cognitive beliefs with Pell and Jarvis (2003) items and replaced the items for self-efficacy with items from the Stebi-B (Bleicher, 2004). We used a 6-point Likert scale (6 = *absolutely agree*, 5 = *agree*, 4 = *somewhat agree*, 3 = *somewhat disagree*, 2 = *disagree*, and 1 = *absolutely disagree*). All survey items were summarised in scales, and a reliability index (Cronbach's alpha) was computed. Scales with Cronbach's alpha values of less than 0.7 were eliminated (e.g., context dependency) or, in the case of cognitive beliefs, were consolidated. The appendix presents the mean and standard deviation values for the final four scales: cognitive beliefs = scientific inquiry attitudes, affective states = anxiety and enjoyment, and perceived control = self-efficacy.

PCK and CK

All items used to measure PCK and CK were newly developed for this study because close alignment with the teaching content was required. The items that were related to the content (CK) requested knowledge in the field of visual perception. The items on PCK were based on two dimensions that are important components of the PCK model of Gess-Newsome (2015):

(4) Knowledge of student understanding of science (e.g., student pre-conceptions of visual perception, student mistakes when planning and conducting experiments or analysing data), and

(5) Pre-service teacher knowledge of instructional strategies (e.g., the functioning of experiments in lessons on biology or the treatment of student misinterpretations of results from experimental results).

Park and Chen (2012), who examined the declarative dimensions of PCK, demonstrated that biology teachers tend to connect knowledge of student understanding and knowledge of instructional strategies and representation, and these two PCK components may comprise a target area for PCK improvement. Following Jüttner and Neuhaus (2012), in addition to the PCK dimensions, the PCK items were organised according to three knowledge dimensions (declarative, procedural, and conditional). Item development for CK was guided by a research project of Dannemann and Krüger (2010), who developed items on the topic of visual perception for the diagnosis of student conceptions. The complete test battery consisted of 22 items for CK and 21 items for PCK. The test items for CK were single choice questions with four options, whereas 17 of the PCK items were true/false questions and four items were open-ended; examples are presented in the appendix.

Sample

Our sample included 121 pre-service teachers of three Swiss universities (n = 53) and one German (n = 68) university in the Lake of Constance area; 3 students dropped out during the course of the project. All students were preparing to teach the subject of biology in secondary schools (grades 5-10 in Germany, grades 7-9 in Switzerland). Participants were required to have attended laboratory or scientific inquiry teaching courses. Thus, most participants were in more advanced study semesters. The range was between the 2nd and 8th semesters, whereas the modus and median were the 6th semester. In total, 75% of the students were female and 25% were male with a mean age of 22.9 years (SD 3.4). Ten students possessed previous work experience, and 15 students had previously studied another subject. Only 29 of the students had not taught biology as part of their practical education over short periods in schools, and many students (55) had never used experiments for their own classes prior to this study.

Analysis

Test-analysis based on item response theory (IRT)

Mplus 7.0 (L. K. Muthén & Muthén, 2012) was used for the analysis. The test data were initially scaled for PCK and CK separately using a three- or two-dimensional 2PL-IRT model with one dimension for each measurement occasion. 2PL models add an item discrimination parameter to the 1PL model that enables the 2PL model to fit data substantially better than the 1PL model (Marsden & Wright, 2010). Higher values for this parameter are associated with items that are better able to discriminate between contiguous trait levels near the inflection point of the characteristic item curve. This relationship is manifested as a different slope for each item of a test. Item parameters were estimated using the probit regression and the WLSMV-estimator. The item parameters for each anchor item were fixed as equal across the measurement occasions.

After checking the item characteristic curves, we conducted an exploratory factor analysis to determine whether the items loaded on their intended factors for the unsatisfactory fit-indices. Non-fitting items were removed until adequate fit-indices were attained. An evaluation of the overall model fit was determined through an investigation of the comparative fit index (CFI), the Tucker–Lewis Index (TLI), and the root mean square error of approximation (RMSEA). Hu and Bentler (1999) recommended the following criteria for model acceptance on each fit index: CFI < .95, TLI < .95, and RMSE < .06. RMSEA is an indication of the correctness of the model in the population (T. Lee, Cai, & MacCallum, 2012). The final CK-Test model was calculated with 13 items for t1 and 8 items for t2. Two items were used for anchoring. *The CK model with a WLSMV-estimator has the following good fit-estimates:* $X^2 = 243.34$. *df* = 191, *p* = .00, CFI = .93, TLI = .95, and RMSEA = .05. For the PCK Test-model, we achieved the following acceptable fit-estimates: $X^2 = 443.62$. *df* = 355, *p* = .00, CFI = .91, TLI = .92, and RMSEA = .05 based on 10 items applied for each time point. Following completion of the

IRT analyses, final person measures based on Bayesian plausible values (Von Davier, Gonzalez, & Mislevy, 2009) were computed for the CK and PCK tests.

Growth modelling

Most analyses provide information regarding how group scores (mean differences) change or the extent to which rank orderings of individual scores (correlations) are similar over time, i.e., inter-individual changes. However, these analyses do not provide information regarding changes that may occur in each individual, i.e., intra-individual changes. Growth models eliminate numerous problems that have traditionally plagued measurements of change (Gibbons, Gibbons, Hedeker, & DuToit, 2010). In latent class growth modelling, different time points are considered classes that define various trends over time in terms of item probabilities. For example, a trend may be linear with an intercept and a slope (B. O. Muthén, 2001).

Cross-lagged models

To investigate our research questions with regards to the development of CK, PCK and scientific inquiry attitudes over time, we used autoregressive path models (McArdle & Nesselroade, 2014). In this type of model, the PCK test values at time t2 are predicted on the basis of the PCK value at t1 (i.e., 'autoregressive' or regressed on itself), and the PCK values at t3 are predicted on the basis of the PCK score at t2 (the second autoregressive component of the model). The same procedure was applied for attitudes and CK; however, only two time points were measured in these cases because it was necessary to limit the test workload and survey execution levels to levels appropriate for the students.

To model longitudinal dependencies between CK, PCK and scientific inquiry attitudes, we added cross-lagged effects. For example, we hypothesised that the PCK values at t2 depended not only on the PCK values at t1 but also the belief values at t1 (i.e., 'lagged' for an effect across time and with 'cross' used as an effect on another variable is concerned).

Longitudinal dependencies were also hypothesised with respect to the effects of PCK at t2 on attitudes at t2, as well as with respect to subsequent relations. Fig. 2 presents the model that resulted from this reasoning. All models were estimated with manifest variable indicators (parcels of items) to reduce the number of parameters calculated in complex models as a result of the sample size (Boivard & Koziol, 2012). To test whether the model is appropriate, model fit indices regarding the items were reviewed (Hu & Bentler, 1999).

Results

Pre-service teacher attitudes towards teaching scientific inquiry

The descriptive statistics regarding teacher attitudes are presented in Table 2. In regards to affective states, we report mean values that demonstrate the biology-focused pre-service teachers who studied at the four universities are not nervous or afraid of employing science experiments in the classroom. Moreover, they are not overwhelmingly enthusiastic regarding the use of experiments in the classroom; however, there appears to be a moderate level of enjoyment with individual variance. The self-efficacy values were moderately positive, whereas the cognitive scientific inquiry attitudes were relatively high, particularly by the end of the project. In relation to the Pell and Jarvis (2003) sample of pre-service primary teachers, our pre-service secondary school teachers present slightly more positive scientific inquiry teaching attitudes.

Table 2: Descriptive statistics and correlations of pre-service teacher attitudes towards teaching scientific inquiry

	Mean	S.D.	1	2	3	4
1. Anxiety t1	3.85	.77				
2. Enjoyment t1	4.44	.87	-.11			
3. Self-efficacy t1	4.46	.41	-.16	.64*		
4. Scientific inquiry attitudes t1	5.06	.55	-.07	.35*	.44*	
5. Scientific inquiry attitudes t3	5.31	.26	.05	.15	.28*	.52*

A relatively high correlation was expected between scientific inquiry attitudes at the two time points, which indicates stability but allows for individual developments. This result is presented in Table 2. Scientific inquiry attitudes and enjoyment levels both positively correlate with self-efficacy. However, this relationship is not true for enjoyment and scientific inquiry attitudes at t3. It must be stressed that enjoyment appears to strongly depend on the existence of high self-efficacy beliefs. Somewhat unexpectedly, there was no significantly negative correlation between enjoyment and anxiety, as demonstrated by the van Aalderen-Smeets and Walma van der Molen (2013) sample. This finding indicates that when teachers employ experiments, both enjoyment and anxiety may occasionally go hand in hand.

Development of pre-service teacher scientific inquiry attitudes during the project

In the subsequent step, we investigated the individual development of student teacher attitudes over time. More specifically, we examined whether our teacher training services had significant effects on the students' scientific inquiry teaching attitudes. This investigation could have been performed by assessing the mean of the whole sample; however, because the students have different backgrounds, individual developments may also be of interest. We thus employed a latent chance growth model (refer to the methods section). Two time points are not ideal when investigating development patterns or using latent growth models because the collection of individual trajectories is limited to a collection of straight lines; however, it allows for the estimation of change levels (Duncan & Duncan, 2009). In calculating the growth model, a Bayesian estimation with a Gibbs-Algorithm was applied. The results indicate significant individual differences in the intercept and slope (Table 3, model 1). The negative correlation between the intercept and the slope reached significance. This finding indicates that a pre-service teacher with a low attitude at t1 presents a higher slope, which suggests this pre-service teacher has changed his or her attitudes stronger than an individual with a positive attitude at t1. Using a second model, we included different background variables and tested different models, and we present the significant background variables in Table 3: self-efficacy and prior teaching experience in biology. The values in Table 3 have been standardised according to the variances of the observed variables.

Table 3: Latent growth curve model of attitudes towards scientific inquiry with covariates

	Model 1		Model 2	
	Estimate	Posterior S.D.	Estimate	Posterior S.D.
Means				
Intercept	5.06**	.07	3.08**	.45
Slope	.25**	.62	1.38**	.43
Slope with Intercept	-.22*	.12	-.16º	.10
Variance				
Intercept	.42**	.13	.31**	.11
Slope	.20**	.11	.18**	.10
Intercept on				
Biology teaching experience (yes)			-.36**	.14
Self-efficacy (higher)			.50**	.10
Slope on				
Biology teaching experience (yes)			.19	.14
Self-efficacy (higher)			-.29**	.09

Note: $N = 121$; **$p < .01$, *$p < .05$, º$p = .067$; unstandardized Bayes estimates.

The intercept and slope values for model 2 in Table 3 indicate that the two covariates of self-efficacy and prior teaching experience in biology do not explain all variance between the pre-service teachers. They represent adjusted values after partialing out the linear effects of predictors of chance (Willett & Keiley, 2000). In regards to attitudes towards teaching scientific inquiry at t1, the students with biology teaching experience exhibit lower values compared with the students without this training. In contrast, the students with increased self-efficacy beliefs at t1 exhibit more positive scientific inquiry attitudes. However, findings related to the slopes indicate that the students with high self-efficacy beliefs changed in the negative direction, which indicates that their inquiry attitudes declined by t2. We note again that the students as a whole developed positive attitudes toward scientific inquiry over time.

Development and interplay between CK, PCK and attitudes in the course of the project

The PCK and CK mean values presented in Table 4 indicate growth for both types of knowledge throughout the project (CK: $F = 34.75$, $p < .001$, $\eta = .23$; PCK: $F = 132.51$, $p < .001$, $\eta = .53$). For PCK, this increase appeared directly after the training on scientific inquiry teaching in biology was delivered (t2). Following the inquiry lesson planning session, the PCK mean value remained more or less the same. Significant correlations were identified within the same construct over time but not between PCK and CK. At the end of the project, PCK and CK had the highest correlation.

Table 4: Descriptive statistics for CK and PCK

	Minimum	Maximum	Mean	S.D.	PCK t1	PCK t2	PCK t3	CK t1
PCK t1	-1.69	1.76	.02	.83				
PCK t2	-1.34	2.44	.59	.87	.83*			
PCK t3	-1.51	2.39	.53	.89	.84*	.95*		
CK t1	-2.03	1.60	-.03	.88	.04	.04	.07	
CK t3	-1.57	2.30	.33	.75	.09	.10	.14	.68*

Note: $N = 121$; Bayes plausible values, calculated as probit regression coefficients; * $p < .01$.

We subsequently analysed how CK, PCK and scientific inquiry attitudes (SIA) interact in a longitudinal model. The cross-lagged model (Figure 2) has the following satisfactory fit indices: $X^2 = 584.38$. $df = 18$, $p = .00$, CFI = 1.00, TLI = 1.03, and RMSEA = .00. Autoregressive paths between the same construct over time denote very high stability for PCK. This finding suggests that the participant rankings remained largely constant with respect to PCK. For CK, we identified stable results, and as discussed in section 4.2, the SIA stability remained; however, the rank orders may have changed to some extent. Not all cross-lagged effects are significant. The most significant effects were identified between PCK and SIA, where PCK was a predictor of SIA. Interestingly, for t1, a negative effect of PCK on SIA was identified at t3. This finding indicates that the pre-service teachers with high PCK at t1 presented low SIA at t3. After the training was delivered between t1 and t2, this relationship changed: the pre-service teachers with high PCK also presented high levels of SIA at t3. CK at t1 had no effect on PCK and SIA at t3, whereas SIA at t1 had minor negative effects on CK at t3 and negligible effects on PCK t3.

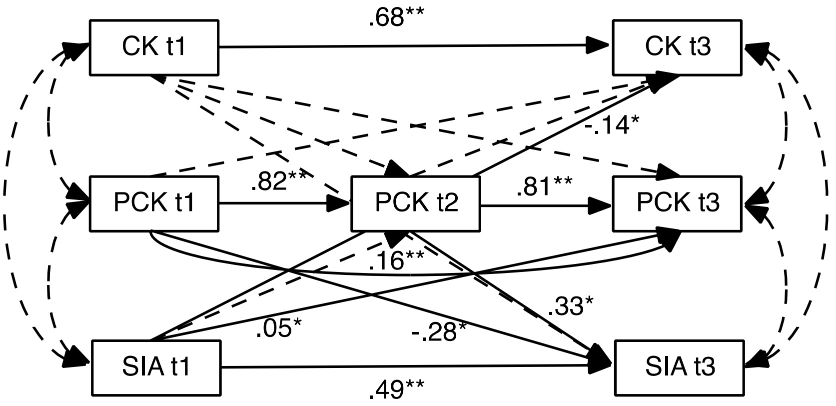

Figure 2: Cross-lagged model for CK and PCK on biology and scientific inquiry attitudes (SIA), N = 121, ** p < .01, * p < .05 and dotted lines for non-significant paths

Discussion

Previous studies have demonstrated that teacher education in the field of scientific inquiry teaching is a complex endeavour because numerous factors must be considered. The slow pace of reform in science education has been attributed to a fundamental characteristic of teacher attitudes: attitudes are stable and highly resistant to change (Bryan, 2012). Providing PCK as a component of experimental courses and presenting models for classroom instruction appear to represent potential solutions for effective training; however, attitudes should not be neglected as indicated in the Park and Oliver (2008) PCK model that includes teacher efficacy. Pre-service teachers tend to evade open inquiry discussions with students because they fear not being able to answer student questions (Roehrig & Luft, 2004). Thus, content knowledge is also necessary to foster the delivery of scientific inquiry lessons in classrooms.

Most studies on scientific inquiry teaching are based on qualitative data and provide insights into the experiences of pre-service teachers who participate in inquiry-focused courses. Few studies have presented longitudinal data models for the development of factors related to scientific inquiry teaching as a component of teacher training. Despite the relatively small sample size of our study, we believe that our results help clarify how CK, PCK and scientific inquiry attitudes interact. Moreover, our study may provide guidance on ways to formulate more effective teacher training courses.

What are the main results of this study?

Question 1: Are there correlations between pre-service teachers' cognitive, affective and control beliefs regarding scientific inquiry?

First, we sought to identify attitudes towards scientific inquiry in the pre-service teachers who participated in our biology-training module. Following the van Aalderen-Smeets and Walma van der Molen (2013) Attitude Toward Science (DAS) model, we distinguished between affective, cognitive and control beliefs. Our pre-service teachers appear to present strong cognitive beliefs regarding scientific inquiry teaching and moderate control and affective beliefs. Only the control (=self-efficacy) beliefs correlate with cognitive beliefs (=scientific inquiry attitudes). However, enjoyment and self-efficacy are also related.

Question 2: Do scientific inquiry attitudes develop during our project? What context factors/personal characteristics affect these developments?

While initially high prior to our study, scientific inquiry attitudes slightly expanded throughout the project. Pre-service teachers with negative attitudes towards scientific inquiry exhibited greater changes in their attitudes compared with teachers with positive attitudes. Two contextual factors (self-efficacy and prior teaching experience in biology) affected this pattern. Before the training was delivered, pre-service teachers with experience presented weaker scientific inquiry attitudes compared with the attitudes presented after the teacher training. In contrast, pre-service teachers with strong self-efficacy beliefs appeared to be less oriented toward scientific inquiry after the project.

Question 3: Do pre-service teachers' scientific inquiry attitudes, CK and PCK correlate and do knowledge and attitudes affect each other over time?

In regards to the effects of CK, PCK and SIA, a major relationship was identified between PCK and scientific inquiry attitudes, whereas only PCK was demonstrated to affect SIA. These findings are consistent with the results presented in a study on mathematics (Blömeke et al., 2014), in which the effects of PCK on attitudes were also reported. In contrast to other studies, there was no significant relation between CK and PCK at both time points. However, Jüttner et al. (2013) recently developed items for measuring CK and PCK in biology as separate constructs that exhibit statistically low but significant correlations between the two items, which indicates the independence of the two constructs. An important difference between our test and the test by Jüttner et al. lies in the choice of the PCK topic. Our PCK test is focused on scientific inquiry teaching, which is a particularly difficult and complex teaching topic (Harlen, 2013). Lotter, Singer, and Godley (2009), who conducted an intensive teacher-training program, also report that their secondary science pre-service teachers struggled to incorporate NOS instruction and inquiry-based instructional practices in their unit plans.

From our project, it appears that even short PCK training seminars may affect pre-service teacher attitudes towards scientific inquiry as suggested by Capps and Crawford (2013a). Tosun (2000a) states that high achievement in science does not guarantee positive attitudes towards science instruction because prospective teachers must also know how to transfer their knowledge to classroom experimentation settings. Thus, PCK enhancement strategies may more directly transform teaching practises compared with CK building when we intend to transform teacher practice. This concept is also suggested by Rozenszajn and Yarden (2015). They further suggest it is important to identify means that may promote the ability to recognise the link between PCK and CK and articulate it during professional development programs.

Theoretical input on scientific inquiry teaching leads to an increase in pre-service teachers' PCK; however, the practice oriented transfer (lesson planning) did not appear to substantially contribute to the growth of professional knowledge despite the postulated effects of reflection as part of successful teacher training in other studies (Van Driel & Berry, 2012). We assume that the quality of the peer coaching sessions in our study varies considerably, and not all dialogues reached the level of co-construction, which is crucial in the learning process (Rytivaara & Kershner, 2012). This matter will be further investigated. To date, despite delivering intensive training that combined theoretical input and practice-oriented transfer approaches (lesson planning), we have not determined how the applied training service may have resulted in the delivery of concrete scientific inquiry lessons. Follow-up sessions and the further reflections recommended by Blanchard et al. (2009) were not employed in our program. Blanchard and her colleagues realise the differences in teachers' future lesson plans cannot be attributed to what occurred during the training sessions. Instead, deeper and more substantive rethinking on teaching that led to an understanding of the theory that underlies inquiry and student learning occurred for some teachers prior to the training experience. It may also be important to consider the experiences of pre-service teachers when they complete practical training in schools. With regards to classroom management beliefs, Hoy and Woolfolk (1990) demonstrated that pre-service teachers are more controlling after completing practical teaching modules compared with their junior counterparts who have not previously undergone this training. It appears that the efficacy beliefs of pre-service teachers are more likely to decline and that teachers become more controlling following pre-service teacher training because of their vulnerability to various pressures when confronted with the realities and complexities of teaching tasks. This may explain why the more experienced pre-service teachers examined in this study exhibited less positive scientific inquiry attitudes compared with the teachers with less experience. Crawford (2007) notes that mentor styles may also affect the inquiry approaches of pre-service teachers. She reports that when a mentor's teaching style is highly structured and even rigid, students rarely attempt to deliver inquiry-based lessons. However, when teachers are highly receptive to enabling students to test out innovative approaches, students still do not attempt to utilise these approaches. Thus, prospective teachers may appear to lack a clear understanding of the ways to teach science as a form of inquiry in the classroom.

For these reasons, we propose additional longitudinal studies that examine the outcomes of teacher education programs in classrooms (Sleeter, 2014). These studies should help determine how to design effective scientific teaching courses where students learn science by actively engaging in the practices of science.

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