Learning to Teach and Teaching to Learn

Primary science student teachers´ complex journey from learners to teachers

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The Swedish National Graduate School in Science and Technology Education, FontD

Linköping university, Norrköping, Department of Social and Welfare Studies, Norrköping, 2008
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Abstract

This thesis concerns the process of student teachers’ learning to teach primary science and is based on four studies involving primary science student teachers during their teacher education program. The overall question that the thesis intends to investigate is in which ways student teachers’ learning about teaching can be illustrated and understood in terms of the critical aspects that are experienced within their teaching and learning practices. The four papers in the thesis purposefully explore student teachers’ complex journey from learners to teachers and illustrate the processes of learning to teach by highlighting important aspects within that process. Further to this, the thesis brings into focus the importance of teacher educators’ professional knowledge and how that knowledge must impact teacher education practice. The first paper explores four student teachers’ learning to teach in a primary school context. In connection to their teaching they were interviewed as they reflected on the video in order to portray their knowledge needs and how they impacted their abilities to handle classroom situations. The second paper investigates a group of primary science student teachers’ experiences from planning, teaching and reflecting on a science lesson with pupils aged between six and eleven in a science learning centre at the university. These student teachers identified critical incidents within their teaching which led them to further portray their own concerns for teaching and their teaching needs. The third paper investigates the joint learning between two primary science student teachers and their mentors during a four week school based practice. Finally the fourth paper investigates primary science student teachers’ development of subject matter of, and a positive attitude towards, physics in a specific physics course at the university, and further discusses the importance of subject matter knowledge and self-confidence in teaching primary science. In making explicit student teachers’ experiences and concerns for teaching and learning science, the practices and processes highlighted in this thesis help to inform how to involve student teachers in developing a knowledge base for primary science teaching.
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List of papers

Paper I

Teaching for understanding - The complex nature of PCK in pre-service teacher education. Nilsson, P. Accepted in International Journal of Science Education

Paper II

From lesson plan to new comprehension: Exploring student teachers’ pedagogical reasoning in learning about teaching. Nilsson, P. Submitted to European Journal of Teacher Education

Paper III

Primary science student teachers’ and their mentors’ joint learning through reflection on their science teaching. Nilsson, P., & Van Driel, J. Resubmitted to Journal of Science Teacher Education

Paper IV

How will we understand what we teach? – Primary student teachers’ perceptions of how to develop subject matter knowledge and a positive attitude towards physics. Nilsson, P., & Van Driel, J. Submitted to International Journal of Science Education
1. Introduction

1.1. Personal background to the study

This thesis concerns the process of learning to teach primary science and is based on four studies involving primary science student teachers during their teacher education program. The research interest is grounded in my background as a teacher and then further as a teacher educator. In the beginning, it was never my plan to become a science teacher. I actually did not like science lessons in school; in physics in particular. Although I was interested in science, I did not experience science lessons in school as events that stimulated my interest. In the end, it was the low level of interest in science lessons that led me to make the decision to become a science teacher. I wanted to find out ways to help others become interested in what I considered should be the exciting world that science offers.

After completing my teacher education program I taught science in secondary school for several years. In 1996, together with some colleagues, I started a project inspired by the Australian Project for Enhancing Effective Learning (PEEL) (Baird & Mitchell, 1986; Baird & Northfield, 1992), in which we evaluated our own teaching. In the project we reflected on our own teaching and encouraged our pupils to take more control or their learning; as well as our teaching. Hence, we used the project to inspire, and further to reflect on questions about how we taught in order to promote pupils’ learning, how the pupils described their learning, how we acted as teachers and how we could improve our teaching.

In 2000 when I started to teach student teachers about science teaching at Halmstad University, questions concerning teaching and learning science became even more important to me. As a teacher, teacher educator and researcher, I considered self-reflection to be a catalyst that pushed me along the path towards deeper understandings of teaching and learning. My own and my student teachers’ self-reflection then became tools to discover my own role in teaching and learning.
processes. I was particularly interested in two questions: “what is science teacher knowledge?” and, “how do we prepare student teachers for the complex task of science teaching?”

At the same time I developed a growing interest in primary science, initiated several projects that aimed to stimulate young pupils’ interest in science and started a science learning centre at the university. The science learning centre (which was the research context in paper two) was used for inviting pupils aged 4-11 to come and visit the university to work on science based experiments and problem solving activities and exercises. During these occasions, the student teachers ran the lessons. My experiences with student teachers and pupils at the science learning centre, and further as a facilitator for student teachers during their school based practice, my ideas that teaching about teaching might be grounded into the student teachers’ own experiences were confirmed. Further to this, and as highlighted by Loughran (2006), for teacher educators to know about the relationship between teaching and learning and how that relationship might influence the nature of their pedagogy of teacher education, studies of student teachers’ experiences are crucial.

One of the main problems that I saw within the student teachers’ learning to teach was for them to make a good connection between the academically and practical knowledge. The student teachers often highlighted how they had experienced difficulties in adapting the pedagogical knowledge and subject matter knowledge they had acquired in their academically based coursework to everyday school situations, and further to translate their subject matter knowledge in ways that might be relevant to primary pupils. They often experienced their pre-service courses as being on a too high level resulting in difficulties for them in managing to apply their content knowledge to the different primary teaching situations. Veenman (1984) described aspects of this phenomenon as a “reality shock” or a “praxis conflict” which could force student teachers to recognize, analyze and address their knowledge needs and reconstruct their images of themselves as teachers. For teacher educators to address
this “reality shock”, it might be assumed that an insight into the practice of teaching and the contextual factors that influenced practice was needed.

I was interested in studying how the conflict in which the student teachers’ often theoretical subject matter knowledge and pedagogical knowledge had to be adapted to primary pupils, influenced their development of a knowledge base needed for teaching. Based on my experiences as a teacher educator I considered that student teachers’ learning to teach and their teaching to learn were strongly connected. Therefore, when I had the opportunity to join the National Graduate School in Science and Technology Education (FontD) at Linköping University in 2003, my research interest became focussed on studying the interaction between student teachers and primary school pupils in the teaching situation, in order to better understand and develop insights into student teachers’ learning to teach through these interactions. Hence, the focus of my research became one designed to illustrate those aspects that needed to be taken into account in the process of developing student teachers’ learning to teach primary science. As such the Ph.D. studies created possibilities for me to further investigate questions which were important not only for me as a curious person, but as a teacher educator in order to shape the learning about teaching that I was attempting to create for my student teachers.

1.2. Background and research aim

The growing focus on learning and teaching about teaching has been highlighted in many ways (Axelsson, 1997; Berry, 2004; Nilsson, 2008). However, much of the research on teacher education programs fail to examine the complex relationship between key learning experiences within teacher education programs and the influence they have on the epistemological beliefs and practices of science student teachers (Anderson & Mitchener, 1994; Cochran-Smith & Zeichner, 2005). In the final chapter of AERA’s panel on research and research report, *Studying Teacher Education*, Cochran-Smith and Zeichner (2005) concluded that teacher education research has paid:
“…little attention to how teachers’ knowledge and practices are influenced by what they experience in teacher education programs and even less attention to how teachers are affected over time by their preparation. There is a clear need to look more at how teachers’ knowledge and practices are shaped by their preparations…” (p. 742).

Further to this, there is a concern for more scientific research on teacher education – particularly in relation to how such studies could influence teacher education practices (Cochran-Smith & Zeichner, 2005). Therefore, in order to move beyond notions of teaching as only the delivery of information, there is an urgent need to unpack teaching and learning to teach from the point of view of student teachers’ experiences in order to create a deeper understanding of their needs and their concerns.

Several important questions have framed the four papers in this thesis. However, the goal of all four studies is to contribute to an understanding of student teachers’ complex journey from learners to teachers. All through the thesis there are different actors that need to be described. The “student teachers” are in their teacher education program, studying to become teachers in maths and science for primary school (in paper one also for secondary school). The “pupils” are school children aged between six and eleven. “Teacher educators” are working at the department of teacher education at the university teaching student teachers in science education or pedagogical knowledge. “Physics teachers” are the science experts at the faculty of physics at the university, teaching student teacher in physics courses. “Mentors” finally are teachers in school who are supervising the student teachers during their school based practice.

The first paper explores four student teachers learning to teach in a primary school context. During one year the student teachers (in pairs) were video-recorded when teaching physics to pupils aged nine to eleven. In connection to their teaching they were interviewed as they reflected on the video in order to portray their knowledge needs and how they impacted their abilities to handle classroom situations. The second paper investigates a group of primary science student teachers’ experiences from
planning, teaching and reflecting on a science lesson with pupils aged between six and eleven in the science learning centre at the university. These student teachers identified critical incidents within their teaching which led them to further portray their own concerns for teaching and their teaching needs. The third paper investigates the joint learning between two primary science student teachers and their mentors during a four week school based practice. Finally the fourth paper investigates primary science student teachers’ development of subject matter of, and a positive attitude towards, physics in a specific physics course at the university, and further discusses the importance of subject matter knowledge and self-confidence in teaching primary science. In making explicit student teachers’ experiences and concerns for teaching and learning science, all four papers give insights into student teachers’ complex journey from learners to teachers.

By focusing on personal practices and experiences, teacher educators inquiring into their own practice might develop better understanding of the complexities of teaching and learning, both for themselves and for their student teachers (Loughran, 2002). As such, research on teacher education practices offers valuable insights into student teachers’ learning needs which, in turn might be helpful for teacher educators in order to improve their teaching about teaching. My starting point in this research is my belief that learning always depends on the context, the situations and the social interaction in which it occurs, and that learning to teach is a never ending journey. Thus, what we do in our teacher education programmes, and no matter how well we do them, is only a starting point in preparing teachers to begin teaching. As highlighted by (Korthagen, 1993) their needs to be a commitment by teacher educators to help student teachers during their teacher education programme to internalize dispositions and skills in order to study their teaching and to become better at teaching over time. The four papers in this thesis purposefully explore student teachers’ complex journeys from learner to teacher and illustrate the processes of learning to teach by highlighting important aspects within that process. Further to this, the thesis brings into focus the importance of teacher educators’ professional knowledge and how that knowledge must impact teacher education practice.
Just as Loughran (2006) highlighted, *developing a pedagogy of teacher education* signifies that “the relationship between teaching and learning in the programs and practices of learning and teaching might be purposefully examined, described, articulated, and portrayed in ways that enhance our understanding of this complex interplay” (p. 3).

As a researcher I wanted to study how student teachers experienced their teaching and learning practices in order to illustrate aspects that needed to be taken into account in the process of developing student teachers’ learning to teach primary science. Thus, the student teachers’ own concerns were central in all four studies; even though the third also included their mentors. Therefore the overall question that this research aims to answer is important not only for the research field on science teacher education but also for its implications on the practice of science teacher education:

- In which ways can student teachers’ learning about teaching be illustrated and understood in terms of the critical aspects that are experienced within their teaching and learning practices?

The answers to this question are crucial to the pedagogy of teacher education. Hence, the practices and processes highlighted in this thesis help to inform how to involve student teachers in developing a knowledge base for primary science teaching.

**1.3. The importance of teacher education research**

It could well be argued that the structure of teacher education may not always offer opportunities for student teachers to transform the knowledge they acquire during course work into the type of knowledge they might need to teach in a [primary] school context. Further to this, student teachers do not always manage to make explicit connections between teachers’ actions and the pedagogical theories that inform practice (Loughran, 2006). Different knowledge bases such as subject matter and pedagogy are often taught separately, thus inadvertently creating a situation in which
student teachers themselves need to find ways of transforming their various forms of “knowledge” into useable and meaningful forms within the context of teaching. Hence, there is considerable merit, both in relation to research and practice, in exploring how student teachers through the use of reflection develop and build on different knowledge bases needed for teaching. Clearly, to do so, student teachers need to move beyond their initial needs and concerns so that they might come to recognize and understand the complexity of teaching and see the value in transforming their knowledge into a form that is useable and helpful in shaping their classroom teaching of science.

Further to this, it might well be argued that in Sweden members of the policy-making community embrace a view of teacher knowledge and skill that represents a limited perspective of what teachers should know and be able to do. In their discussions policy makers often emphasize the importance of strong subject matter knowledge, but they only briefly discuss how this subject matter knowledge is to be transformed in a way that promotes pupils’ understanding. As a consequence of policy-makers’ discussions, teacher education programs as well as school curricula are most likely influenced in a variety of ways. Yet, organizational changes and the complexity of teaching highlights the necessity for more focussed research into the relations between these different elements that constitute teacher knowledge, and how these are developed and integrated during teacher education.

In their review of teacher education research, Anderson and Mitchener (1994) stressed that despite the important role that teacher education programs played for school development, there had been a relatively small amount of research on teacher education. However, in this new century teacher education is beginning to be better valued as an object of academic research. Korthagen, Loughran and Russell (2006) highlighted the importance of research on teacher education. They presented seven principles that they considered important in shaping teacher education programs and practices in ways that might be responsive to the expectations, needs and practices of teacher educators and student teachers. Among those principles “learning about
teaching involves continuously conflicting and competing demands” (p. 1025) is one that particularly stresses the importance of student teachers’ learning from experience and building on their professional knowledge in order to shape their thinking about their teaching. “Helping student teachers recognize and respond to competing demands in their learning to teach is one way of helping them to learn in meaningful ways through experience” (p. 1027).

Educational researchers have attempted to document and describe the process of teacher reflection and associated activities, and the relationship between these processes and teacher development (Korthagen, 1985, 1993; Russell & Munby, 1991). Concepts such as “reflective thinking”, “action research”, “research based” and “inquiry-oriented” teacher education have been embraced by both teacher educators and educational researchers all over the world (Zeichner, 1994). Further to this, Calderhead (1988) highlighted the need for teacher educators to be aware of the complexity of learning to teach in order to consider more critically how tasks in teacher education might lead to knowledge development. Student teachers’ awareness of the process of learning to teach might enable them to analyze their own experiences in professional development and to identify areas of knowledge and skills that must be built up (Calderhead, 1988). As highlighted by Zeichner (1994), the research agenda in teacher education should involve research efforts carried out publicly by teacher educators that focus on ways in which particular programme structures and activities, and their own actions, are implicated in the particular kinds of reflective practice that constitutes teacher education:

“We need research that increases our understanding of the ways in which both individual and social factors affect teachers’ reflections and actions so that we can continually adjust our actions in our programmes in response to these data. These accounts of the reflective practice of student teachers under particular programmatic conditions can also be used as reading material for teacher-education students to help them examine their own patterns of reflection” (p. 21).
Based on the literature reviewed above, it is reasonable to suggest that in order to develop an understanding about student teachers’ learning to teach, research in the context of teacher education is crucial. Not only for teacher educators’ learning to teach about teaching, but also for the way the structure of teacher education programs might be considered in the future.

1.4. Researching on a researchers’ practice

As a researcher you are often confronted with the question of how your research might have an impact on practice. As Russell (2002) highlighted, the theory-practice gap (i.e., that between teaching and research) is just as great in teacher education as in education in general. Hence, it might well be argued that research on a teacher educator’s practice (i.e., how to promote student teachers’ learning to teach) might shape the understanding of the student teachers with whom he/she works. In the research on science teacher education there are examples of how teacher educators have returned to school teaching in order to learn more about the context in which their student teachers will work (e.g., Pinnegar, 1995; Russell, 1995). Aiming to see how the experiences of daily school teaching in physics affected his thinking about his regular work as a physics teacher educator, Russell (1995) returned to the physics classroom for a semester. By returning to the physics classroom, he recognized anew the significance of personally learning the details of a science textbook’s problems, ways of organizing curriculum content and the challenge of learning to use the equipment available in a particular classroom; things that perhaps “slip from the consciousness” when one is a teacher educator rather than classroom teacher.

In this research I have considered a lot of epistemological relationships such as: the need to unpack the experiences of student teachers in a teaching practice within a larger theoretical context (the relationship between theory and research); the value of respect between the researcher and “the researched” in the research process (the relation between research and practice); and, the importance and power of myself as a researcher and therefore the need to articulate and critique my role in the research.
process (the relationship between theory, research and practice). Therefore, in all four
studies of the papers that comprise this thesis I have carefully tried not only to describe
what I feel as “best practice” of teacher education, but also to focus on how the
complex journey from learner to teacher was experienced and illustrated within the
student teachers’ descriptions of their experiences.

Even though this thesis mainly focuses on student teachers´ learning, as student
teachers interact with teacher educators as well as with pupils and mentors in the school
context, all participants´ learning from and about each other could be illustrated as in
figure 1. Teacher educators learn from and about student teachers through observing
how they act and interact with pupils as well as the mentors in the classroom. They
also learn through listening to the student teachers’ reflections and through taking part
in how they experience their teaching and learning. Teacher educators also learn from
and about pupils´ and mentors´ ideas and actions as they participate in the classroom
context. Furthermore, student teachers learn from and about each other, the teacher
educator and the pupils. The different levels of learning are presented in figure 1.
Finally, the pupils, as they take part in science teaching, learn from the student
teachers. It might also be reasonable to suggest that the pupils might learn something
from and about teacher educators as they participate in classroom teaching.

![Diagram of participants' learning from and about each other](image)

Figure 1. Participants’ learning from and about each other
Loughran (2006) argued that common starting points for self-study inquiries are the questions, problems, tensions and dilemmas that so often cause one to ponder the problematic nature of practice. Therefore, another dimension that can be added to the figure above is that of teacher educators’ research on their own practice as something that (hopefully) also helps them to learn about themselves as teacher educators. In the same way, as student teachers are part of research project where they are stimulated to reflect together with mentors and peers, they also learn about themselves and their knowledge and beliefs.

Kelchtermans and Hamilton (2004) defined self-study as “a mixture of systematic reflection or a form of inquiry that tries to answer relevant questions through a systematic collection of data and their analysis” (p. 786). Loughran (2002) described one characteristic of and purpose in self-study as teacher educators’ desire to increase student teachers’ learning about teaching and to do so in ways that involve more than teaching as telling. Thus, a renewed focus on the complex nature of teaching about teaching and learning about teaching serves as a catalyst for careful attention to teacher education practices - where the examination of thoughts and actions of practitioners was being conducted by the practitioners themselves (Loughran, 2002).

In his chapter about improving teacher education practices through self-study, Kuzmic (2002) argued that self-study of teacher educators cannot simply be about the lives, practices and history of the teacher educator. It must also understand these in relation to and through the experiences and perspectives of those with whom we are involved (e.g., student teachers).

“We cannot simply objectify the teachers and students that contextualize our lives as teacher educators. Their lives, their concerns, their perspectives and their struggles must find a place in our studies of the self. Thus thinking about self-study as the study of self-in-relation-to-others involves moving beyond recognition of my own complicity in the Othering of teachers in our discourse about teaching, teacher education, and research to a consideration of avenues for change.” (p. 233).
Even though through this research I did not set out to study myself, but rather to study and further analyze the experiences, concerns, perspectives and struggles of student teachers, it is obvious that the research results aim to give implications with regard to my own practice as a teacher educator. Hence, it is my intention to transform research knowledge into a form which can readily enter the professional discourse through which student teachers develop a knowledge base needed for teaching. Then clearly, the thesis has that double aim that Bassey (1981) highlighted; to result in generalizations in the form of theories of learning and the knowledgebase needed for teaching, and to contribute to a change in the practice of teacher education. Bassey (2001) further claimed that it is possible to formulate the outcomes of empirical research as fuzzy generalisations (i.e., particular events may lead to particular consequences) and hence be useful to both practitioners and to policy-makers in education. However, as one of the background intentions of this research was to improve my understanding of student teachers’ professional learning needs in order to find ways of incorporating such knowledge into my teaching about teaching, this research might be placed along the continuum of self-study (Berry, 2004; Kelchtermans & Hamilton, 2004; Loughran & Russell, 2002) and action research (e.g., Axelsson, 1997; Elliot, 1991; Hansson, 2003; Russell, 1995; Stenhouse, 1975; Wennergren, 2007). The usefulness of action research will be further explored in the next section.

1.4.1 Action Research in teaching

In this research on student teachers’ learning to teach, I have used the perspective of action research to guide me in terms of what to pay attention to, how to approach the research problem and how to frame the process of researching practice in order to improve that practice. In the area of teachers’ professional development, action research has been widely acknowledged as a way to study teachers as professionals generating practical knowledge (Cochran-Smith & Lytle, 1999; Schön, 1983). Action research can bridge the gap between theory and practice as it helps teachers to understand the purpose of educational research and in turn, inform educational theory.
about classroom practice (Lytle & Cochran-Smith, 1999). Stenhouse (1975) used the term teacher-as-researcher and argued that in the end it was teachers who would change the world of the school by understanding it. He further argued that being an extended professional involved studying the work of teaching and researching it oneself, not leaving it to others. Elliot (1991) advocated that the fundamental aim of action research was to produce knowledge and theories in order to improve practice. However, action research improves practice by developing the practitioner’s capacity for discrimination and judgements in particular complex situations. “It unifies inquiry, the improvement of performance and the development of persons in their professional role.” (p. 52). Pedagogical strategies to handle classroom management were, according to Stenhouse (1975), highly context dependant. Thus, it might be possible to generalize strategies from past experiences in several situations but their applicability to future classroom situations must be examined in situ.

Further to this, in terms of research into learning strategies, Bassey (2001) stated that researchers and policy-makers would like clear statements, like if we do x in y circumstances, z will be the result. However, as it might be assumed that pedagogical strategies are context dependant, those predictions might be impossible to make. In a similar manner Elliot (1991) argued that generalizations constitute the denial of the individual practitioners. It reinforces the powerlessness of teachers to define what counts as knowledge about their practice. The more the researcher tries to generalize teachers’ knowledge, the more threatening it is to teachers because it will contradict their experience of themselves as sources of expert knowledge (Elliot, 1991).

Action research has often been criticized for having problems with objectivity. However, as Stenhouse (1975) advocated this does not need to be a problem:
“The problem of objectivity seems to me as a false one. Any research into classroom must aim to improve teaching. Thus any research must be applied by teachers, so that the most clinically objective research can only feed into practice through an interested actor in the situation. There is no escaping the fact that it is the teacher’s subjective perception which is crucial for practice since he is in a position to control the classroom” (p. 157).

Cochran-Smith (2001) argued the importance of research on how student teachers’ work with professional commitments in order to construct knowledge, open their decision making strategies to critique and further to use the research of others as generative of new questions and strategies. However, as advocated by Cochran-Smith and Lytle (1990), the unique feature of teachers’ questions is that they emanate solely neither from theory nor from practice, but from “critical reflection on the intersection of the two” (p. 6). In this critical reflection, an approach inspired by self-study and/or action research might be useful.

Feldman, Paugh and Mills (2004) discussed the ways in which action research is and is not related to self-study. They concluded that a self-study focuses on the self; it favours the use of life history and narrative forms of inquiry and has been developed within the context of teacher education. Action research is often characterized by the relationship between the outsider as an expert who helps the insider to gain knowledge and other forms of expertise. However, concerning action research it is important to note that while teachers (or teacher educators) are part of the research team, the focus of the inquiry is on the organization and their own practice rather than on the self (Feldman et al., 2004). To conclude this chapter it might be assumed that a teacher educator’s research on student teachers’ learning needs will significantly influence what is known about teaching and learning. As such, it could be assumed that this knowledge might impact on the organizational structure of the teacher education program as well as modifying and transforming the teacher educator’s own beliefs and practice.
2. Theoretical background

2.1. Primary school and teacher education as communities of practice

It might well be argued that teacher education should prepare student teachers to become members in the teachers’ community and to participate in educational practices in a competent way. In doing so teacher education can be viewed as involving student teachers in meaningful practices and providing access to resources that enhance meaningful participation in those practices. Therefore, an important theoretical point of departure in this thesis is the premise that [student] teachers learn through practical experiences that are reflected and reasoned and through situated and social interactions with peers and mentors with whom they discuss and get and give feed-back on mutual interests (i.e., teaching and learning science). One approach to think about student teachers’ complex journey from learners to teachers is to use the perspective of a community of practice (Wenger, 1998). Lave and Wenger (1991) noted that most of the learning associated with professions comes through the practice situation, and that learning, thinking and knowing take place when people are engaged in activities within communities of practices. Using this framework, we can begin to think about what role participating in primary school teaching might play for student teachers and how teacher education can support student teachers’ transition into the community of practice of primary teaching.

Abell (2006) stressed that the situated learning perspective could well be applied to teacher learning.

“The authentic context is the elementary classroom, where students of teaching take part in apprenticeships in which they join, peripherally at first, and more fully as time goes on, the community of practice of teaching...Thus, the situated learning perspective provides theoretical support for the field experiences from which to build models of practice.” (p. 77)
In terms of the practice of a primary school community student teachers are often considered as “newcomers” (Wenger, 1998). As highlighted by ten Dam & Blom (2006) “Becoming a more central participant in society is not just a matter of acquiring knowledge and skills; it also implies becoming a member of a community of practice. This requires people to see themselves as members, taking responsibility for their own actions (including the use of knowledge and skills) in that position” (p. 651). The title of this thesis “learning to teach and teaching to learn” implies that student teachers’ participation in the community of primary school practice is for them both a learning objective and a means for learning.

In this research context, it is further assumed that for meaningful participation in a community, student teachers need to reflect on their initial aims and their interactions with peers, mentors and pupils in order to transform their knowledge of teaching and the content of that teaching through their teaching experiences into pedagogical content knowledge. Within the community, the student teachers act as resources for one another, exchanging information, sharing new ideas and giving each other feedback. Further to this, the student teachers invite others in the community (e.g., mentors) to participate in their experiences. In such a way, they may well attempt to influence the community and create new knowledge together through that process. When entering the community of primary school practice student teachers bring with them a lot of ideas concerning science content and science teaching. As primary teachers often tend to have limited science knowledge (Appleton, 2003, 2006; Harlen, 1997), working with science student teachers might in turn give them new ideas and thus help the community of primary school practice to further evolve (paper 3).

The research outlined in the four papers points out that participation in a community of practice also requires active involvement in that community. As described by Wenger (1998) participation in this sense is a complex process that combines doing, talking, thinking, feeling and belonging. Thus, it is my belief that participation in a community of practice is an active process where the student teachers (in primary school and in the university course context) through a process of reasoning and action shape each
other’s experiences of teaching and learning science. However, student teachers need to be supported in different ways to develop that unique knowledge that enables their competent participation in the practice of teaching. This thesis presents several ways (e.g., stimulated recall sessions and group reflections) of supporting student teachers to actively participate in their learning to teach primary science and simultaneously being data sources for researching those processes and practices. Further to this, participating in the community of practice involves not only acquiring the technical skills needed for teaching but also a personal framework of how to value those skills and how to value oneself as a teacher. As such, it might be assumed that for student teachers to develop their identities as teachers they must engage in the community of practice of primary school. However, as highlighted by Wenger (1998), what is crucial about this kind of engagement as an educational experience is that identity and learning serve each other.

With a focus on early childhood, Fleer (2006) raised the question of “How do early childhood preservice teachers move from being peripheral participants to becoming full members of a science community?” (p. 107). Primary student teachers must cross a border from the community of practice known as “early childhood education” to the community of practice known as “science education” during their science learning. However, if student teachers do not have a framework for the kind of questions and ideas that pupils might have while experiencing and discussing science through objects and experiments, then to become members in the community of practice known as science education will be difficult (Fleer, 2006).

Wenger (1998) argued that participation in a community of practice involved three aspects: engagement; the exploration of new territory; and, commitment. With respect to engagement, the interaction between student teachers and their young pupils in the science learning centre and the classroom (papers 1 & 2 & 3), and with each other during coursework (paper 4) offered opportunities for them to engage in teaching, in discussions of important aspects within their teaching (e.g., pedagogical content knowledge and subject matter knowledge) and hence, in their own learning. The
exploration of new territories was highly addressed as the student teachers explored the school context and the new territory of teaching science. Concerning Wenger’s (1998) third aspect commitment, the student teachers acknowledged the commitment of their mentors and peers to further consider how different ideas (mostly concerning classroom management) might be used in their own classrooms. Hence, participation in discussions with their peers enabled the student teachers to reflect on their teaching and how they might begin to move into that community. As such, sharing teaching with others might be considered as a means of further developing their teaching.

Cochran-Smith and Lytle (1999) stated that through inquiry “teachers make problematic their own knowledge and practice as well as the knowledge and practice of others” (p. 273). Teachers’ professional learning is not only a simple case of adding new information to the existing base of teacher knowledge. Professional learning is an ongoing task in which teachers “need to restructure their knowledge and beliefs, and, on the basis of teaching experiences, integrate their new information in their practical knowledge” (van Driel et al., 2001, p. 140). The fact that people participate in different communities of practices (Wenger, 1998) suggests a mechanism for understanding the interaction and relations among those practices. The goal of teacher education should be to prepare student teachers for the complex task of teaching. Hence, teacher education needs to offer opportunities for student teachers to learn the subject to be taught, as well as ways of presenting this subject in a way that promotes pupils’ understanding.

Swedish primary teacher education is mainly built up from three different areas (educational science, subject matter and school based practice). During the school based practice (about 20 weeks during the three and a half years of education) student teachers are expected to synthesize their theoretical knowledge of subject matter and pedagogy with practice in order to develop professionally. The process of synthesizing is, except for the mentoring teachers, most often left to the student teachers themselves.
The focus of this thesis is primary science student teachers, not as individuals but in terms of their development of a knowledge base needed for teaching and the social context in which this development occurs. Therefore, theories of how practice shapes social categories and how knowledge is created within a practice setting (e.g., Lave & Wenger, 1991) have been important for my own understanding of student teachers’ learning to teach through teaching. As advocated by Lave and Wenger (1991) knowledge is connected to the situation in which it is practiced.

“Learners inevitably participate in communities of practitioners and that the mastery of knowledge and skill requires newcomers to move forward full participation in the sociocultural practice of a community” (Lave & Wenger, 1991, p.29).

Learning comes from participating in a culture and the community of practice which means to know, but also being together, living meaningfully, and develop an identity of profession (Wenger, 1998). The learning is not only an individual process as the understanding and experiences are in constant interaction. With this framework to structure our thinking, as a community of science teacher educators, we too can be thoughtful and clear about our practice in ways that enable us to educate ourselves and others about science teacher education (Schneider, 2007).

2.2. Science teaching in primary schools

In her review on science teacher knowledge Abell (2007) posed the question: “Do teachers who know more science make better science teachers?”

“If this was true then surely the best science teaching would take place at the university level by teachers who possess Ph.D. in their science field. Yet we know that this is not necessarily so; university science students cite poor teaching as one of the main reasons for dropping out of science majors” (Abell, 2007, p. 1105).

She goes on to pose a question about what science teachers should know in addition to science knowledge and how they come to know it. During the last two decades,
Swedish primary teachers have been confronted with new challenges concerning science teaching. In Sweden as in several other countries, primary teachers are faced with teaching several subjects and coping with shifting roles in different subject matter contexts. Primary teachers therefore need to have content knowledge in all these different subject areas. As many science teachers have had negative experiences in science during their own schooling they have tended to avoid science in their higher education studies (Skamp, 1997). As such, it might well be argued that the tendency for primary school teachers to avoid science has resulted in their limited science content knowledge and low confidence in teaching science.

Similar to other countries, Sweden has experienced government interventions leading to reforms of teacher education programs, school curricula, national tests and other criteria for measuring the quality of schools and teaching. Also teachers’ attitudes and beliefs have been found to be a major influence in the implementation of the science curriculum (see for example, van Driel, Beijaard & Verloop, 2001). In 1994 the national school curricula changed to present goals that pupils should achieve in every subject. In the context of primary science teaching, the new curricula stipulated a large amount of goals to be reached in physics, chemistry, biology and technology. These new curricula raised discussion about primary teachers’ scientific knowledge, attitudes towards and confidence in teaching science. Another important issue for primary science is that in Sweden, like in several other countries, evaluations of secondary pupils’ scientific knowledge through such things as TIMSS and PISA have had a great impact on policymakers’ requirements for science teaching in primary and secondary schools. Most primary teachers are struggling to survive the demands that the national primary science curricula requires. However, they need to develop subject matter knowledge as well as a positive attitude towards and self-confidence in teaching science if the educational needs of their pupils are to be met.

Research on primary student teachers’ learning to teach (Appleton, 2006; Nilsson, 2008; Skamp, 1997), have emphasized the importance of primary science student teachers’ framing and reframing of their practice (Schön, 1983, 1987) in order to gain
new insights into what and how they perform teaching. An important task of the primary science teacher is not only to help pupils to acquire content knowledge of science but also to inspire them and stimulate their interest. In order to teach science in ways that might promote pupils’ understandings as well as their interests, Shulman (1986, 1987) claimed that teachers need pedagogical content knowledge (PCK), a special kind of knowledge that teachers have about how to teach particular content to particular pupils. However, as highlighted by Appleton (2006), “Given that many elementary school teachers have a limited science content knowledge and therefore limited science PCK, how do such teachers manage to teach science at all?” (p. 32). One way for teachers to manage science teaching in primary schools is to develop a working set of science PCK through the use of science “activities that work” (Appleton, 2002). These are activities with which teachers feel comfortable, that they have taught before and that have fairly predictable outcomes in providing pupils with science knowledge (Appleton, 2003).

Even though there are primary teachers who teach science effectively and regularly, we know from research that primary and elementary school teachers have limited science knowledge (Appleton, 2003, 2006; Harlen, 1997; Harlen & Holroyd, 1997). They tend to lack confidence in the adequacy of their own science knowledge and in their ability to do and learn science for themselves (Appleton, 2006). Thus, the level of complexity of one’s subject matter knowledge structure is a critical factor in how easily knowledge structures influence classroom practice and embodies the content fundamental to the development of PCK.

Harlen and Holroyd (1997) designed a study of primary teachers’ subject matter knowledge to evaluate their knowledge about different concepts. Three groups of correct and incorrect conceptions were defined: (i) concepts already understood by the teachers; (ii) concepts of which understanding developed during the interviews; and, (iii) concepts that were less commonly understood. It was also determined that a lack of everyday language of physics was at the source of teachers’ inaccuracies. Osborne & Simon (1996) claimed that primary teachers’ lack of ability, confidence and
enthusiasm for the science subject resulted in the use of less stimulating methods and that teachers did not respond effectively to pupils’ questions. Further to this, teachers who have little subject matter knowledge have limited options “…especially if they lack confidence to choose activities that work from science topics about which they know little, or to acquire new science content knowledge for themselves” (Appleton, 2006, p. 42).

Palmer (2001) emphasized that subject matter knowledge and science pedagogical content knowledge increased teachers’ confidence in primary science teaching. Harlen (1997) found that teachers’ depth of subject matter knowledge could affect the ability of the teacher to ask appropriate and meaningful questions. Planning often became limited and defined by what the teacher knew rather than an exchange of knowledge between the learner and the teacher (Harlen, 1997). This was confirmed by Carlsen (1991), who found that the less the teacher knows, the more often discussions with the pupils appeared to be dominated by the teacher. Further to this, the less competent the teachers were, the more difficult it was for them to follow the child’s lead and to explore their ideas (Carlsen, 1991).

To plan learning experiences that engage and challenge pupils’ thinking of science, teachers need to develop knowledge of science teaching, pupils, pupils’ learning and the curriculum that can be translated into meaningful practice. As pre-service teacher education is often teachers’ first opportunity to reflect on the actual use of their subject matter knowledge, the importance of such opportunities can not be over-emphasized (Lederman & Gess-Newsome, 1999). Teachers need to understand the structure and nature of their discipline, have skills in selecting and translating essential content into learning activities, and recognize and highlight the applications of the field to the lives of their pupils (Gess-Newsome, 1999).

The relationship between teachers’ attitudes and behaviour was highlighted by Bandura (1977, 1981) who proposed that every person has a sense of self-efficacy which was connected to his/her beliefs in their own abilities to perform an activity.
Applying Bandura’s theories of self-efficacy to teaching science would suggest that teachers’ behaviour with regard to teaching would be determined by their own confidence in their ability to teach science. It can be seen that teachers have a high self-efficacy while teaching a well known subject, but low self-efficacy while teaching science. In the context of science teacher education an important issue might then be to cultivate a more positive self-efficacy by developing student teachers’ confidence to teach science effectively. In so doing, science teacher educators must empower student teachers to see themselves as learners of both science and science teaching, and also involve them in constructing their own science understandings (Koch, 2006).

2.3. Experience and reflection in teacher education

In order to learn from practical experiences it is reasonable to suggest that experiences must be reflected and reasoned upon with peers as well as with mentors. Therefore an ultimate goal of teacher education might be to develop student teachers’ competence to frame and reframe problems, to reason about solutions according to their interpretations of the situations and to formulate ideas for their future actions. Teachers in general, but perhaps science teachers in particular have to face new challenges all the time in both what they teach (because the scientific knowledge in the society is constantly developing), how they teach it (experimental methods can be unpredictable) and why (school science has for some pupils’ and primary teachers a low priority). In his pedagogical credo (1897) Dewey described beliefs that served as the starting point for a discussion about education:

"I believe that one of the greatest difficulties in the present teaching of science is that the material is presented in purely objective form, or is treated as a new peculiar kind of experience which the child can add to that which he has already had. In reality, science is of value because it gives the ability to interpret and control the experience already had. It should be introduced, not as so much new subject-matter, but as showing the factors already involved in previous experience and as furnishing tools by which that experience can be more easily and effectively regulated." (Dewey, 1897)
Reflecting on one’s own teaching practice can be an intense but also a useful process (Loughran, 2002). Therefore, it seems reasonable to suggest that by encouraging primary science student teachers to reflect on their own teaching they may well develop deeper insights into their understandings of science teaching and learning. As such, learning from experience is crucial in shaping the development of a knowledge base for teaching. Therefore, familiar approaches to teacher research draw on notions of reflective practice (Dewey, 1933; Schön, 1983, 1987). Dewey (1938/1997) drew attention to the need for experience in the development of thoughtful student teachers. Hence, to reflect on and share the learning through experience is critical to the development of student teachers’ learning to teach.

Dewey (1916/1966) described learning as taking place in different situations and not limited to one special situation. A person experiences a situation, successful or unsuccessful, reflects on it and develops a method to handle the situation. We do something, fail, do something new and continue until we finally do something that works and then we use the successful method in the next situation. In the same way people learn from successes. We do something successful which we bring into the next situation. However, we do not always manage to see how actions and consequences are linked together. But if we know on what the results depend, we might also examine what conditions are needed for a good result. Further to this, if we know what conditions are required we can also work in order to satisfy the conditions needed. In such ways, the quality of an experience is changed and we can call it a reflective experience (Dewey, 1916/1966). As Dewey (1933) advocated, “reflective thinking” involves among other things a state of doubt, hesitation and perplexity, and also an act of searching and inquiring to find materials that will resolve the doubts. Hence, the process of reflection is an active one, whereby knowledge is created through experience.

It has been argued (above) that student teachers learn from their experiences. However, it is reasonable to suggest that an individual’s experience has an authority of its own that should be contrasted with other people’s experiences as well as
educational arguments (Munby & Russell, 1994). Building on Schön’s (1983) work on developing knowledge-in-action, Munby and Russell (1994) used the term “authority of experience” to inform oneself about the acquisition and the use of professional knowledge. Accordingly, one way of helping student teachers begin to see into the complexities of teaching and learning in new ways is to foster a sense of trust in their “authority of experience”.

If we transfer this reasoning to the context of science teacher education we can say that student teachers must be given opportunities and possibilities to recognize and further reflect on failures (e.g., failed experiments and demonstrations) and successes in order to acquire a higher metacognitive level, develop an authority of their own experiences and a knowledge base for teaching. Therefore, recognizing that which is a problem (or a success) in practice becomes important starting points for the reflective process. To achieve such a metacognitive perspective, student teachers must not only recognize situations within their teaching but also come to a deeper understanding of their own behavior and the theories and ideas that shape their action strategies. However, it is reasonable to suggest that student teachers’ experiences during practicum placements can be viewed as data from which they might become more informed about their own development as teachers. Having the capacity to reflect on your own practice paves the way to making decisions about the nature of professional learning that also will improve your practice. Hence reflection and analysis might help to identify a person’s needs, both in improving what you already know and in recognizing what you do not know (Bishop & Denley, 2007).

Several studies (e.g., Calderhead, 1988, Korthagen, 1993; Korthagen & Kessels, 1999; Loughran, 2002; Munby & Russell, 1993; Shulman, 1987) emphasize that teachers should become reflective practitioners in order to develop expertise in their practice. Indeed the practice of reflection has become a cornerstone in many teacher education programs. Korthagen (1993) defined reflection as people’s learning to subject their personal beliefs of teaching and learning to a critical analysis, and thus take more responsibility for their actions. According to Boyd and Fales (1983), reflection was a
process of creating and clarifying the meaning of experience in relation to self, but also of self in relation to the external world.

Schön (1983) used the terms “reflection-in-action” and “reflection on action” to refer to a set of skills. According to Schön (1983), “Reflection-in-action” was used to explain how practitioners develop a certain kind of thinking that was incorporated in action which makes them more able to accomplish their work. Hence, the “thinking” was incorporated in practitioners’ doing, in their actual, situated, action. However, according to van Manen (1995) classroom work assumes action over which there is no time to reflect. Theoretical knowledge, knowledge of a special subject and teaching skills are not always directly applicable in the actual classroom of chaos and unexpected events. Other forms of skillfulness are required to master these situations. Van Manen (1995) used the term “Pedagogical tact” to describe this practical and experience-based competence that he recognized as a position between theory and practice and between thinking and action.

Many studies support the view that student teachers should become reflective practitioners in order to develop their practice beyond the technical alone (Calderhead, 1988, Korthagen, 1993; Loughran, 2002). However, as highlighted by Van Manen (1995), studies into reflection illustrate that beginning teachers often experience tensions between their beliefs and their actions in the practice of teaching. Therefore, it could well be argued that the earlier student teachers become aware of their teaching needs the earlier they may begin to systematically study their practice. For that reason, preparation of teachers who are reflective about their practice continues to be a dominant theme in teacher education. As teacher educators, we want our student teachers to recognize and see what factors matters in a classroom (Nilsson, 2008). For that reason, as highlighted in the four papers in this thesis, for student teachers there is a clear need to make explicit their own concerns in order to choose how they might act on them. Therefore “effective reflection” (Loughran, 2002) might help student teachers to recognize aspects within their teaching which they might not have been able to see otherwise.
2.4. Teacher knowledge

In their review of the cognitive and psychological nature of teacher thinking and decision making Clark and Peterson (1986) argued that teachers’ actions were directed by their thought processes and that there was an interactive relationship between teachers’ thoughts and actions. In other words, teachers’ actions were guided by their thoughts which, in turn, were influenced by their actions. Thus, conceptions of teaching influenced teachers’ classroom behaviour and their teaching activities influenced their conceptions of teaching. In their review, Clark and Peterson (1986) highlighted that a major goal of research on teachers’ thought processes was to increase understandings of the “how and why” of the process of teaching (i.e., what does it look like and why does it look that way?)

Clark and Peterson (1986) developed a model consisting of two domains that were important in the process of teaching, teachers’ thought processes and teachers’ actions and their observable effects. They suggested that teachers’ thought processes occurred “inside teachers’ heads” and are unobservable; in contrast to this, teachers’ actions are observable and are more easily subjected to empirical research methods. Therefore, bearing in mind the interactive relationship between teachers’ thoughts and actions, through acts of teaching that are reasoned and reflected upon collaboratively with others (e.g., mentors and peers); student teachers’ learning about teaching might be able to be mapped and therefore illustrated in new ways to others. Thus, it is important to do empirical research on what student teachers do but also do research on stimulating their reasoning about how they interact with pupils, mentors and peers in order to say something about how their interactions influence thinking about, as well as the act of teaching.

It could well be argued that student teachers are often interested in knowledge that is practical and can be applied in the classroom. It is also a common assumption that student teachers do not always manage to make explicit connections between teachers’ actions and the pedagogical theories that inform practice. Theoretical knowledge is not
experienced as immediately useful for student teachers in addressing their problems in practice (Loughran, 2006). Student teachers’ problems of connecting theoretical knowledge with the practical knowledge could well be illustrated by a “zipper metaphor” (Kelchtermans & Ballet, 2006), where one side of the zipper illustrates theory and the other side illustrates practice. When closing the zipper it can get stuck, which then forces the person to stop and to reflect on what is wrong. If we transfer this to the practice of teaching, student teachers might experience critical incidents (Tripp, 1993) when they try to connect theory to practice within their teaching. Those incidents force them to conceptualize aspects of their practice that they need to address in order to meet their explicated pedagogical concerns. However, approaching the development of knowledge as learning through experience can help to bridge theory and practice (i.e., close the zipper) in a meaningful way.

An ongoing concern in the learning to teach literature is the need to help student teachers move beyond notions of teaching as the “delivery of information”, and begin to critically reflect on, and seek to actively develop, stronger links between their teaching, their pupils’ learning and, importantly, their own learning to teach (see for example, Berry, 2004; Chin, 1997; Feiman-Nemser, 2001). Kagan (1992) noted that:

“university courses fail to provide novices with adequate procedural knowledge of classrooms, adequate knowledge of pupils or the extended practical needed to acquire that knowledge, or a realistic view of teaching it in its full classroom/school context” (Kagan, 1992, p. 162).

As the literature makes clear, this is a difficult transition for student teachers because their “apprenticeship of observation” (Lortie, 1975) has created a strong sense of experiencing teaching as telling. Fuller and her colleagues (Fuller, 1969; Fuller & Bown, 1975) performed innovative research (at that time) in developing a picture of the first year of a teacher’s career. In her work she integrated the existing research on teachers’ concerns over time with research on the perceived problems of student teachers, experienced teachers and beginning teachers in order to find “teaching
phases” helpful for teacher educators in developing more appropriate training programmes. Fuller & Bown (1975) posited three distinguishable stages of concerns that were characteristic of teachers. The first stage involved survival concerns which were concerns about one’s adequacy and survival as a teacher, class control, being liked by pupils and being evaluated. The second stage included teaching situation concerns which were about limitations and frustrations in the teaching situation such as methods and materials. The third stage reflected on concerns about pupils, their learning and their social and emotional needs. However, the experience of becoming a teacher involved coping with all three stages.

Teacher knowledge literature refers to a host of words describing the knowledge base needed for teaching. These could be craft knowledge, tacit knowledge, situated knowledge, professional knowledge, personal knowledge, pedagogical content knowledge and pedagogical context knowledge. These names might not necessarily refer to different types of knowledge, but could be, in some way, like names we give to people. Hence it is important not to argue about what we call the certain knowledge, but instead focus on the actual meaning of the concept and what the name stands for. A person is given a first name, a nickname and sometimes also one or two additional names. Even if the context of use might be different, the names always refer to the same person.

In transferring this discussion to Shulman’s (1986, 1987) notion of pedagogical content knowledge (PCK), the concept might be helpful in our thinking about what student teachers need to learn, and what science teacher education needs to offer in order to “effectively” instruct them. The concept of PCK can be helpful in our continuing discussions about what is teacher knowledge and how is it developed. It can be used as a theoretical as well as a methodological framework to structure research on teachers’ knowledge and how it is developed. However, if Shulman wanted to initiate a world wide discussion about the nature and definitions of the knowledgebase needed for teaching, he was surely successful. “Shulman certainly started a ball rolling when he initially (and quite loosely) formulated the concept of
PCK. It may continue to be one of those unfolding stories where the journey is more important than the destination (Bishop & Denley, 2007, p. 204).” Therefore, in the next section the concept of PCK will be carefully discussed.

2.4.1. The notion of Pedagogical Content Knowledge

The question of what makes PCK important and how it might be recognized and developed, initiates an important discussion about what we actually know of science teachers’ professional abilities and the tacit nature of teaching practice. However, does the construct of PCK help or constrain our endeavour of educating teachers? Regardless of what concept of teacher knowledge that best explains the knowledge teachers need to possess, the concept of PCK as a construct and a model has proven to be fruitful. In this thesis the concept of PCK is used as the knowledge a teacher needs to construct and implement science learning experiences for pupils. It is a dynamic form of knowledge that is constantly expanding and being transformed from other forms of teacher knowledge, and through the experiences of planning, conducting and reflecting on science teaching and learning. As highlighted by Bishop and Denley (2007), if we could define the knowledgebase needed for teaching, it might assist new teachers’ structure their professional learning and know better how to acquire it.

In his overview of the research on teachers’ knowledge, Shulman (1986) stressed that research about the content of teaching in relation to the act of teaching was missed during the last century. Shulman further stressed that these questions were important in the context of teacher education as well as for experienced teachers. Shulman (1986) raised the question about the knowledge bases needed for teaching and whether or not teachers possess them. How should the teacher use the content to build on analogies, metaphors, examples and demonstrations in order to promote pupils’ understanding?

In his first PCK paper, Shulman (1986) distinguished between three categories of knowledge: Subject matter content knowledge, pedagogical content knowledge and curricular content knowledge. Subject matter content knowledge was important as the
teacher must not only be knowledgeable of his/her subject but also possess other qualities related to the subject such as the subject matter structure, which content was central and which was on the periphery and in what way the subject could be questioned and criticized. Curricular knowledge was central for the knowledgebase for teaching as the teacher should be aware of the specific curricular goals but also materials and different ways of presenting a teaching content. In the same way as a doctor needs to know more than one way to treat different categories of infectious diseases, a teacher needs to know more than one way to handle a teaching situation. Pedagogical Content Knowledge (PCK) was defined by Shulman as a knowledge that focused on the teaching of the subject: “the most useful forms of representation, the most powerful analogies, illustrations, examples, explanations, and demonstrations” (p. 9). PCK also includes knowledge about what makes the subject difficult or easy to understand (i.e., conceptions and misconceptions about the subject). As such, PCK is a specific form of knowledge for teaching which refers to the transformation of subject matter knowledge. As highlighted by Shulman (1986), teachers need a special type of knowledge to structure the content of their lessons and then to use specific representations or analogies in order to promote pupils’ understandings.

In his second (PCK) paper, Shulman (1987) elaborated his definition of teaching knowledge to comprise seven different categories: “content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, knowledge of educational ends, purposes, and values and their philosophical and historical grounds.” Among those seven, Shulman considered that PCK was of special interest as: “…it identifies the distinctive body of knowledge for teaching. It represents the blending of content and pedagogy into an understanding of how particular topics, problems or issues are organized, represented and adopted to the diverse interests and abilities of learners, and presented for instruction” (p. 8). Hence PCK is strongly related to the teaching of a specific subject. As such, Shulman saw PCK as content knowledge transformed by the teacher into a form that makes it understandable to pupils. So, science PCK then included knowledge of the content to be taught and how
to promote pupils’ learning. Shulman went on to include in PCK “an understanding of what makes the learning of specific concepts easy or difficult: the conceptions and preconceptions that pupils at different ages and backgrounds bring with them to the learning” (p. 9). So, it might well be argued that PCK includes a knowledge of pupils and their pre and misconceptions; hence a pupil-centred pedagogy.

Shulman (1987) then went further to describe the process of pedagogical reasoning and action in which the knowledge base for teaching is developed and used. Pedagogical reasoning though is not as simple as just thinking about teaching. According to Shulman (1987) and Wilson et al. (1987), pedagogical reasoning comprises a cyclic process. Teaching begins with comprehension whereby teachers first need to understand the subject matter themselves and also understand how the ideas within their discipline are interrelated and connected. Comprehension also comprises an understanding of the aims and purposes of teaching. Following comprehension is transformation in which teachers transform their content knowledge into forms that are pedagogically powerful and adaptable so that the content might be understood despite the diversity of pupils’ learning styles. Instruction follows transformation and involves such things as organizing and managing the classroom, explaining, interacting effectively with pupils, discussing and providing effective teaching. Evaluation follows instruction and that includes checking for pupils’ understanding and misunderstanding, as well as the formal testing and evaluation that teachers do to provide feedback and grades. Interestingly, evaluation is also directed at one’s own teaching, at the lesson and the materials employed in those activities. In that sense it leads directly to reflection. Reflection is what a teacher does when she/he looks back at the teaching and learning that has occurred, reconstructs, re-enacts and recaptures the events, the emotions and the accomplishments. Finally then, the process of pedagogical reasoning cycles back to influence new comprehension as a result of the learning achieved through experience. Therefore, through acts of teaching that are reasoned, new comprehension of the content, pupils and the processes of pedagogy emerge.
The exact relationship between PCK and the model of pedagogical reasoning and action was not clearly expressed by Shulman (1987) but could be inferred in general terms from the descriptions above. Knowledge suggests something static, and reasoning and action implies a dynamic state where knowledge is being tested and refined and a new understanding is generated. Shulman (1987) stressed that teacher education should provide student teachers with the understandings and the performance abilities they would need for their pedagogical reasoning. A natural question might then be: “Is it possible to provide the student teachers with “critical incidents” (Tripp, 1993) which might help them recognize and identify important issues for this development to occur?” Thus, teacher educators need to engage student teachers in activities that create experiences and stimulate reflection.

2.4.2. Interpretations and explorations of the concept of PCK

Shulman’s ideas of PCK have created a considerable interest for research as well as for the practice of teaching. Various scholars have further developed conceptualizations of PCK (e.g., Appleton, 2002; Gess-Newsome, 1999; Loughran, Mulhall & Berry, 2004, 2006; Magnusson, Krajcik & Borko, 1999; Van Driel, Verloop & de Vos, 1998) as an academic construct representing specialist knowledge of practice. As such, PCK has become a way of understanding the complex relationship between teaching and content through the use of specific teaching approaches and is developed through an integrated process rooted in classroom practice (Van Driel et al., 1998). On the international arena the concept has been accepted in the educational research.

“PCK has become an accepted academic construct that represents an intriguing idea. It is an idea rooted in the beliefs that teaching requires considerably more than delivering subject content to students…PCK is the knowledge that teachers develop over time, and through experience, about how to teach a particular content in particular ways in order to enhance students’ learning” (Loughran et al., 2006, p. 9).
Despite that, a lot of researchers still aim to identify the concept. However, it is important to consider that it is not the concept itself that needs to be discussed but the knowledge of what the concept actually stands for. Bishop and Denley (2007) highlighted that rather than seeing PCK as a different “type” of knowledge, it could be viewed as a sophisticated process of combining knowledge bases together for particular contexts in relation to classes, topics or other factors. Therefore, instead of arguing about the definition of PCK it is important to focus on the processes that are involved in the development of PCK.

With a focus on science education, Gess-Newsome and Lederman (1999) made the first systematic effort to synthesize the research on PCK and the model from which the concept originated. Their aim was to find implications for the concept in research as well as in practice. They raised questions about the common conceptions of PCK: “What research exists to support PCK and the related constructs of teacher subject matter knowledge and pedagogical knowledge? How have researchers used both PCK and its related constructs to develop lines of research on teacher thinking and learning? and, How have visions of PCK been applied to teacher preparation program development and evaluation?” (Gess-Newsome, 1999, p. 4)

In her introductory chapter Gess-Newsome (1999) described two extreme models of teacher knowledge, the Integrative and the Transformative model. In the Integrative model, PCK does not exist as a domain of knowledge and teacher knowledge is explained as an intersection of subject matter, pedagogy and context. When teaching in the classroom, knowledge from all the three domains is integrated to create effective learning opportunities. According to Gess-Newsome (1999), an expert teacher, then, is one who has well-organized individual knowledge bases that are easily accessed into and could be flexibly drawn upon during the act of teaching. An advantage (in terms of considering the development of practice) of an integrative model is that domains of knowledge can be developed independently and be integrated at a later stage. Therefore, later on, knowledge of specific teaching can be deconstructed to its original area, to be deepened or reorganized later (Gess-Newsome, 1999). A potential danger
with the Integrative model is that teachers may never see the importance of such knowledge integration.

The Transformative model represents a synthesis of all knowledge needed in order to be an effective teacher. Knowledge of subject matter, pedagogy and context, whether developed separately or integrated are transformed into a new form of knowledge that is more powerful than its constituents parts. Thus, the three knowledge bases become more useful when transformed into PCK. An expert teacher, then, has well formed PCK for the topics commonly taught. The danger with this extreme is that it could be seen as objectifying teaching and so student teachers’ decision making skills, personal growth and creativity might be overlooked.

Grossman (1990) conceptualized PCK as consisting of four components: knowledge of subject matter; knowledge of pupils’ conceptions and difficulties; knowledge of curriculum; and, knowledge of instructional strategies. PCK is then developed as a result of a knowledge transformation, but unlike the transformative model of Gess-Newsome (1999) there is a reciprocal relationship between the domains. Magnusson et al. (1999) suggested that teachers hold different views and beliefs about teaching and learning. They identified orientations (e.g. academic rigor, conceptual change, activity driven, discovery, project based science, inquiry and guided inquiry) that influenced teachers’ choices of aspects such as learning goals, learning experiences and teaching strategies. Magnusson et al. (1999) further developed a model of PCK for science teaching through which the “overarching knowledge for teaching” consisted of five different components: (1) orientations toward teaching science, (2) knowledge of science curricula, (3) knowledge of pupils’ understanding of science, (4) knowledge of assessment in science, and (5) knowledge of subject-specific and topic-specific strategies. As the components interact in complex ways effective teachers need to develop expertise in all aspects of pedagogical content knowledge, and with respect to all topics they teach.
Magnusson et al. (1999) used the term orientation to represent a general way of viewing or conceptualizing science teaching. Knowledge and beliefs in this area guide a teacher’s instructional decisions about the organization of activities, the content of pupils’ assignments, the use of textbooks and curricular materials and the evaluation of pupils’ learning. They further stressed that the development of PCK is a complex process which is determined by the content to be taught, the context in which the content is taught and the way the teacher reflects on his/her teaching experiences. If the student teachers are to be successful in creating classroom environments in which subject matter and pedagogy are integrated in a way that promotes pupils’ learning, they must experience such learning environments themselves (Magnusson et al., 1999).

To describe the relationship between PCK and the other six categories of knowledge that Shulman (1987) proposed, Bishop and Denley (2007) used a metaphor of a spinning top with coloured segments (knowledge categories) that were discrete and readily distinguished from each other when the top was still, but which merged to form a different colour when spun. The new colour was generated from the component colours but was different from them. As Shulman (1987) defined PCK as an amalgam of knowledge, the “spinning top metaphor” illustrated PCK as a dynamic construct which is not amenable to static representation and can only be “seen” in action (Bishop & Denley, 2007). The focus on the thinking behind the selection and application of knowledge instead of the individual bits of knowledge themselves is somehow close to the notion of “pedagogical content knowing PCKg” developed by Cochran, De Ruiter & King (1993). Hence, PCK is to be considered as a dynamic knowledge generated in practice through the capability of the teacher to be able to combine or blend the individual knowledge bases together (Bishop & Denley, 2007).

Even if there is a large amount of research on teacher education and the expertise of teaching, the Swedish research on science teacher education has been relatively limited. Lager-Nyqvist (2003) followed student teachers during their teacher education and then as beginning teachers in order to make them express their ideas about the
teacher’s role, the teaching methods and content and also about the practical training
during their teacher education. Lager-Nyqvist (2003) concluded that teacher education
programs had obviously not changed the student teachers’ ideas and neither had it
offered the student teachers opportunities to develop their PCK according to their own
goals and the school curricula. Ekborg (2002) studied how student teachers developed
relevant knowledge in science for teaching about the environment, and how the
student teachers’ reasoning about complex scientific relationships developed during
teacher education. Further to this Zetterqvist (2003) explored the complexity of teacher
education when investigating biology student teachers learning to teach evolutionary
biology.

Across the views of PCK described above, what kind of PCK is relevant from the
point of view of science teacher education? Giving support to the ideas of considering
PCK as a dynamic knowledge generated in practice through the capability of the
teacher to combine the individual knowledge bases together, there is commonality in
terms of three well recognized knowledge bases: Pedagogical Knowledge (PK);
Subject Matter Knowledge (SMK); and, Contextual Knowledge (CK). However, their
specific definitions and their relation to PCK must be explored. Pedagogical
Knowledge (PK) consists of general elements regarding teaching, classroom
organization and management, instructional models and strategies, classroom
communication, lesson plan development and implementation, and student evaluation.
Hence, Pedagogical Knowledge concerns the processes and practices or methods of
teaching and learning and how it encompasses overall educational purposes, values
and aims. As such, pedagogical knowledge requires an understanding of cognitive,
social and developmental theories of learning and how they apply to pupils in their
classroom (Mishra & Koehler, 2006). Contextual Knowledge (CK) is strongly
connected to PK and represents knowledge of school departments, traditions, behavior
of pupils, the climate in the classroom, the relationship between individuals, and the
context in which teaching takes place. The contextual knowledge therefore also
includes an understanding about social and special need education knowledge and
theories and, their applicability in the classroom.
Finally, a teacher also needs to understand the central concepts and structures of the discipline(s) in order to create learning experiences that make the content meaningful to all pupils. Therefore Subject Matter Knowledge (SMK) refers to a teacher’s quantity, quality and organisation of information, conceptualisations and underlying constructs in a given field of science (Zeidler, 2002). As mentioned in earlier research (Abell, 2007; Gess-Newsome, 1999), lack of SMK makes it difficult for student teachers to relate phenomena to everyday situations, but subject matter alone is not sufficient. Different knowledge needs to be transformed.

Thus, from the point of view of this thesis, PCK is considered as a dynamic construct. A complex entity built on definable knowledge bases, where the components of knowledge function as parts of a whole and a lack of coherence between components can be problematic in developing and using PCK. As the components interact in a highly complex way (e.g., in the spinning top), it is important to understand not only the particular components of PCK, but also to understand how they interact and how their interaction influences thinking about, as well as the act of teaching.

Loughran et al. (2006) emphasized the importance of helping student teachers as well as experienced teachers in understanding their practice in order to increase their understanding of their tacit knowledge, and hence, influence their foundation of PCK. Thus, to recognize different aspects in a teaching situation and also to interpret the impact of those aspects becomes important for the development of a knowledge base needed for teaching (i.e., PCK).

2.5. Experts and novices in different contexts

In the context of teacher education research, the discussion of teaching expertise and how it develops are important issues. Further to this, as student teachers (in this research context) spend about twenty weeks in the school context working together with experienced teachers, the relationship between the novice (student teacher) and the expert (mentor) must be investigated and further explored (paper 3). As we know
from research (e.g., Berliner, 2004; Björklund, 2008) expert teachers operate in a qualitative different way than novices. Based on comparative studies on expert and novice teachers, Dreyfus (2004)\(^1\) and Berliner (1988) introduced a five stage model of teacher development: *novice* (class-room teaching is rational and relatively inflexible); *advanced beginner* (the teacher develops strategic knowledge and classroom experiences and the contexts of problems begin to guide the teacher’s behaviour); *competent* (the teacher makes conscious choices about actions, knows the nature of timing and what is and is not important); *proficient* (intuition and know-how begin to guide performance and a holistic recognition among contexts is acquired. The teacher can predict events); and, finally *expert* (intuitive grasp of situations, teaching performance is fluid as the teacher no longer consciously chooses the focuses of attention).

As advocated by Kagan (1992) the stages in Berliner’s model were distinguished from each other concerning how a teacher monitors the events in the classroom and the degree of consciousness involved in the teaching. Kagan (1992) described the behavioural and conceptual development of beginning and novice teachers in five components: an increase in metacognition (novices become more aware of what they know about pupils and classrooms and how their knowledge and beliefs are changing); the acquisition of knowledge about pupils (knowledge of pupils are used to modify the novices image of self as a teacher); a shift in attention (the attentions shifts from self to the instruction and learning of pupils); the development of standard procedures (novices develop standardized routines that integrate instruction and management); and, finally, growth in problem solving skills (thinking associated with classroom problem solving grows more differentiated, multidimensional and context-specific).

Kagan’s (1992) model accounted for the shift in a novice’s concerns from self to the pupil suggesting that the novice’s initial focus constituted necessary and valuable

\(^1\) A summary of the author’s fivestage model of adult skill acquisition, developed in collaboration with Hubert L. Dreyfus. An earlier version of this article appeared in chapter 1 of Mind Over Machine: The Power of Human Intuition and Expertise in the Era of the Computer (1986, Free Press, New York)
behaviour. Before the initial self-image was adapted and reconstructed, the novice could not progress. Thus, the development of expertise was identified through a move towards an unconscious recognition of common patterns, flexible automated routines (Kagan, 1992).

As Berliner (1988) argued, there might be too little in the minds of student teachers about what actions that might be realistic, relevant and appropriate in a teaching situation. As mentioned by Bransford, Brown and Cocking (2000), the idea that experts recognize features and patterns that are not noticed by novices is potentially important for improving teaching. One dimension of acquiring greater competence in teaching then appears to be the increased ability to “unpack the practice” and learning how to see and recognize important aspects needed for teaching (Nilsson, 2008). Further to this, if you can get expert science teachers to articulate what they know about teaching, student teachers might be able to use these insights in their learning to teach (i.e., teaching needs in paper 1 & 2). Research on expertise suggests the importance of providing pupils with learning experiences that specifically enhance their abilities to recognize meaningful patterns of information. Referring to Bransford et al. (2000) a person who has developed expertise in a particular area of knowledge is able to think effectively about problems in that area. Hence, an expert can notice the features and meaningful patterns of information acquired from nature through observations or experiments.

Even though the idea of expertise might apply to all sorts of fields, in connection to expert teachers’ and student teachers’ (novices) recognition of important aspects of their PCK, it could be possible to make a comparison with the expertise of wine tasting. Hughson and Boakes (2002) emphasized that experts and novices used different criteria to categorise domain-specific problems, in that novices use simplistic surface features whereas experts use underlying principles. Comparing this to the context of teaching, expert teachers might have more descriptive abilities with respect to describing a teaching situation and hence to recognize important aspects needed for teaching. Further to this, Parr, White, & Heatherbell (2004) explored the nature of
wine expertise through investigating the recognition of wine-relevant odours as a function of wine expertise. However, surprisingly they found that the recognition memory for domain-specific aromatic compounds by wine experts was, despite their odour-identification skills, similar to those of novices. One possible reason for this result might be the fact that many wine-relevant odours are also everyday odours and for people who enjoy cooking and gardening it could be well known odours.

Let us return to the recognition of aspects needed for teaching. Every person who has been in the school context, either as a pupil, parent or teacher might recognize factors that identify “best teaching”. But this must not necessarily mean that they would be able to teach in the “best way”. General factors such as “knowing the subject and to like children” might be recognized by all conceivable persons, but more underlying principles (Hughson & Boakes, 2002) connected to PCK might be more difficult to recognize. The expert wine taster has experienced hundreds of different wines and has learnt to interpret and analyze the factors that make the wine good or bad. As a result of long experience the expert has learnt to recognize different nuances, differentiate between two wines and even put words on and identify the difference. If we again transfer this reasoning to student teachers learning to teach, their ability to recognize their teaching needs (i.e., elements that constitute the knowledge base of teaching) is crucial if they are to develop those elements and transform them into pedagogical content knowledge.

Van Driel et al. (1998) emphasized the importance of classroom experience in order to develop PCK. Hence, this would suggest that student teachers with very brief teaching experience would lack PCK. Using the metaphor of the wine taster, the novice does not have enough knowledge about what characterizes a good wine. To appreciate a Chateaux Muzar you must learn to recognize its good characteristics. To be able to develop your PCK you must learn to recognize elements that build it up. With this background PCK might be considered as a useful concept in order to analyze, describe and characterize the complex phenomena called science teaching. Although student teachers (novices) can not always identify their own needs it might be reasonable to
suggest that one important factor for enhancing a development of PCK is through \textit{recognizing} and \textit{confronting} the difficulties and dilemmas of practice. Therefore, they must be offered adequate tools to manage this recognition. The methods used in the papers in this thesis (stimulated-recall, story-lines, interviews) but also reflective portfolios (Nilsson, 2008) are all tools to stimulate student teachers; “seeing” into their own practice.

There is a need to capture the different elements needed for teaching and to find ways of how student teachers might “spin the top” (Bishop & Denley, 2007) during teacher education. “The best strategy might be to combine a theoretical and empirical analysis to generate as complete a picture of PCK as possible and yet keep it grounded in classroom practice” (Marks, 1990, p. 11). Also, a proper understanding of the sophisticated development of PCK with student teachers may support teacher educators’ thinking about what student teachers need to learn, and what science teacher education needs to offer in order to effectively instruct them.

3. The research process

3.1. Framing the four studies

During the years I have worked with the four papers my intentions have been to find issues that student teachers themselves identified as important for their learning to teach. Hence there are several issues in the papers that tie them together. The first issue is that all four studies concern student teachers’ own expressed experiences and concerns for learning and teaching science that ground the basis for empirical data. The second issue concerns the methods as all four papers deal with reflection on teaching and learning. The third issue is the concept of PCK, which is discussed in all four papers. As such all four studies in the thesis were concerned with my own efforts as a teacher educator researcher to investigate how different knowledge bases needed for teaching were perceived by student teachers through reflection on their teaching
experiences (paper 1-3). Further to this, as the first three papers all highlighted the importance of a positive attitude towards science and an appropriate subject matter knowledge, the fourth paper then focused on how different factors, such as practical experiments and following group discussions, contributed to primary student teachers’ development of subject matter knowledge in combination with a more positive attitude towards physics. Thus, the studies together aimed to contribute to the knowledge of ways student teachers’ learning about teaching can be portrayed and understood and the critical aspects that student teachers experience within their teaching and learning practices.

The data that this thesis builds on comes from four different studies, all four on primary science student teachers at the department of teacher education. In the first study, four student teachers in the final year of a four and a half year pre-service program (Maths/Science for primary and secondary school) participated in a specific research project: Journey of knowledge in physics. This project aimed to inspire primary school pupils’ interest in science and technology, and to provide student teachers with possibilities to regularly teach and learn science in a school setting. Over the course of a year, the four student teachers taught physics once a week. They worked in pairs in their teaching assignments. As the project was not a regular part of their pre-service training, they planned the lessons themselves, with no input from the teacher educators. During the year, each pair was video recorded by the researcher for six lessons. In two different stimulated recall interviews, the researcher discussed three of the six video recorded lessons with the student teacher pairs (i.e., Interview 1: Lessons 1, 2, 3; Interview 2: Lessons 4, 5, 6). The data obtained from the stimulated recall sessions were analysed in order to produce a description of what the student teachers raised through their reflections. Hence, the aim of the recall approach was to present a detailed description of the student teachers’ experiences with the goal of seeking to better understand the complex notion of their professional learning.

The context of the second study was a primary science teacher method course in a Science Learning Centre located at the university. The Science Learning Centre is a
specific room, specially designed to stimulate pupils’ scientific learning. It is also used in primary science teacher education methods courses as it offers many opportunities to prepare and evaluate different experiments, but it also provides an opportunity to experience science teaching in an out of school environment. The Science Learning Centre was initiated in 2002 and has since been used in teacher training and in science teacher professional development courses. In addition it also offers an opportunity for pupils aged four to eleven to attend the centre to experience science lessons as an additional component to regular schooling. The lessons normally include different experiments aimed to encourage the pupils to experience science as something interesting. The pupils are stimulated to work in a problem-based manner, putting forward hypotheses, documenting their observations and discussing their results.

The student teachers who participated in the second study were studying in a three-and-a-half year’s educational program, where one year was dedicated to teaching math and science to pupils aged up to eleven. At the time of the study they were in their third term having a task to plan and conduct a lesson with a group of pupils in the Science Learning Centre. The student teachers worked in pairs or trios and the themes of the lessons concerned mostly different scientific phenomena related to an everyday context.

The data collected consisted of (A) questions to the student teachers before the lesson, (B) questions to the pupils and (C) written answers of the questionnaire at the seminar and (D) tape recordings of group discussions concerning the answers of the questions of A, B and C and the student teachers’ spontaneous reflections in the seminar. As the questions before the lesson and the questions to the pupils were all sources of written data, and were only shared by the student teachers who taught the lesson, the intention of conducting a group seminar after the lesson was to place the reflection in a social context to stimulate student teachers’ pedagogical reasoning.

The third study concerns what and how primary science student teachers and their mentors learn from planning and reflecting together on each other’s science lessons for
pupils aged 7 to 9. It examined what two mentoring primary teachers and two primary science student teachers learned from their common experiences while planning, carrying out, and reflecting on different science teaching activities during a four-week school practicum. The student teachers had had training in scientific knowledge, but only brief experiences of teaching. The mentors were well experienced in the pedagogy of teaching and mentoring, but did not feel confident about their science content knowledge and the teaching of science. During the four weeks, two lessons of each of the student teachers and mentors were video recorded. The student teachers and the mentors, working in pairs, reflected on each video-recorded lesson in a stimulated recall session. During their reflections, the student teachers and the mentors expressed several examples of their joint learning experiences throughout the process of working, observing, and reflecting together.

The research context of the fourth study was an eight-week physics course in the second term of a three-and-a-half-year pre-service primary teacher programme where one year was dedicated for science (c.f. study two and three). The study aimed to investigate how different factors, such as practical experiments and subsequent group discussions, contributed to primary student teachers’ development of subject matter knowledge in combination with a more positive attitude towards physics. During an eight-week course, 40 primary science student teachers worked in groups of 13-14 in experimental workshops on practical experiments and problem-solving skills in physics. The experiments had an open design and were built on everyday phenomena (such as investigating acceleration and forces in an elevator). The student teachers were video recorded in order to follow their activities and discussions during the experiments. In connection with every workshop, the student teachers participated in a seminar; they watched the video-recording in order to reflect on how they communicated their conceptions in their group. After the eight weeks of coursework a questionnaire including a storyline was used to elicit the student teachers’ perceptions of their development of subject matter knowledge from the beginning to the end of the course. Finally, five participants were interviewed after the course.
3.2. **Research questions**

In the introduction chapter the overall research question was presented as:

- In which ways can student teachers’ learning about teaching be portrayed and understood in terms of the critical aspects that are experienced within their teaching and learning practices?

In the four papers, several specific research questions have been posited in order to more fully outline the research. These are summarized below:

*Paper 1:*
- Which elements of PCK were perceived by the student teachers in their reflections about teaching pupils aged nine to eleven?

*Paper 2:*
- What critical incidents influence student teachers’ pedagogical reasoning in learning to teach?
- What teaching concerns do student teachers recognize in their own practice as they reflect on their learning to teach?
- What teaching needs do the student teachers formulate in order to manage their identified teaching concerns?

*Paper 3:*
- What knowledge do student teachers develop from their mentors while jointly planning and reflecting on each other’s science lessons?
- What knowledge do mentors develop from student teachers while jointly planning and reflecting on each other’s science lessons?
- What knowledge do student teachers and mentors develop from pupils while jointly planning and reflecting on each other’s science lessons?
Paper 4:

- What factors do primary science student teachers consider important for their development of subject matter knowledge in physics?
- How do these factors contribute to the student teachers’ development of SMK and a positive attitude towards physics?

The answers to all these questions offer meaningful insights into student teachers’ learning to teach and hence their complex journey from learners to teachers.

4. Methodological framework and research design

Underpinning the qualitative methods (Cohen, Manion & Morrison, 2007) used in the four studies was the assumption that issues concerning teaching and learning do not happen in a social or a cultural vacuum but in communities of practices. From the perspective of Vygotsky (1934/1986) and Wenger (1999) the sociocultural nature of learning suggests that work with other individuals is a critical component of the learning processes. Further on, as highlighted by Dewey (1933) learning is highly dependant on the activities in which a person participates and how the person reflects on his/her experiences. Hence, when student teachers (and mentors) are encouraged to reflect on and discuss their teaching and learning experiences with peers, they might [or not] conceptualize important aspects related to their development of a knowledge base needed for teaching.

As this research focuses on individual actors (or groups of actors) attempting to understand their perceptions of events, the research has been inspired by a case study approach (Cohen et al., 2007). Case studies observe effects in real contexts and recognize that the context is an important determinant of both causes and effects. Therefore, in this thesis student teachers and mentors within the context of teacher education and primary school practice are considered as cases.
According to Cohen et al. (2007) the context is unique and dynamic; hence case studies investigate and report the complex dynamic and unfolding interactions of events, human relationship and other factors in a unique instance. Case studies are concerned with a rich and vivid description of events relevant to the case and strive to illustrate what it is like to be in a particular situation and to catch “thick descriptions” (Geertz, 1973) of participants’ lived experiences of, thoughts about and feelings for a situation. Further to this, case studies look at cases or phenomena in real life context usually employing many different types of data (Cohen et al., 2007). In the context of this research, I have been aware of the ways in which my perception and background as a teacher educator shaped the research and how the cases were designed and data was collected. However, my awareness of the effects that my background could have on the research process has stimulated my reflexivity (i.e. recognition of how previous experiences might impact on the interest of and the implementation of the examination).

In the four papers, several methods of data collection have been used to illustrate student teachers’ learning about teaching in terms of the critical aspects that were experienced within their teaching and learning practices. In three papers (papers one, three and four) stimulated recall interviews were used to stimulate student teachers´ (and mentors´) reflections on their teaching. In paper two both written reflections and group interviews were used. Except for the stimulated recall sessions, in paper four storyline questionnaires and semi-structured interviews were also used. Thus, even though the four studies all attempted to answer the same overall research question, each paper highlights different aspects concerning student teachers´ teaching and learning science. Therefore, appropriate methods to collect data were selected in order to respond to the different research questions that were posed in the four papers and to collect reliable data appropriate to the specific nature of each study comprising the specific paper.

According to Cohen et al. (2007) triangular techniques in the social sciences attempts to map out or explain more fully the richness and complexity of human behaviour. In
this thesis triangulation is not used in all four individual papers, but taking into account that the four papers all refer to the overall research question, the concept of triangulation is worth to be mentioned. As research methods are like a filter through which the environment is selectively experienced, they are never neutral in representing the world of experience. Exclusive reliance on one method might then distort a researcher’s picture of the particular aspect being investigated. However, what is important concerning the different methods of data collection in this thesis is that they are all designed in order to seek to illustrate the nature of participants’ learning to teach (student teachers and mentors) and may be described as interpretive or subjective. Therefore, the purpose of the different methods used in this thesis is designed to illustrate, analyse and interpret situations through accessible accounts (e.g., student teachers’ reasoning and reflections) to give a richer and deeper picture of each particular case. Case studies are also used to capture the complexity of behaviour and to contribute to action and intervention (Cohen et al., 2007). The “cases” in the four studies consisted of student teachers and mentors (paper three).

Finally the methods for analysing the collected data in all four papers were based on qualitative methods. According to Cohen et al. (2007) qualitative data analysis involves organizing, accounting for and explaining the data: “in short, making sense of data in terms of the participants’ definitions of the situation, noting patterns, themes, categories and regularities.” (p. 461).

In qualitative analysis, the researcher decides which data are to be selected for description and further investigation. This usually involves some combination of deductive and inductive analysis. While initial categorizations are shaped by the pre-constituted research questions, the researcher should remain open to inducing new meanings from the data available. Thus, analysis becomes a reflective interaction between the researcher and the de-contextualized data that are already interpretations of a social encounter. The researcher brings to the data his or her preconceptions, interests, background and agenda. Therefore, in conducting qualitative data analysis, a
great deal of self awareness and caution must be exercised by the researcher (Cohen et al., 2007).

In the four papers that comprise this thesis, content analysis (Miles & Huberman, 1994) has been used in order to reveal the different ways in which student teachers (and their mentors) perceived their teaching and learning. The aim of the content analysis was to identify, and further analyse transcriptions within the data which appeared to be central in the participants’ reflections. According to Cohen et al. (2007) content analysis examines any form of communicative material and may be applied to substantive problems at the intersection of culture, social structure and social interaction. Hence, content analysis can be undertaken with any written material and is often used to analyze large amounts of text data. Content analysis involves coding, categorizing (relating meaningful categories into which words, phrases and sentences can be placed), comparing categories and making links between them and finally drawing conclusions from the text data (Cohen et al., 2007).

4.1. Data collection methods used in the studies

As described above, in order to capture the complexity of student teachers’ learning to teach and thereby make explicit the factors that student teachers described as important within their journey from learners to teachers, different methods were used. Stimulated recall interviews were used in study one and three, written questionnaires were used in study two and four, group interviews were used in study two and finally storylines and semi-structured individual interviews were used in study four.

4.1.1. The stimulated recall interview

Video-recording of the teaching in the classroom was used to stimulate the student teachers’ (and mentors’ in paper three) reflections on their teaching and to remind the participants of their own activities and thinking. This “stimulated recall approach” has been used in several studies to facilitate student teachers’ and teachers’ learning from
their experiences where respondents comment on their work (Alexandersson, 1994; Brown & Harris, 1994; Calderhead, 1981; Clark & Peterson, 1986; Davis, 2003; Freitas et al., 2004; Mead & McMeniman, 1992; Stough, 2001). Thus, the teacher is enabled to recollect and report on his or her thoughts and decisions during the teaching episode. The teacher’s reports and comments about thoughts and decisions while teaching are audio-taped, transcribed and subjected to content analysis (Clark & Peterson, 1986).

Jensen (2002) described stimulated recall as an enlightening and detailed method to elicit information about student teachers’ teaching. During the stimulated recall interviews in study one and three the participants studied the video tape together with the researcher and were asked to stop the tape and comment on “special events” in the teaching situations. The notion of a special event was explained to the participants before the session to be something that made them reflect, e.g., connected to their activity and their interaction with the children during their teaching; e.g., how they experienced the lesson, their feelings, attitudes and intentions. In paper four, stimulated recall was used to stimulate student teachers’ reflections on their activities and discussions during the experimental workshops. In all three studies, the stimulated recall sessions were designed to explore what student teachers themselves perceived as important components for their own knowledge base for teaching and how these aspects of teaching were transformed during classroom practice. In so doing, it was anticipated that responses would offer insights into the development (or otherwise) of participants’ PCK.

4.1.2. The story-line method

In study four the story-line method was used as one way of collecting data. The story-line method focuses on teachers’ stories, i.e., the way teachers make sense of, evaluate and clarify their own experiences and events in practice (Beijaard, Van Driel & Verloop, 1999). Beijaard et al. (1999) tried to determine how and under what conditions this method could be used to best elicit teachers’ practical knowledge about
relevant current and prior experiences and events in their professional lives. The method was also used by Gergen (1988) to evaluate college students’ feelings of general well-being and by Henze (2006) to view the development of teachers’ knowledge as teachers’ learning in a workplace. As mentioned by Beijaard et al. (1999), a story-line can be qualified as progressive (from a negative to a positive evaluation), stable or regressive (from a positive to a negative evaluation). Further to this, not only the direction of the story-line but also the incline contains information of a certain experience or event.

The story-line method was used to “trigger” the student teachers’ reflections in order to uncover events during the eight weeks that pertained to their development of subject matter knowledge. The student teachers were asked to grade (on a five point scale where 1 was low and 5 was high) how their subject matter knowledge in physics developed every week. Hence, the story-line represented student teachers’ evaluation of their level of knowledge of physics on the vertical line of the graph on a 5-point scale, which was plotted in time on a horizontal time scale during eight weeks.

According to Gergen (1988) the information collected with the story-line method can sometimes be too general or fail to do justice to all details. Therefore, a questionnaire was also used where all the student teachers were asked to clarify their story-lines and describe events that influenced high and low points in the graph in order to “unpack” factors that they perceived as important for their attitudes towards and learning of physics.

4.1.3. Semi-structured interviews

Semi-structured interviews (Cohen et al., 2000; Kvale, 1996) were used in the fourth study in order to get a deeper insight into the student teachers’ ideas and perceptions. According to Kvale (1996) semi-structured interviews are conducted with a quite open framework which allows a two-way communication between the researcher and the
researched. Hence, semi-structured interviews can be used both to give and receive information.

In study four the interviews were based on the written questionnaire with the storyline. Unlike the questionnaire where detailed questions were formulated, in the semi-structured interviews firstly the student teachers were questioned about their experiences of the course. Then they were asked to carefully comment on their storylines and to explain what had caused the high and low points, the directions or changes of directions and the directions of inclines. Finally they were asked to further elaborate their answers in the questionnaire. Significant for the semi-structured interviews were that several questions were created during the interview, which allowed both the researcher and the student teacher the flexibility to probe for details or discuss issues.

4.2. Validity of the study

In qualitative research the relationship between the researcher and the respondent(s) might be considered as an ethical concern. How can my desire as a researcher to receive feedback in the interviews be reconciled with the need to avoid influencing the informants’ stories?

Cohen et al. (2007) highlighted that validity might be addressed through the honesty, depth, richness and scope of the data achieved, the participants approached, the extent of triangulation and the objectivity of the researcher. In qualitative data the subjectivity of the respondents, their opinions, attitudes and perspectives together contribute to the results of the study. However, data are socially situated and the natural setting and the context become important. In naturalistic research (as opposed to positivistic), the researcher is a part of the researched world and as we live in an already interpreted world a double ‘hermeneutic exercise’ is necessary to understand others’ understandings of the world (Cohen et al., 2007). There should also be holism in the research and the researcher, rather than a research tool, constitutes the key instrument of research. Cohen et al. (2007) further argued that in naturalistic research the data are
descriptive and there is a concern for process rather than simply with outcomes and data are analyzed inductively rather than using a priori categories. Data are also presented in terms of the respondents rather than researchers, hence, seeing and reporting the situation should be through the eyes of participants. As stressed by Cohen et al. (2007) we as researchers are part of the world that we are researching and we cannot be completely objective about that.

One important aspect of validity concerns reflexivity. Reflexivity is, according to Cohen et al. (2007), the recognition that researchers are a part of the social world that they are researching and that this social world is an already interpreted world by the actors undermining the notions of objective reality. Researchers bring their own biographies to the research situation and participants behave in particular ways in their presence. As stressed by Cohen et al. (2007) reflexivity suggests that the researcher should acknowledge their own selves in the research seeking to understand their part in or influence on the research. Rather than trying to eliminate the researcher’s effect, which is impossible as the researcher is a part of the world they are researching, they should hold themselves up to the light. As such, “highly reflexive researchers will be acutely aware of the ways in which their selectivity, perception, background and inductive processes and paradigms shape the research” (Cohen et al., 2007, p.172).

The notion of reflexivity is also central to action research because the researchers are a part of the social world they are studying. However, what has been required in the notion of reflexivity is a self conscious awareness of the effects that the participants-as-practitioners-and researchers are having on the research process and how their values, attitudes, perceptions, opinions, actions, feelings etc. are feeding into the situation being studied. Finally reflexivity is when the researcher during the research process tries to see things from different perspectives. Reflexivity concerns the researcher’s own interest for the problem and own connection to the research project and how previous experiences might impact on the interest of and the implementation of the examination. Further to this, reflexivity could be about how to approach the empirical
data and how the researcher comments and reflects on the relation between the interviewer and the respondent.

Kvale (1997) outlines different kinds of validity of which I see at least three of them as central to this work, pragmatic validity, communicative validity and inter-subjective validity. First, pragmatic validity includes the extent to which the research outcomes are considered as useful. Pragmatic validity is based on observations and interpretations, and is joined with a commitment to actions related to the interpretations. Hence, the validity of the knowledge is tested through the way it actually is brought into action in order to change practice (Kvale, 1997). As such, if the action results in the desired result, the knowledge is valid. Thus, justification of knowledge is replaced by application, with a pragmatic concept of validity. Action research is one of those approaches that emphasize actions that in turn can change practice. In action research, researchers and respondents develop a common knowledge about a social situation and then apply this knowledge through new actions in this situation, whereas the validity of the knowledge is then tested in practice. The research outlined in this thesis seeks to bring together student teachers’ actions and reflections. Hence, central to these studies is the importance of the relationship between theory and practice and how to interpret practical knowledge that comes out of student teachers’ [and their mentors’] experiences. Therefore, the research process in itself may generate important insights into student teachers’ learning to teach, as well as a frame to interpret these insights.

Second, Kvale (1997) outlines a communicative approach to validity. This approach is built on the notion that an interpretive process can never be objective, but is always inter-subjective and the data is interpreted as experienced by the researcher (Kvale, 1997). However, communicative validity concerns the way the researcher argues for the relevance of his/her interpretations. Communicative validity is related to the inter-subjective validity which concerns the way the research has been reviewed and criticized during the process and also the academic status of the persons who have discussed the work. In a research context where data can be interpreted in many
different ways, the researcher’s ability to argue convincingly for the interpretation that they have proposed must be stressed. The researcher does not search for the ‘right’ interpretation, but for an interpretation that is defensible, in a context where the researcher is selecting from a range of possible interpretations (Kvale, 1997). On this basis, both the research methods and final interpretation need to be regarded as appropriate by the relevant research community. Participation in research seminars, conference presentations and peer reviewed journals provide a source of feedback from a communicative approach to validity. Communicative validity is developing through communication and both the researcher and the respondents learn and change through the dialogue. However, the researcher’s interpretation is not objective as the researcher searches for underlying, often implicit meanings in the data. Further, as an individual’s experience of a phenomenon is often dependent on the context, there is no expectation that the respondent would experience exactly the same situation the next time.

This research is supported by pragmatic validity as well as communicative and inter-subjective validity. Concerning pragmatic validity, the methods used, the research design and the results imply that the research actually has a practical application and is useful to school teaching as well as science teacher education. Concerning communicative validity the research studies have all been discussed in research seminars and conferences. All four papers have been discussed by reviewers as well as research colleagues who have promoted important feedback in developing the ideas. Finally concerning inter-subjective validity, all four papers have been reviewed and criticized by peer-reviewers as well as research colleagues during the process. Hence, different researchers have discussed the work and have participated in the process of analyzing and discussing the data.

Cochran-Smith and Lytle (1990) advocated that cooperative research provided valuable insights into the relationship between theory and practice but it often constructs and predetermines the respondents’ and the researcher’s roles in the research process. Hence, the teacher’s perspective might be framed through the researcher’s perspective. In this research the relation between the researcher and the
respondents permeate every aspect of the research process and determines the quality and quantity of the collected information (Cole, 1991). As such, an important condition for the research is the feeling of trust for the researcher. Only a respondent who feels safe in relation to the researcher will be prepared to share his or her experiences. The relation of trust should allow the respondent to “feel sufficiently free and relaxed to be themselves” (Woods, 1985, p. 14).

To achieve this feeling, in all four studies, I explained to the respondents how the research process would be carried out and that my intention as a researcher was not to examine or to assess them but to listen to their stories and try to interpret their experiences. Further to this they were told why and how they were selected for the study and that they were not required to participate if they felt discomfort. They were also assured confidential treatment of the data.

For me as a researcher the reciprocal relation was important for the trustfulness and reflexivity. Therefore, as a researcher I tried to be an active, interested and non-evaluative listener with an open and loyal attitude towards the respondents (Woods, 1985). In much qualitative research the researcher as a person, with his/her interpretative competencies to explore and understand the experiences of the respondents, is an important research instrument. In all four papers the data analysis followed a bottom-up procedure rather than categorizing statements in a pre-determined scheme. As such the research became an inductive process where the empirical data “talked” its own language. My background as a teacher and a teacher educator helped me to recognize different aspects as essential in the collection and interpretation of the data. As Cochrane-Smith and Lytle (1990) advocated, teachers’ participation in research is needed to increase professionalism and raise the level of teaching.
4.3. Ethical considerations

All participants (teachers, student teachers and pupils) received information about the project concerning their involvement, research aims, methodologies and the use of data. In three of the four studies (paper 1, 3 & 4) video-recording was used as a tool to stimulate participants’ reflections. As the research context for study one and three was in a primary school classroom I was very careful to inform the pupils of why I was there and that their participation was voluntary. I also wrote a letter to all pupils’ parents to obtain their written permission to be video-record in the classroom. Further to this, I informed the headmasters of the participating schools.

Concerning the student teachers participating in all four studies, they were all informed that participation was voluntary. All participants were carefully informed about the purposes of the studies and asked for permission to quote them in a research context, such as seminars, lectures, conferences and papers, but that they were guaranteed individual confidentiality and anonymity. In all four studies the participants were guaranteed that the video-recordings should be used only for my own research purpose and should not be showed for anyone else. However, it is important to consider the impact that the video-recordings might have had on the participants. In the first study the video-recording lasted a year. One reason for that was to make the student teachers more confident with the idea that they were video-recorded in the classroom. In the third study I installed the video-camera in the classroom to avoid being “in the way” of the participants. In the fourth study the student teachers themselves were responsible for video-recording their work during the experimental workshop. They installed the cameras in one place in the room and did not pay much attention to it during the workshop.

Other ethical considerations worth mentioning are, for example, my efforts to avoid being normative and ‘pointing finger’ at anyone for not keeping up to their expectations concerning science teaching and learning and expressing ‘wrong’ views. Instead, I wanted to focus on the participants’ stories as the objects of exploration.
5. Results - The four pieces of a puzzle

After almost five years of research on student teachers’ learning to teach, it is natural to be critical to the questions of “What are the results?” and “In what way do the results contribute to the research field in science education?” My first approach to this chapter was to make a ‘copy-paste’ from the abstracts of the four papers and briefly present the results from each paper below. However, considering each paper with its large amount of rich qualitative data, I decided that presenting the results in that way would not do justice to the student teachers’ (and mentors’) vivid descriptions of their experiences. I realized that these five years of thinking, reading, collecting and analyzing data has resulted in four pieces of a puzzle of a very complex picture of student teachers’ learning to teach and teaching to learn. A puzzle where all of the four pieces contribute to the understanding of student teachers’ development of a knowledge base needed for teaching during pre-service teacher education. This chapter starts with a presentation of the four pieces (for more reading see appendix 1-4). Then it goes on to, according to the overall research question, present: (1) ways to illustrate and understand student teachers’ learning about teaching; and, (2) critical aspects that student teachers experienced within their teaching and learning practices (table 1). As such, the patterns and characteristics of the whole puzzle might tell something about the processes that underpin student teachers’ complex journey from learners to teachers.

5.1. Paper 1 - Teaching for understanding - The complex nature of PCK in pre-service teacher education

Paper one initiates a discussion about the knowledge student teachers need to develop in order to be prepared for teaching science in primary schools. As the paper is published in a special issue on pedagogical content knowledge (PCK), and, as it is the first paper in the thesis, it explores the nature of PCK and how it is (or is not) developed during pre-service teacher education. As such, the paper is concerned with science teacher education and examines the difficulties associated with trying to
manage learning about teaching as well as the sophisticated development of PCK with pre-service student teachers.

The paper explores how different elements of PCK may be recognized and individually enhanced and highlights the importance of the need for a conceptualization that shifts PCK from an abstract to a concrete construct. The paper further makes clear how the ways in which PCK is understood and conceptualized impacts on how the construct can be interpreted, developed and implemented in science teacher education to create new ways for student teachers to consider the nature of their own professional learning. Further to this, the paper gives an insight into how, through stimulating student teachers’ reflections on their own classroom experiences, it might influence their understanding of the complex relationship between their teaching, subject matter content and the context, and how such an understanding might foster possibilities for the development of PCK.

Four student teachers in mathematics and science participated in a project teaching pupils aged 9-11 in physics once a week over a period of two semesters. One third of the lessons were videotaped and the student teachers were later interviewed using the video-tape for stimulated recall. Participants reflected on their classroom practice based on their conceptual understanding of physics, their teaching strategies and their interaction with the pupils in the classroom. The research aimed to consider what elements of professional knowledge the student teachers managed to recognize in their practice and how such recognition influenced (or not) the development of PCK.

Through an analysis of the illustrative transcriptions from the four student teachers’ reflections in the stimulated recall interviews, the results draw attention to the way each of the elements of pedagogical knowledge, subject matter knowledge and contextual knowledge were (or were not) recognized in their science teaching. In the paper Gess-Newsome’s (1999) two extreme models of teacher knowledge, the Integrative and the Transformative model are discussed in relation to the empirical data. However, the results in the paper support a view of PCK development as a
process of transformation of pedagogical knowledge (PK), subject matter knowledge (SMK) and finally contextual knowledge (CK). In some situations the student teachers brought up the different knowledge bases as separate units and in some examples they were recognized by the student teachers in a transformed way. The results illustrate how specific examples of the knowledge bases were recognized and sometimes transformed into PCK. Those specific needs emphasized by the student teachers themselves give an insight into student teachers’ struggles and experiences.

Concerning pedagogical knowledge (PK) the student teachers emphasized their need for knowing how to handle their teaching in the classroom such as planning, preparing and deciding on the teaching methods, and how to interact and communicate with the pupils in the teaching situation. They emphasized the use of different teaching methods and ways of explaining phenomena to guide the pupils towards a better understanding; something which also required an act of transformation of PK into PCK.

Concerning their need for subject matter knowledge (SMK) the student teachers emphasized the importance of having strong subject matter knowledge to manage and to feel confident in their teaching. They argued that during their university courses they had learnt different scientific concepts, laws and formulas but this did not necessarily mean that they had understood the content. The relationship between student teachers’ subject matter knowledge and their teaching ability, self-confidence and attitudes towards science was clearly evident.

Finally the need for contextual knowledge (CK) concerned knowledge of pupils’ abilities and learning strategies, pupils’ attitudes about school science topics, the social and cultural environment of the school and pupils’ prior knowledge of the concepts to be taught. The need to be familiar with tasks and unwritten rules of the school that influenced their teaching was important, for example, in relation to classroom management. Further to this the pupils’ relationships with each other, relations between boys and girls and the group dynamics in the classroom were also stressed.
The student teachers recognized well the role that classroom context played in influencing their teaching. They could see the importance of group dynamics and the need to know their pupils, their ideas, abilities and interests and they emphasized the importance of being aware of the different factors that influenced the classroom climate, particularly in relation to pupils’ special problems and needs.

As the data illustrated, it may appear as though the processes of collaboration, teaching and reflection as implemented in the research outlined in this paper enhanced the transformation of student teachers’ knowledge to develop their PCK. In their reflections the student teachers gave examples of how the three different knowledge bases in different ways were recognized as important in shaping their teaching. Further to this, the paper concludes that different “knowledges” needed to be transformed, but to encourage this transformation through student teachers’ practice; they needed to be confronted by real classroom situations to reflect on. It appears as though the way their knowledge interacted in practice was evolutionary and dynamic and as separate compartments of knowledge SMK, PK and CK were, of themselves, insufficient to manage practice alone; hence the importance of transformation.

5.2. Paper 2 - From lesson plan to new comprehension: Exploring student teachers’ pedagogical reasoning in learning about teaching

The results of this paper give an insight into the ways in which student teachers learn about the issues and concerns that shape their learning to teach. During the process of planning, conducting and evaluating a science lesson in a science learning centre at the university, primary science student teacher participants (n = 22) were stimulated to reflect upon critical incidents in order to facilitate identifying their teaching concerns. The process of pedagogical reasoning and action (Shulman, 1987) was used to systematically elucidate different critical incidents that student teachers experienced in order to develop deeper understandings of the complex task of learning to teach primary science.
The results illustrate examples of: (1) critical incidents and (2) their related concerns for learning to teach and (3) teaching needs that the student teachers emphasized (critical incidents → concerns for learning to teach → teaching needs). Concerns in this context were defined as issues that worried the student teachers and/or that they felt anxious about. Needs were defined as things to be done or formulated actions that might resolve a situation. The student teachers’ reflections on their experiences during the process, from planning through to conducting the lesson, were grouped into two overarching themes of critical incidents; critical incidents connected to classroom management and critical incidents connected to pupils’ attitudes and learning.

The first category of critical incidents was connected to classroom management and mostly concerned limitations and frustrations in the teaching situation such as methods and materials, but also their own [lack of] sufficient preparations or subject matter knowledge. These incidents most notably emerged when an experiment failed or when they were asked questions by their pupils, or their accompanying teachers, that they were not able to answer.

The pupils’ questions sometimes led to feelings of frustration and discomfort when the student teachers could not answer them. The student teachers also emphasized incidents that emanated from their difficulties in transforming their subject matter knowledge to a primary school practice. The second category of critical incidents was connected to pupils’ attitudes and learning. All student teachers highlighted that evaluating the pupils’ experiences of the lesson also made them identify important aspects from their own teaching.

The teaching concerns that the student teachers felt anxious about were grouped into three overarching questions: How do we adjust instruction to meet the pupils’ learning needs and prior conceptions?; How do we stimulate the pupils’ interest, “train them in formulating hypotheses”, explain phenomena and help them concretise their thoughts?; and, How do we develop our learning about teaching primary science?
As for the first concern, several student teachers emphasized the knowledge of how to be well prepared for the pupils’ questions but also for being able to explain phenomena. Deep subject understanding, practical experiments and knowledge of metaphors and analogies appropriate to particular concepts were perceived as important in transforming student teachers’ content knowledge in ways that might be meaningful for their pupils. Many of the student teachers came to recognize that knowledge of common misconceptions in science and knowledge of the appropriate level of subject matter were important in shaping a pedagogical situation.

In their pedagogical reasoning all student teachers emphasized their concerns for learning about how to teach primary science and the factors that influenced that learning. The student teachers stressed the importance of self-reflection and the need – as teachers – to review, reconstruct and critically analyze their own and the class’s performance. Knowing how to reflect was also emphasized as an important issue for their professional development. They considered it to be important that as teachers, they needed to develop a positive attitude toward gathering and understanding pupils’ thoughts and ideas. It was also assumed that if a teacher had a positive attitude towards science teaching then they were also more competent in stimulating pupils’ creativity. They also came to see the importance of transforming the theoretical knowledge (of pedagogy and subject matter) into practice as well as displaying sincerity, enthusiasm and joy.

The pedagogical reasoning used in the study also helped the student teachers to recognize their teaching needs. These teaching needs were of a different nature. Some aimed at improving the technical effectiveness of the specific teaching experiences and others aimed at addressing more general objective issues applying to many different situations. The five overarching teaching needs are presented and discussed below.

Within their pedagogical reasoning, all student teachers stressed the need for good content knowledge in order to feel more confident in a teaching situation and to know how to explain phenomena to their pupils. One example was the need to put scientific
concepts into an everyday situation for their pupils so that they might better understand different phenomena. As they began to recognize the problematic nature of teaching they stressed the need to have a large repertoire of experiments and activities to visualize the different phenomena. Better knowledge of pupils’ common [mis]conceptions was also emphasized as an important need. Almost all student teachers emphasized the need for knowing how to reflect and the need – as teachers – to review, reconstruct and critically analyze their own and the class’s performance.

5.3. Paper 3 - Primary science student teachers’ and their mentors’ joint learning through reflection on their science teaching

This study examined what two mentoring primary teachers and two primary science student teachers learned from their common experiences while planning, carrying out, and reflecting on different science teaching activities during a four-week school practicum. The student teachers had had training in scientific knowledge, but only brief experience of teaching. The mentors were well experienced in the pedagogy of teaching and mentoring, but did not feel confident about their science content knowledge and the teaching of science. During the four weeks, two lessons of each of the student teachers and mentors were video recorded. The student teachers and the mentors, working in pairs, reflected on each video-recorded lesson in a stimulated recall session. During their reflections, the student teachers and the mentors expressed an increased understanding of both teaching and learning science, an improvement of their own practice, and a joint learning experience throughout the process of working, observing, and reflecting together.

Shulman’s concept of PCK was used to structure the teaching knowledge and several knowledge elements were used as codes to analyze the data. Some of these elements were elements of PCK according to the model of Magnusson et al. (1999), in particular if participants discussed the use of instructional strategies to teach science (i.e., instructional knowledge), or if they referred to pupils’ learning of science content (i.e., knowledge of pupils). Since the participants also discussed issues related to their
subject matter knowledge and general pedagogical knowledge, those two were also used as codes.

The results highlight several aspects concerning what the student teachers learned from their mentors. For example, concerning the instructional knowledge the student teachers came to see the importance of making the teaching concrete (e.g., including practical experiments) and linking the content to pressing issues, such as climate change and water recycling, in order to make it meaningful to the pupils. Both student teachers stated that they developed instructional knowledge while observing their teaching and discussing with the mentor how they asked and responded to questions, and dealt with unforeseen incidents during their teaching. Concerning the knowledge of pupils the student teachers described how the mentors taught them to recognize and interpret pupils’ behaviour, for example, silence and body language, which was very useful in the teaching situation. Concerning the pedagogical knowledge both student teachers emphasized how their mentors helped them to learn how to handle the pupils, to interpret classroom events, and to manage teaching in a more general way.

The results also illustrate what the mentors learned from the student teachers. Particularly, both mentors stated that they had learned scientific methods and instructional strategies for science from the student teachers such as hypothesizing and working in a problem-based manner. In their reflections, they described their learning from observing and discussing each other’s handling of unforeseen questions and incidents connected with their own [lack of] subject matter knowledge. The results highlight several situations that made the mentors realize that they needed more scientific knowledge to better grasp the moments and to stimulate the pupils’ interest in learning science.

Finally, the results demonstrated what knowledge the student teachers and mentors developed from the pupils. As the student teachers and mentors learned how the pupils perceived and understood scientific ideas and methods (knowledge of pupils), they were also forced to consider their teaching and how to find new ways to make the
content understandable for the children. Further to this, as they identified how the pupils’ language, explanations, and questions uncovered their thoughts and preconceptions, they learned how the pupils perceived and understood scientific ideas and methods which were important for their teaching. The mentors and the student teachers stated that they learned a lot from the pupils’ explanations, and that they used the pupils’ explanations of scientific phenomena as a way of exploring their own ideas of specific concepts.

Overall, both pairs stated that they learned methods of promoting pupils’ understanding (e.g., how to make science concrete and link it with everyday life, how to do exciting experiments, how to stimulate pupils’ discussions and questioning). The student teachers had better subject matter knowledge than their mentors, but they had no previous experience of classroom management. Nevertheless, the subject matter understanding of the student teachers was not adequate to answer all the pupils’ questions and to handle unforeseen incidents. The mentors had a lot of teaching experience, but did not always feel confident in their teaching of science. The results indicate that the learning environment implemented (incorporating opportunities for jointly planning, teaching, observing, and reflecting) was effective in promoting student teachers’ and their mentors’ learning processes (i.e., the construction and extension of their professional knowledge). The data also clearly indicate that the pupils played an important part in this process.

5.4. Paper 4 - How will we understand what we teach? – Primary student teachers’ perceptions of how to develop subject matter knowledge and a positive attitude towards physics

As all three papers above have highlighted the importance of subject matter knowledge and self-confidence in teaching science, this fourth paper then goes on to investigate how different factors, such as practical experiments and subsequent group discussions, contributed to primary student teachers’ development of subject matter knowledge in combination with a more positive attitude towards physics.
During an eight-week course, 40 primary science student teachers worked in groups of 13-14 on practical experiments and problem-solving skills in physics. The student teachers were video recorded in order to follow their activities and discussions during the experiments. In connection with every workshop (see 3.1.), the student teachers participated in a seminar; they watched the video recording in order to reflect on how they communicated their conceptions in their group. After the eight weeks of coursework a questionnaire including a storyline was used to elicit the student teachers’ perceptions of their development of subject matter knowledge from the beginning to the end of the course. Finally, five participants were interviewed after the course.

An overview of the 40 storylines indicated that most student teachers perceived that they developed subject matter knowledge in physics during the course (60 % of the storylines were labelled \textit{progressive constant}, 37.5 % were \textit{progressive with ups and downs}, 2.5 % were \textit{stable}, and none were \textit{regressive}). During the analysis of the data (questionnaires and interviews), four categories connected to student teachers’ development of subject matter knowledge emerged: (1) Discussing subject matter with a person with more knowledge, or explaining it to others; (2) connecting the theoretical subject matter knowledge gained at the course with a practice of primary teaching through experiments, everyday phenomena, and problem solving; (3) being self-confident; and, (4) seeing the subject matter knowledge as meaningful. They also stressed that the group seminars after the workshops gave them a better picture of how concepts were linked. Further to this they emphasized that their understanding was helped when the physics teacher in the course explained concepts and phenomena with the use of metaphors.

They claimed that the “open design” of the workshops was good as this forced them to look deeper into the subject matter and to discuss it with their peers, to reflect on what they did during the experiments, and to compare each other’s results. They also mentioned that it was good to explain concepts and phenomena to each other as it helped them to gain an insight into their own difficulties and how they could be dealt
with. When they had to explain phenomena to their peers they were forced to put their own knowledge into words. However, all emphasized the importance of having someone more knowledgeable in the discussions to explain difficult concepts.

In the questionnaires as well as in the five interviews the student teachers emphasized the importance of succeeding with the different practical experiments as a way to connect theory with practice. They mentioned that it was important not to be “given” the knowledge, but instead to work actively to construct their own knowledge. Hence, prior subject matter knowledge to build on was also mentioned by the student teachers as improving their development of subject matter knowledge. In the interviews, all five student teachers highlighted self-confidence as an important aspect both for developing subject matter knowledge, but also for their ability to teach physics. They also emphasized that the group discussion in which they were supported by their peers was important for their self-confidence, and further for their development of subject matter knowledge. Almost all of the student teachers said that they were more motivated to learn physics when they felt that the knowledge was meaningful to them and could be used in their future teaching, something which also influenced their own development of subject matter knowledge.

As for their attitudes, all 40 student teachers mentioned in their written questionnaire that their attitudes towards physics had changed during the course. Most referred to their secondary school physics as the cause of a negative attitude towards physics when they started the program, but they said they felt more positive about it at the end. Everyone said that their attitudes towards physics had improved, and that they were now more curious about things that they did not know about before. Almost all student teachers highlighted the connection between the feeling of success (e.g., to manage an experiments) and a positive attitude. Several student teachers emphasized the connection between the sense of uncertainty and their attitudes towards the subject. However, all of them stressed that working in groups with everyday experiments (with no given answers) challenged them which also made them develop a more positive attitude towards learning and teaching the subject.
5.5. The puzzle as a whole - Learning to teach and teaching to learn

So, in what way do the results outlined in the four papers contribute to the knowledge of student teachers’ learning to teach? The overall question that this research has aimed to answer has a pragmatic character important not only for the field of science teacher education but also for its implications. The practices and processes highlighted in this thesis have aimed to answer the question: “In which ways can student teachers’ learning about teaching be illustrated and understood in terms of the critical aspects that are experienced within their teaching and learning practices?” This section will present the critical aspects (table 1, p. 82) that student teachers experienced within their teaching and learning practices, and the ways in which student teachers’ learning about teaching can be illustrated and understood. Finally I will summarize those aspects through two claims concerning student teachers’ learning to teach primary science.

As a case study reports on the complex dynamic and unfolding interactions of humans and factors in real contexts that are inevitably unique, the student teachers’ rich stories make an important contribution to the puzzle as a whole. Hence, my contribution to the research field of science [teacher] education is to, through empirical studies of different interactions in different contexts, try to highlight the nature of the gap between theory and practice and, in so doing, try to connect the “what is taught in teacher education” with “what is experienced and recognized by the student teachers themselves”. However, the research that the four papers build does not intend to measure student teachers’ learning, but instead to give an insight into the processes that underpin that learning. The results present “critical aspects” important to the student teachers in shaping their understanding of their own practice. Thus, the four papers indicate that in order to discuss student teachers’ learning to teach through teaching, student teachers’ own personal stories must be carefully investigated and analyzed.
The first way in which student teachers’ learning about teaching can be illustrated and understood concerns the research design. The research outlined in all four papers investigates different contexts for teaching and learning science through a systematic exploration of the nature and substance of the student teachers’ interactions with different individuals. Within the four studies they interact with the young pupils in school and in the science learning centre, with their mentors and with the teacher educators and physics teachers during a university course. Also, within all four studies, the student teachers’ interaction with each other (in pairs or in groups) gives an important insight into the complexity of their learning to teach science. Another way to illustrate and understand student teachers’ learning about teaching concerns the methodology (e.g., methods to collect data) with which this research was conducted. As the results in paper one, three and four indicate, the stimulated recall methodology helped the participants to recognize and in fact emphasize aspects within their teaching and learning of science. Further to this, the story-line method used in paper four helped student teachers to not only indicate important aspects for their development of subject matter knowledge in physics, but also to explore why those aspects were critical.

A third important aspect in order to illustrate and understand student teachers’ learning about teaching concerns the way student teachers (and mentors) managed to recognize both their needs for different knowledge bases and the way these impacted the possible foundations of PCK. The way each of the knowledge bases (in paper 1), concerns (in paper 2), knowledge elements (in paper 3) and subject matter knowledge and attitudes (in paper 4) were recognized and explained by the participants as well as the interplay between them suggested that, through reflection with mentors and peers, transformation into PCK for primary science teaching might well be occurring.

Concerning critical aspects that were experienced within the student teachers’ teaching and learning practices a common pattern in the four studies was how the student teachers came to recognize that a lack of subject matter knowledge (SMK) made it difficult for them to relate phenomena to everyday situations, but that subject matter alone was not sufficient. Different knowledge needed to be transformed, but to
encourage this transformation through student teachers’ practice, they needed to be confronted with real classroom situations to reflect on, and learn from these concrete examples. As such, the student teachers often stated that they needed more work with representations and experiments and activities that could be used in the primary science classrooms to handle pupils’ difficulties in understanding certain topics.

Another critical aspect which was evident in all four papers was the importance of subject matter knowledge to handle the situations in the classroom. Finding out about the need for subject matter knowledge might be considered as an obvious result, but the fact that student teachers, through reflecting on their teaching experiences, themselves identified their needs is of great importance. Concerning their need for subject matter knowledge, the interface between SMK and PCK proved to be critical in the process of how to transform the science content which further indicated the complex relationship between subject matter understanding and the subsequent PCK development. In paper one, two and three a critical aspect that was highlighted was that each of the student teachers experienced a gap between the subject matter knowledge they had gained at the university and the physics they taught in school. This gap emanated partly from their difficulties in transforming their subject matter knowledge and in relating theory to practice, largely derived from a lack in their own subject matter knowledge. The results from paper one, two and three support the ideas of Gess-Newsome (1999) and Hashweh (1987) who emphasized that the development of teachers’ SMK and PCK are related in complex ways, and that both are crucial to good science teaching. The importance of subject matter knowledge to be meaningful for primary teaching and to be connected to everyday situations was further highlighted as a critical aspect in paper four. However, all results support student teachers’ need to experience how the classroom context influence their ability to teach and learn science. The teaching together with a peer or a mentor in paper one, two and three and the group discussions in paper four were also important critical aspects of the studies and offered access to the reasoning underpinning student teachers’ ideas and actions. Another critical aspect was the importance of “grasping the moment” (i.e., take the chance when it comes) to initiate discussion with pupils and examine pupils’
ideas and concepts in ways that could not be totally planned in advance. For example, in the interaction with the pupils they saw into the problematic nature of teaching and how through a failed experiment discussion about the nature of science and scientific experiments could be examined. Another critical aspect was how the student teachers realised that not every pupil enjoyed experimenting which made them question their initial aims. The student teachers also had a preconceived notion that pupils were curious by nature and always asked questions about “how and why”. During their demonstration they found out that this was not always the case. Further to this the student teachers in general emphasized the importance of giving the pupils good motives for learning science. Concerning pedagogical knowledge, a critical aspect that the participating student teachers experienced within their teaching and learning experiences, which was also a common pattern in paper one, two and three, concerned the student teachers´ difficulties to see the pupils’ needs and interpret their feelings. Further to this the student teachers experienced difficulties to manage different situations during teaching such as dealing with conflicts, encouraging all pupils to participate in activities, and seeing and hearing all pupils. However, an important issue was then to learn to see and interpret pupils’ engagement and activities in the classroom. As the student teachers [and mentors] reflected together in the stimulated recall sessions and in the group seminars they stressed that they helped each other to see, recognize, and interpret critical incidents and situations in their teaching activities. Those activities, the student teachers claimed, helped them to find a different (deeper) dimension in their own teaching.

Within all four studies the student teachers gave several examples of critical aspects of their learning experiences. One example was how they learned from pupils´ (paper 1-3) or from their peers´ (paper 4) explanations and questions, which led them to an understanding of what might be difficult and too abstract for the pupils in a teaching situation, and also to an awareness of their own subject matter knowledge. As one of the mentors in paper three explained; those experiences had taught her to take a step back and take a broad perspective while observing and reflecting on how she and her student teacher asked and responded to questions and unforeseen incidents. Another
example was how they learned a lot through exchanging feedback and critique with their peers and their mentors (paper 3) and also through criticizing themselves. They stressed that they learned how to use specific teaching methods to represent subject content, to enhance pupils’ understanding, and to develop their attitudes and motivation. Another aspect within their teaching and learning experiences which they highlighted was that they learned from the pupils as they practiced strategies that were fruitful in challenging and “reorganizing” the pupils’ understanding. Trying to analyze others’ thoughts and what things they considered difficult helped them to shift from understanding something yourself, to explaining it to others. Another critical aspect within the student teachers’ teaching and learning experiences and hence, a way to portray and understand student teachers’ learning to teach was that all four papers provide insight into how aspects such as self-confidence, a positive attitude towards science, the usefulness and the meaningfulness of scientific knowledge became important aspects in primary science student teachers’ teaching and learning science. Concerning their development of SMK in physics practical experiments and everyday knowledge (e.g., the experiment in the elevator in paper 4) was particularly good as it could be used in a primary school setting and was easy to connect with everyday situations. The student teachers in all four studies also mentioned that they had realized the importance of starting with science in primary school. In table 1 the critical aspects are clustered into the three different knowledges; subject matter knowledge (SMK), pedagogical knowledge (PK) and pedagogical content knowledge (PCK). The first knowledge (SMK) lists conditions concerning student teachers’ subject matter knowledge to be useful to primary science teaching and teacher education. The second knowledge (PK) lists aspects of things that student teachers should know or be able to do concerning general elements regarding teaching, classroom organization and management, instructional strategies and classroom communication. The last knowledge (PCK) mostly refers to aspects that are crucial to the development of PCK.
| Critical aspects related to subject matter knowledge (SMK) | • SMK is important to handle the situations in the classroom but SMK only is not enough to transform the science content into teaching  
• SMK at university courses should build on practical experiments and everyday knowledge in order to become meaningful and relevant for primary school teaching |
| Critical aspects related to pedagogical knowledge (PK) | • Important to be flexible and to take the opportunity to discuss and examine pupils’ ideas and concepts  
• Important to see the pupils’ needs, interpret their feelings, manage dealing with conflicts and encourage all pupils’ participation  
• Important to practise strategies that are fruitful in challenging and “reorganizing” pupils’ understanding  
• Important to give pupils good motives for learning science |
| Critical aspects related to pedagogical content knowledge (PCK) | • Teaching experience, self-reflection and exchanging feedback and critique with peers and mentors are important  
• Self-confidence and a positive attitude towards science are important  
• The relation between SMK and PCK is critical in the process of how to transform the science content to promote pupils’ understandings  
• Ability to recognize and explain the need for different knowledge bases, the interplay between them and the way these impact on teaching primary science are important |

*Table 1. Critical aspects that student teachers experienced within their science teaching and learning practices*
In summary, the results of the four papers highlight student teachers’ difficulties in learning and understanding the science content for themselves, as well as transforming their knowledge into appropriate pedagogical practices in primary school. The critical aspects listed above, as well as student teachers’ detailed perceptions of their teaching and learning experiences, indicate some of the complexity inherent in teaching and learning about science teaching.

First, as the relation between SMK and PCK proved to be critical in the process of how to transform science content, student teachers needed to understand the science content for themselves. Secondly, student teachers needed to know how to teach the content in a way that might promote pupils’ understanding (i.e., they needed to possess and develop PCK). Hence, considering the range of critical aspects experienced by these student teachers, it is reasonable to suggest that pedagogical content knowledge needs to be understood as dynamic knowledge generated in practice mediated by the capability to combine or blend individual knowledge bases together so that they are transformed in practice. In order to summarize the results from the four papers in this thesis, I suggest two claims which will be further discussed in the following sections:

1. Student teachers experience a problem concerning the relation between what they learn both in science content courses and courses of pedagogy, and that knowledge that is actually needed in their teaching in a primary school context.

2. There is a consistent lack of attention to, or demonstration of, pedagogical content knowledge in science content courses as well as in courses of pedagogy which results in difficulties for student teachers in transforming their subject matter knowledge through pedagogical practice into a form that is meaningful for their pupils’ learning of science.

The critical aspects outlined above demonstrate that teaching science is not so much about making the content simple, it is about teaching the content in ways that make it understandable to pupils by stimulating their interest and learning. However, there is
not one correct way of developing pedagogical content knowledge and not one correct way of teaching student teachers how to develop it. Student teachers learn in different ways as do the pupils they teach – each have different abilities, interests and learning needs. Therefore, as highlighted by Bishop and Denley (2007), learning to teach (as illustrated through the development of PCK) could be viewed as a sophisticated process of combining different knowledge bases together in particular contexts; all of course influenced by individual pupils, classes, colleagues, topics, etc. Further to this, if it was actually possible to define the knowledge needed for teaching, it might assist new teachers to know better for themselves, how to work to learn to acquire it.

6. Discussion – Primary science student teachers’ complex journey from learners to teachers

For teachers the construct of pedagogical content knowledge (PCK) has largely been used to define teaching as a professional practice. Shulman (1986, 1987) conceptualized PCK as “the category [of teacher knowledge] most likely to distinguish the understanding of the content specialist from that of the pedagogue” (1987, p. 8). Shulman further claimed that teachers need strong PCK to be the best possible teachers. Thus, considering the second claim suggested above, it might well be argued that also teacher educators’ PCK (in science as well as in pedagogy courses) should include knowledge about how to promote a student teacher’s journey from learner to teacher. Furthermore, with respect to student teachers’ difficulties in understanding science content (suggested in claim one above and which was highlighted in all four papers), teacher educators’ PCK needs to demonstrate how they have developed and come to use different “ways of representing and formulating the subject that makes it comprehensible for others” (Shulman, 1986, p. 9). Shulman (1986) noted that teacher education programs in general seem to be based on the view that student teachers will teach effectively once they have acquired subject matter knowledge, strategies of innovative curriculum and have practiced using them. However, as many beginning teachers feel so insufficient prepared for their teaching that the term “reality shock”
(Veenman, 1984) has come to be frequently used, this approach to teacher education might seem to have failed. This touches at the very heart of the question about what it really means to acquire the knowledge base needed for teaching and how it might be supported during teacher education. Korthagen et al. (2006) stressed that the learning of student teachers is only meaningful and powerful when it is embedded in the experience of learning to teach.

The papers in this thesis support the idea that for student teachers’ learning to teach, a crucial issue has proved to be the interaction between pupils as well as mentors and peers in the teaching situation. Therefore, teacher educators need to create situations where these interactions become natural parts of teacher preparation. In such a way, one precondition for student teachers’ learning to teach might then be to recognize and to further understand important elements needed for teaching science while actually teaching it.

This thesis illustrate the idea that the sharing of reflective experiences, the reconsideration of what it means to understand the particular concepts as a learner and a teacher and the learning about the “how”, are all embedded in the practice of teaching. However, as the components in teacher knowledge will interact in a highly complex way, it is important for student teachers to understand not only the particular components, but also to understand the contexts in which they develop, how they interact and how their interaction influences the thinking about, as well as the act of, teaching. Therefore, the subtitle “Primary science student teachers’ complex journey from learners to teachers” highlights three issues that I want to explore and connect to the theoretical background as well as the empirical data. First the journey, then the complexity and finally from learners to teachers.

6.1. The journey

Let us begin to illustrate teacher education in the way it is researched in this thesis, with a journey where every stop represents an activity or an interaction with different
people and places through which the student teachers experience different critical aspects (table 1).

First, it is reasonable to suggest that all student teachers travel on different personal learning journeys, interpret and learn from the interactions in different ways. The journeys might take many different turns and contain several interesting meetings in different contexts. However, it might well be argued that at the centre should be the student teachers’ experiences and their reflections and analysis of these specific experiences. The student teachers’ learning journeys presented in this thesis include three “stops” where every stop represents an interaction between student teachers and places (such as teacher education or primary school) as well as other actors (mentors, pupils or teacher educators). As university coursework and school based practice are integrated all through the 3,5 - 4,5 years of teacher education program, the three stops presented below are not related in time.

6.1.1. Interaction with teachers in science courses as well as in courses of general pedagogy at the university

One “stop” of the student teachers’ complex journey from learners to teachers is the interaction with university teachers and activities in science courses as well as in courses of general pedagogy at the university. Student teachers enter their programs not only with a concern to learn about teaching [science], but also with at least 12 years experience of school teaching - but from the other side of the teachers’ desk. They are familiar with classrooms and the school context and in most cases they have their own perceptions and beliefs about what it is to teach science and how they might learn to teach. For teacher educators then to give student teachers opportunities to confront and redefine those existing beliefs might be considered as a challenge.

There has been an ongoing discussion about the relevance of university based courses in teacher education. Pinnegar (1995) stated that teachers often criticize the teacher education coursework that was offered them as too theoretical and “not merely
unhelpful but unrelated to issues in classrooms” (p. 56). This view is supported in paper one, two and three in this thesis as the student teachers during their journey often experienced difficulties to connect theoretical pedagogical knowledge and subject matter knowledge gained in their university courses to a primary school context. Further to this, student teachers often ask for practical work such as “tips and tricks” or “activities that works” (Appleton, 2003) which are easy to connect to their future teaching. Similarly, as confirmed in the papers in this thesis, student teachers often argue that their university courses contain too much theory and that the real learning takes place in school during practicum experiences. Thus, student teachers seem to be more interested in courses that focus on what a teacher needs to do as opposed to what a teacher needs to know. Hence, as highlighted by Russell (1997) and Korthagen (2001), for many student teachers, coming to understand teaching as being problematic and therefore moving beyond expectations of learning to teach as being “told how to do teaching”, is a constant challenge.

All through the four papers it has been highlighted that the student teachers had difficulties connecting the theoretical pedagogical and subject matter knowledge gained at the university to relevant primary science teaching practice. However, it might be reasonable to suggest that student teachers also need to be able to theorize practice in order to know and be able to articulate the what, how and why of teaching. In her self-study, Pinnegar (1995) returned back to school after 20 years of work as a teacher educator in order to explore the dilemmas of practice that she experienced during her first year of teaching. She wanted to see if she now, after 20 years of academic coursework, could teach school students in the ways she was teaching her future teachers to do. When reflecting on her teaching she was able to identify the ways in which theory guided, framed and emerged in her thinking about practice. Bearing in mind the theory-practice gap mentioned above, she concluded her paper arguing that teacher educators:
“…should get beyond the questions whether theories, ideas, and research taught in teacher education programs are evident in the practice of teachers, to focus instead on how such learning is evident. Perhaps some of the problems of practice might be more clearly explained by examining how theories emerge rather than discussing whether they do or do not.” (Pinnegar, 1995, p. 67)

Therefore, it might be argued that in teacher education courses it is not enough to simply present student teachers with suggestions for teaching practice (i.e., how to connect theory to the teaching practice). Student teachers also need to be engaged in theorizing about how to learn to teach as well as theorizing about those suggestions for practice.

Just as people visit different places on a journey and experience the places in different ways depending on their interests and previous knowledge, student teachers enter their primary science teacher education programs with different pre-knowledge and also with different attitudes towards science and science teaching. In paper one and four, there were examples of student teachers who stressed that they experienced physics as a difficult and sometimes boring subject and that some even tended to avoid physics in their future teaching. Others maintained that they had always liked the subject and saw science teaching as a way of stimulating students’ problem solving skills. However, even though the student teachers entered the primary science teacher programs with different views on teaching science, it might well be argued that they all shared an interest in interacting with primary students and the exciting experiences that these interactions might offer. A journey might offer a range of activities, meetings and interactions with people as well as places that challenge people’s conceptualizations and interpretations. In the same way, teacher education courses offer a range of experiences for student teachers to challenge and conceptualize their view of science and science teaching.

As mentioned above, the student teachers in this thesis often stressed that they had difficulties connecting the theoretical knowledge gained at the university to a primary
school context. There have been several attempts to understand approaches of teacher education that might assist in shaping alternative conceptualizations of the theory-practice gap highlighted in this thesis. Kessels and Korthagen (2001) and Korthagen et al. (2001) used the constructs of episteme (the theoretically derived knowledge) and phronesis (the practical knowledge arising out of specific experiences) as a way of responding to the difficulties associated with connecting theory to practice. Episteme consists of assertions of a general nature that applies to many different situations and problems and is often described in abstract terms. On the other hand, phronesis is a form of practical knowledge that is derived through understanding of specific situations and cases (Korthagen et al., 2001).

When student teachers, like in paper one, two and three in this thesis, are encouraged to incorporate theory into their practice, they often have difficulties in bridging the gap and close the “zipper” (Kelchtermans & Hamilton, 2004) between the two. There is also a common view of student teachers that in teacher education programs the “real” teaching is not informed by the university’s theoretical coursework but in the classrooms. Therefore teacher educators need to get beyond questions of whether theories, ideas and research taught in teacher education programs are evident in the practice of teachers, to focus on how such learning is evident (Loughran, 2006). One way of so doing within the university coursework was elaborated in paper two. The research project in the science learning centre was based on the assumption that if a student teacher is encouraged first to identify and further to reflect on critical incidents (Tripp, 1993) in their own practice, that they might then conceptualize aspects of their practice that they need to address in order to meet their explicated pedagogical concerns.

As indicated in paper four, the level of student teachers’ development of, for example, subject matter knowledge in a university physics course was highly dependant on the usefulness and meaningfulness of that knowledge in relation to their teaching of the subject. Hence, modelling Shulman’s (1986, 1987) notion of PCK (as an amalgam of content and pedagogy) in teacher education might be helpful to understand not only
what knowledge (content) might be useful for student teachers, but also how (pedagogy) it might be used and further developed in a teaching practice.

Finally it might be assumed that one reason that student teachers confront difficulties in attempting to connect their subject matter knowledge of science to their teaching practice is linked to the different characteristics of both science and pedagogy. In the context of science teacher education as it is researched in this thesis, the subject matter knowledge comes from science disciplinary fields, while the understanding of teaching comes from the field of pedagogy or education. Hence, it is reasonable to suggest that this separation reinforces a model of science that is different from models of teaching and learning science. In the science discipline scientists construct their theories carefully and systematically and test hypotheses empirically so that explanations have a firm basis in facts. Further to this, according to Cohen et al. (2007) scientists tend to be concerned with relationships amongst phenomena that are systematic and controlled. On the other hand, the immense complexity of human nature and the elusive quality of social phenomena contrast strikingly with the order and regularity of the natural world (Cohen et al., 2007). In humanistic and social science (e.g., pedagogy) individuals’ behaviour is perhaps best understood by researchers by sharing their frames of reference. Therefore social sciences might be seen as a subjective rather than an objective undertaking as a means of dealing with the direct experience of people in specific contexts where the social scientist understands and explains social reality through the lens of the participants (Cohen et al., 2007).

Myrdal (2007) discussed the differences between the cultures of natural science and human/social science and stressed that natural science and human science must accept each others research methods and have insight into each others theoretical perspectives in order to respond to “big questions” in the life of human. However, it might be well argued that the questions about “teaching and learning” are considered as such big questions. Hence, as science education as a research field investigates people’s conceptions, teaching and learning of science and not the nature per se, it is reasonable to suggest that the epistemological questions of how such knowledge can be attained
are as much related to humanistic and social science as to natural science. This might in turn influence the attention to what, why and how science is taught in science teacher education in order to prepare student teachers for teaching in a primary school context. University science is characterized by its own culture which is different from the culture of primary school science. The student teachers bring with them the language, concepts and methods of university science into primary school which results in conflict. Further highlighted in the research literature (c.f. van Driel et al., 1998) is the situation whereby science teachers approach scientific problems differently than scientists due to their understanding of the pedagogical implications of learning science (hence the distinction some draw between science and science Education). The separation between the science content and pedagogy (i.e., understanding of teaching and learning) might lead student teachers to struggle in adjusting their understanding of science per se to understanding of science education. Hence, in order to “bridge the gap” between university learning of science and primary school teaching, a challenge that science teacher education faces is finding ways of gaining insights into how the different ontological perspectives of science and pedagogy (in the university as well as in the school context) influence student teachers’ teaching and learning about teaching.

6.1.2. Interaction with pupils in the primary school context

Another “stop” in student teachers’ journey is the interaction with primary school pupils in the school context. As highlighted by Morine-Dershimer & Kent (1999), student teachers need opportunities to practice instructional processes in the actual lessons that they plan, conduct and evaluate so that they can learn from review and discussion of each other’s lesson. Further to this, Loughran et al. (2006) argued that opportunities for student teachers to experience a sense of frustration in teaching matters if they are to move beyond being comfortable with tips and tricks alone (that is to see and feel the problem in order to decide to do something about it).
Lederman and Gess-Newsome (1992) used an analogy between Shulman’s (1986, 1987) conception of teachers’ knowledge and the ideal gas law. Just as the ideal gas law does not perfectly describe the behaviour of real gases it is difficult to perfectly describe classroom teaching and the conception of teachers’ knowledge. In a similar way, if different individuals visit different places on a trip around the world, the student teachers will experience the interaction with primary school pupils in the school context in different ways depending on their previous knowledge and experiences of the school context, their own personalities and the different individuals they meet. Further to this, their experiences will also depend on how well prepared they are for the trip.

Compared to a journey, if people have learned different languages they are better able to communicate with the citizens and to understand their feelings and ideas. In the same way, student teachers who have learnt how to communicate with pupils, who have learnt to interpret their conceptions and ideas and to communicate the science content in order to make it comprehensible for pupils, are also better prepared to manage the complexity of teaching science. In the same way as the student teachers in three of the four papers highlighted the importance of being well prepared for science teaching, it might be assumed that someone who goes on a journey would better benefit from it if they, for example, had carefully studied a traveller’s guide.

The student teachers in two of the four studies interacted with pupils in the primary school context. Lave & Wenger’s (1991) notion of “learning as participation” and Wenger’s (1999) concept of “community of practice” could well be used to explore this destination of student teachers’ journey. However, for student teachers to become more central participants in the community of school practice they are required not only to interact with the pupils but also to identify themselves as members in the “teachers’ society”. Thus, central to the notion of “community of practice” as a means of acquiring knowledge is the process by which a student teachers move from peripheral to full participation in the community (i.e., going from learners to teachers). Thus, in order to capture and better understand the community of practice student
teachers need opportunities to interact with students as well as teachers. That is why the context in which the interaction takes place, for example the social and cultural environment of the school (Gess-Newsome, 1999), also becomes an important factor as to how student teachers experience the destination of their journey. Further to this, to foster the development of student teachers’ professional knowledge of the amalgam that is PCK, they need tools to help them attend to issues in the interaction with their pupils. Such tools could be exemplified as teaching needs (paper 1 & 2) or PCK elements (paper 3) to be used in their classroom practice. Returning to the journey, even though exploring the city on your own may also promote learning experiences, the tools mentioned above could be illustrated through the travellers guide book by promoting several “tips and tricks” of how to enjoy the destination.

6.1.3. Interaction with mentors in the primary school context

The third “stop” in student teachers’ complex journey from learner to teacher that was explored in this thesis is the interaction with mentors in the primary school context. Paper three aimed to document and understand two primary science student teachers’ and their mentors’ joint learning through reflection on their science teaching during a four week practicum. In general, school based teacher education requires mentors to share their expertise with student teachers in a context of cooperative learning. As such, mentoring is a way of helping student teachers to study their practice with others so that alternative perspectives and possibilities might become apparent and could be acted upon. For example, Maynard and Furlong (1993) defined mentoring as a “nurturing process in which a more skilled or more experienced person, serving as a role model, teaches, sponsors, encourages, counsels, and befriends a less skilled or less experienced person for the purpose of promoting the latter’s professional and/or personal development” (p. 29). Halai (2006) identified a mentor’s roles as those of expert-coach, subject specialist, critical friend, and learner. However, as paper three concerned the joint learning between the student teacher and the mentor, the mentor as a learner-perspective stressed by Halai (2006) becomes an important issue.
As highlighted in paper three, the way in which a student teacher experiences the interaction with the mentor in the school based practice (the ‘stop’ in the journey) is based on a range of interrelated tasks. Further to this, the results in paper three indicated that as the student teachers could be seen as a catalyst for mentors in clarifying their thoughts and needs as teachers, the interaction between student teachers and their mentors also promoted advantages for the mentors. The mentor should observe the pupils as well as the student teacher and further discuss and analyse the student teachers’ teaching practice. Further to this, a key feature in mentoring is allowing student teachers access to the ‘craft knowledge’ of mentors where one task of the mentor is to model teaching and general classroom management (Lazarus, 2000). However, as stressed in paper three, to ensure thoughtful interactions, mentors and student teachers need to listen to each other’s ideas and give each other instructive feedback. This will improve mentors’ abilities in dealing with student teachers, as well as improve the student teachers’ educational experiences in the classroom.

The mentors have daily experiences of communicating with pupils in school, teaching students with widely different abilities and motivations etc. Hence, it might be reasonable to suggest that mentors normally know which way is best to organize the class, to give out instructions and to help student teachers to deal with conflicts, encourage all pupils to participate in activities and finally to see and hear all pupils (critical aspects in table 1). As such, the mentors ‘open up’ their classrooms for student teachers allowing them to observe and discuss their teaching. However, as the mentor possesses both a theoretical and practical perspective, it might be assumed that one goal of the mentoring process should be to bridge the ‘doing’ and the ‘knowing why one is doing’. However, Furlong and Maynard (1995) found that mentors were able to talk about the content of their knowledge, but describing how they applied that content in the classroom was much harder.

In order to support student teachers, mentors must be able to articulate beliefs, views, knowledge and know-how, which may be implicit or intuitive, in a way that suits both the mentor and the student teacher (Lazarus, 2000). As such, this stop on a student
teacher’s complex journey from learner to teacher very much relies on the interaction and relationship between the mentor and the student teacher. The mentors observe student teachers’ lessons and provide oral or written feedback which should be based on openness and confidence between the mentor and the student teacher. As the student teachers in paper three also provided oral feedback on their mentors, the importance of openness and confidence between the two became even more important. Another dimension is that the mentors also played an important role in assessing student teachers against formally prescribed criteria, decided by the teacher education curricula. This shift from critical friend to assessor is not always easy or comfortable. Lazarus (2000) highlighted the importance of a good relationship between the mentor and the student teacher.

“The mentor should be a good listener, a critical observer or a person who encourages and challenges the trainee to reflect on different aspects of teaching and learning. Mentoring relies heavily on the development of professional and personal relationships as most work is carried out on a one-to-one basis” (p. 112).

Book (1996) noted that mentors have begun to realize that their role in supervising student-teachers has enabled them to learn more about teaching. In helping novices to improve, they have to articulate more explicitly what they know and believe about teaching. Having to articulate their actions to another person sharpens up mentors’ thinking and makes them re-evaluate much of their unconscious or implicit assumptions (Lazarus, 2000). In paper three the joint learning between the two student teachers and their mentors was carefully investigated and discussed in relation to their development of pedagogical content knowledge. Thus, what this paper brings into light is that this ‘stop’ on the journey (i.e., the interaction between the student teacher and the mentor in the mentoring process) is not only a part of the learning journey of the student teacher but also of the mentor.

Let us return to the metaphor of the journey. It might well be argued that in order to benefit the most from a guided tour requires the guide to be able to make explicit
his/her knowledge about the different places. Hence, one important aspect for the guide must then be to help the visitor to see and recognize aspects within the area that he/she would not have been able to see alone. Thus, the guide could provide the visitor with information about what to see, how to act, communicate and respond to people as well as places with which they interact during the tour. However, the guide must not only be able to know about the area, but also be able to conceptualize this knowledge and tell interesting stories about it. It could well be argued that another important aspect of the guiding metaphor which was highlighted in paper three might then be that when preparing for and then later guiding the visitor, the guide will see and recognize aspects within the area that he/she might not have noticed before. Further to this, the guide has to articulate more explicitly what they know about the places. Hence, similar to the mentors, having to articulate their knowledge about the different tourist attractions to a visitor might “sharpen up” a guide’s thinking and make him/her re-evaluate much of his/her unconscious or implicit knowledge.

In the same way, the mentor might act as a guide for student teachers’ learning in the classroom. The interaction with the mentor provides opportunities for student teachers to teach and get feedback in order to develop confidence and learn about their teaching as well as their students’ learning. Hence, planning, conducting and evaluating teaching together with the mentor become important for the student teacher in terms of developing self-confidence and knowledge not only of what to teach but also of why and how. Similar to a guide who might learn more about the places to which he/she brings the visitor, paper three supports the notion that mentoring serves as a catalyst in the mentors’ thinking. This initiates a process of growth or development of the mentors, as they re-examine aspects of their professional lives. To guide student teachers’ learning, mentors need to understand how student teachers think and learn about science teaching. They must also have knowledge about specific strategies of science teaching, students’ learning, and the subject matter in order to guide their student teachers in learning to teach science. Hence, this “stop” on a student teacher’s complex journey from learner to teacher then provides opportunities for both student
teachers and their mentors to directly verify and develop their own teaching skills and to step back and to reflect on each other’s teaching.

6.2. The complexity

Why is the journey complex? It might be assumed that one answer to the question concerns the characteristics of science teaching. The student teachers’ (and mentors’) voices in the four papers all hinted at the various ways in which they experienced their primary science teaching and learning. Even though the student teachers had tried the experiments several times, they still failed. Even though they felt that they had prepared for difficult questions from the pupils, they received unexpected questions that they could not answer. Even though they thought they knew about the pupils’ pre-conceptions, they were surprised that the pupils often knew more than they had expected. Even if the mentors had more than twenty years of teaching experience, they felt like novices when actually teaching science.

Already in 1986, Clark and Peterson stressed that “classroom teaching is a complex social process that regularly includes interruptions, surprises, and digressions” (p. 268). Teaching science requires a diverse knowledge of resources such as materials, curricula, students, methods and strategies, most of which are acquired over several years. These resources then form the tools that teachers use in order to promote pupils’ learning. During their pre-service programs student teachers should have the opportunity to become familiar with those tools. Further to this, the complexity of teaching derives from several other aspects such as the diversity of students in school, the changing world of society as well as of school organisation and changing demands and requirements on teachers.

Another reason for the complexity is the structure of science teacher education. During their years of education, the student teachers in this thesis entered several different arenas for learning. They interacted with courses and university teachers from different cultures (such as science faculty and faculty of pedagogy) with different ontological
perspectives, which, as highlighted in the papers, means they do not always experience them as being in agreement in the actual primary school context in which they will teach.

Finally, it might be reasonable to suggest that the complexity in a student teacher’s journey from learner to teacher also depends on the nature and quality of reflection, in university courses as well as in school based practice. In this thesis reflection has been a major issue and in all four papers different tools have been used to monitor student teachers’ reflections. Normally student teachers are encouraged to reflect on their teaching practices, how they managed to reach their goals and their experiences of teaching. Those reflections are often documented in portfolios and discussed in seminars. However, the question still remains as to how do they reflect and what is the quality of their reflections. Björklund (2008) stressed that student teachers (as novices) have a limited ability to see and interpret classroom situations and therefore they are only able to reflect superficially on their teaching. Hence, it is important not only to encourage student teachers to reflect, but also to evaluate the depth and status of that reflection. It might be assumed that student teachers learning to teach also include “learning to reflect”, which then might hint at the complexity of a student teacher’s journey from learner to teacher. Further to this, for teacher educators to evaluate and reflect on student teachers’ teaching and learning science, they must also be able to see and recognize student teachers’ difficulties, needs and concerns.

6.3. From Learner to Teacher

Interest in better understanding the knowledge base needed for teaching and how it is developed has been running high for at least the last twenty years. As Berliner (2004) outlined, it takes 5 to 7 years to acquire high levels of teaching skills where the teacher is no longer surprised by what happens to them in their schools and classrooms. Berliner (2004) added that this period might be shortened, or be made richer if some coaching were to take place. Shulman (1987) began his paper with a portrait of teaching expertise asking: “What does Nancy (the person portrayed as an expert)
believe, understand, and know how to do that permits her to teach as she does? Can other teachers be prepared to teach with such skill?” (1987, p. 3).

However, the student teachers’ vivid “stories” in this thesis support the ideas of Bishop and Denley (2007) that:

“…becoming a science teacher is not only a case of learning a predefined set of procedures and a static body of knowledge, it is about engaging with a dynamic and exciting subject and facing the challenges of presenting to students in an accessible way (p. 2)”.

The journey from learner to teacher is a never ending process of investigating, reflecting and analyzing one’s own activities in the classroom in order to formulate one’s own personal professional theories and to use these theories to guide future actions. Further to this, it seems reasonable to suggest that a strong sense of self-motivation is needed to drive student teachers to continue their learning journeys as life-long learners. Even though student teachers might often be looking for safety in their teaching, it is reasonable to suggest that they also need opportunities to “take risks” in order to learn through experiencing the discomfort of being less certain of what is [or might be] happening. In so doing, they may begin to capture and better understand the complexity of [science] teaching and learning.

Finally then, let us return to the entire subtitle “Student teachers’ complex journey from learners to teachers.” However, given the nature of teaching, it is reasonable to suggest that there is a number of “unknown domains” of teachers’ practices that teachers need to explore in search of answers that will guide their future actions. As such, teacher education is a beginning place for teachers’ professional learning journeys, not an end. Therefore teacher education needs to foster and inspire student teachers for their ongoing professional learning journey. Further more, teacher educators (and student teachers themselves) need to research student teachers’ experiences and concerns in order to learn to teach about teaching more effectively. Munby and Russell (1994) suggested the authority of our own experiences matter and the same applies to teacher education researchers who also need to develop a powerful
voice and influence in how teacher education programs might be further developed. Our understanding of what we, as teacher educators, are doing is connected to our interactions with student teachers and their concerns and dilemmas. In the same way as student teachers are travelling on a complex journey, teacher educators are doing the same. We encourage student teachers to begin their learning journeys, but we must not forget to join them on that journey, and hence, become reflective practitioners in the complex enterprise of teacher education practice.

7. Implications and future research

What then are the implications for this research on student teachers’ complex journey from learners to teachers? What do we learn from it and in what way might the results contribute to that double aim that Bassey (1981) highlighted; to result in generalizations in the form of theories of learning and the knowledge base needed for teaching, and to contribute to a change in the practice of teacher education? Just as teacher education programs must be targeted at student teachers’ concerns to translate required knowledge into effective classroom practice, there is also a need for more extensive research on the required knowledge and how it is developed during pre-service teacher education. However, the goal of teacher education is not to “tell” student teachers how to teach, but to educate them to reason soundly about their teaching as well as helping them make explicit their needs and concerns for teaching. Sound reasoning requires both a process of thinking about what and how they are doing and an adequate base of facts, principles and experiences from which to reason. Further to this, in order to close the “zipper” between theoretical knowledge (of science as well as pedagogy) and practical knowledge, teacher educators must be able to clearly demonstrate not only that theories, ideas, and research taught in teacher education programs are evident in the practice of teachers, but also how the theoretical knowledge is actually linked to practice. To be trustworthy in such a task (i.e., in helping student teachers to close the zipper), teacher educators also need to “enter the school classrooms floor” to teach (Pinnegar, 1995; Russell, 1995) or to study
classroom interactions (e.g., like in the studies presented in this thesis) and what is actually happening in a teaching situation.

In order to teach physics for primary science student teachers, it might well be argued that deep physics knowledge itself is not enough. Also, it is reasonable to suggest that university teachers need to know something about the primary school context in which the student teachers will teach in their future professions. Hence, if pre-service teacher education programs are to facilitate the professional development of student teachers, teacher educators must understand the processes by which student teachers grow professionally and the conditions that support and promote such growth. One idea of so doing might be to create arenas for learning about teaching (such as focus groups) for teacher educators to interact with school teachers as well as university teachers from different disciplines (e.g., science and pedagogy).

Another interesting issue raised through this thesis is that of a pedagogy of teacher education. It is too often the case that studies (such as this) draw attention to particular aspects of learning, teaching or teacher education but do not link those outcomes to the ways in which the teaching of teacher education is conducted. This thesis highlights the importance of listening to student teachers’ personal stories to consider the difficulties that they face within the teaching and learning processes so that they might, as Veenman (1984) suggested, begin to identify, analyze and address their teaching concerns. As such, one of the main results of this thesis concerns the need for, and the practice of, conscious reflection on learning and teaching practices; for student teachers as well as teacher educators. Thus, action research projects in teacher education, where teacher educators and student teachers document and further explore their teaching and learning processes (e.g., through stimulated recall sessions) might be one possibility to work with conscious reflection in teacher education.

Another implication of this thesis concerns the usefulness of the PCK framework. The concept, as it was illustrated by Bishop and Denley (2007) as a spinning-top, could well be used in teacher education to design pedagogical strategies as well as an
analytic lens to study [the development of] “successful teaching”. The PCK framework can also guide further research and curriculum development work in the area of teacher education in order to integrate different knowledge such as subject matter, pedagogy and knowledge of the context. Hence the PCK framework might help us to identify not only what is important but also why and how aspects of teacher knowledge might become important to promote pupils’ learning. However, it might be suggested that what is required is a shift in focus in science teacher education whereby science teacher education curricula could be built around PCK, as an essential tenet in leading to improvements in student teachers’ problems with the interface between SMK and PCK. Therefore, further research is crucial on how student teachers experience the practice of teaching science, how to interpret those experiences, what constitutes teacher knowledge and in what way that knowledge impacts pupils’ learning. As such, it is important that teacher educators, in developing their pedagogy of teacher education, seek to find ways of incorporating student teachers’ needs and concerns into their teaching about teaching in ways that are sympathetic to their context but that explicitly challenge student teachers’ learning about teaching in ways that are based on their own experiences of teaching. In so doing, teacher educators’ pedagogical content knowledge and reflective skills are important.

To end, what is the next stop in my own (as a researcher) learning journey and where do I go from here? One of the tracks that I have already started to travel along is to further investigate teacher educators’ teaching and their learning journeys in order to develop pedagogical content knowledge. Further to this there is a need to look closer to the ontological perspectives of the discourse of university science and how it is related (or not) to the discourse of school science.

Another missing link in this thesis is the relation between teaching and the pupils’ learning and experiences of the science teaching. I began this research five years ago with an intention to study primary pupils’ communication and learning in physics through physics teaching and practical experiments in the classroom (Nilsson, 2004, 2005). However, as a problem became evident to me when I observed what happened
to primary school teachers who normally did not teach physics in primary schools, my research interest shifted from only studying pupils’ learning to studying student teachers’ learning to teach in interaction with the pupils. Now as I conclude the work on this thesis, one idea might be to explore pupils’ ideas of science teaching and learning (e.g. what critical aspects within their teacher’s teaching do pupils consider as important for their learning?)

In 1986 Shulman noted that teacher education research was overlooking the central role of content and subject matter, a phenomenon he called the “missing paradigm”:

“The missing paradigm refers to a blind spot with respect to content that now characterizes most research on teaching and, as a consequence, most of our state-level programs of teacher evaluation and teacher certification….What we miss are questions about the content of the lessons taught, the questions asked, and the explanations offered.” (Shulman, 1986, p. 7-8)

Now, more than 20 years later, as the policy makers (in Sweden) hold very strong beliefs on teachers’ subject matter knowledge, we must be careful that we do not contribute to new “missing paradigms” (e.g., pupils’ experiences of their learning of science, or teacher educators’ pedagogical content knowledge). Therefore, for future research and for my own continuing journey, I will not only continue together with student teachers but I will also invite university teachers and pupils into this lifelong learning journey.

8. References


Appendix 1 – Paper 1
Teaching for understanding – The complex nature of PCK in pre-service education

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Abstract

This paper explores the development of student teachers’ Pedagogical Content Knowledge during pre-service education. Four student teachers in mathematics and science participated in a project teaching students aged 9-11 in physics once a week over a 12 month period. One third of the lessons were videotaped and the student teachers were later interviewed using the video tape for stimulated recall. Participants reflected on their classroom practice based on their conceptual understanding of physics. This empirical study emphasizes the role of teaching experience and reflection in science teacher education as a way of better understanding the complex entities that constitute a knowledge base for teaching. The paper draws attention to the value of student teachers participating in experiences that might contribute to the development of their PCK and supports a view of PCK development as a process of transformation.

Introduction

Learning to teach is a complex process and an emerging concern in the research on teacher education revolves around the relationship between teaching and learning and the importance of better understanding how that relationship might influence the work of teacher educators and the nature of their pedagogy of teacher education (Loughran, 2006). This growing focus on learning and teaching about teaching has been highlighted in many ways, perhaps none more so than that of Cochran-Smith and Zeichner’s (2005) recent concern for more scientific research on teacher education,
particularly in relation to how such studies could influence teacher education practices. Therefore, in order to move beyond notions of teaching as only the delivery of information, there is an urgent need to unpack teaching and learning to teach from the point of view of student teachers’ experiences in order to create a deeper understanding of their needs and concerns.

It seems reasonable to suggest that by encouraging science student teachers to reflect on their own teaching that they may well develop deeper insights into their understandings of science teaching and learning. With this in mind, this study examines, how by focusing attention on particular aspects of the knowledge base for teaching (Shulman, 1986, 1987; Wilson et. al., 1987), student teachers’ understanding of practice might be mapped and conceptualized; in this case through considering some aspects of the development of their Pedagogical Content Knowledge (PCK).

It could well be argued that the structure of teacher education may not always offer opportunities for student teachers to transform the knowledge they acquire during course work into the type knowledge they might need to teach in a [primary] school context. Different knowledge bases such as subject matter and pedagogy are often taught separately, thus inadvertently creating a situation in which student teachers alone need to make find ways of transforming their various ‘knowledges’ to useable and meaningful forms within the context of teaching. Hence, there is considerable merit, both in relation to research and practice, in exploring how student teachers through the use of reflection develop and build on different knowledge bases (i.e. knowledge of pedagogy, subject matter and context) in a transformative process to develop the amalgam that is PCK. Clearly, to do so, student teachers need to move beyond their initial needs and concerns so that they might come to recognize and understand the complexity of teaching and see the value in transforming their knowledge into a form that is useable and helpful in shaping their classroom teaching of science.
Based on a project in which four student teachers, in pairs, taught physics to students aged 9-11, once a week over the course of a year, this paper investigates how some of the different knowledge bases - Subject Matter Knowledge (SMK), Pedagogical Knowledge (PK) and Contextual Knowledge (CK) - described as fundamental to PCK were recognized and further understood by these student teachers. Through collaboration and structured reflection on their teaching experiences, their understandings of SMK, PK and CK were examined to explore how such explication influenced the foundations of their PCK.

Theoretical Background

Nature and development of Pedagogical Content Knowledge

Shulman (1986, 1987) introduced the term pedagogical content knowledge (PCK) to draw attention to the value of the special amalgam of content knowledge and knowledge of general pedagogy that a teacher needs to be the best possible teacher. Various scholars have further developed conceptualizations of PCK (e.g., Appleton, 2003; Gess-Newsome & Lederman, 1999; Gudmundsdottir, 1990; Loughran, et al., 2004, 2006; Van Driel et al., 1998; Zeidler, 2002) as an academic construct representing specialist knowledge of practice. As such, PCK has become a way of understanding the complex relationship between teaching and content through the use of specific teaching approaches (Loughran et al., 2001) and is developed through a process rooted in classroom practice (Van Driel et al., 1998). PCK then refers to a teacher’s integration of subject matter knowledge and pedagogy in ways intended to enhance students’ learning.

Although PCK has attracted much attention, there is no universally accepted definition or conceptualization. Epistemological issues about the nature of PCK led Gess-Newsome (1999) to describe two extreme models of such teacher knowledge, the Integrative and the Transformative model. In the Integrative model PCK does not exist and teacher knowledge is explained as an intersection of subject matter, pedagogy and context. When teaching in the classroom, knowledge from all three domains is
integrated as needed to create effective learning opportunities. “An expert teacher, then, is one who has well-organized individual knowledge bases that are easily accessed into and can be flexibly drawn upon during the act of teaching” (Gess-Newsome, 1999, p. 11). An advantage of an Integrative model is that domains of knowledge can be developed independently and be integrated at a later stage. A potential danger with the Integrative model is that teachers may never see the importance of such knowledge integration. The Transformative model represents a synthesis of all knowledge needed in order to be an effective teacher. Knowledge of subject matter, pedagogy and context, whether developed separately or integrated are transformed into a new form of knowledge that is more powerful than its constituents parts. Thus, the three knowledge bases become more useful when transformed into PCK. An expert teacher, then, has well formed PCK for the topics commonly taught. The danger with this extreme is that it could be seen as objectifying teaching and so student teachers’ decision making skills, personal growth and creativity might be overlooked.

Grossman (1990) conceptualized PCK as consisting of four components: the overarching idea of teaching subject matter; knowledge of students’ conceptions and difficulties; knowledge of curriculum; and, knowledge of instructional strategies. PCK is then developed as a result of a knowledge transformation, but unlike the Transformative model of Gess-Newsome (1999) there is a reciprocal relationship between the domains. Magnusson et al. (1999) developed a model of PCK for science teaching through which the “overarching knowledges for teaching” (knowledge of: science curricula; students’ understanding of science; instructional strategies; assessment of scientific literacy) were conceptualized as shaping “orientations towards science teaching”, all of which then impact what PCK might be. Magnusson et al. (1999) used the term orientation to represent a general way of viewing or conceptualizing science teaching. Knowledge and beliefs in this area guide a teacher’s instructional decisions about the organization of activities, the content of student assignments, the use of textbooks and curricular materials and the evaluation of students’ learning.
Knowledge bases needed for teaching

Across these views of PCK there is commonality in terms of three well recognized knowledge bases: Pedagogical Knowledge (PK); Contextual Knowledge (CK) and Subject Matter Knowledge (SMK). Pedagogical Knowledge (PK) consists of general elements regarding teaching, classroom organization and management, instructional models and strategies and classroom communication. Morine-Dershimer and Kent (1999) suggested that pedagogical knowledge must be adapted to fit the particular contexts in which teaching takes place. Thus, practical experience emerges as an essential ingredient in understanding how to apply instructional strategies in real classroom situations and must impact the development of PCK. Contextual Knowledge (CK) is strongly connected to PK and represents knowledge of school departments, traditions, behaviour of students, the climate in the classroom, the relationship between individuals, and the context in which teaching takes place.

Finally, Subject Matter Knowledge (SMK) refers to a teacher’s quantity, quality and organisation of information, conceptualisations and underlying constructs in a given field of science (Zeidler, 2002). Gess-Newsome (1999) suggested that SMK also included scientific literacy, participation of the scientific discourse and an understanding of the structure and the nature of the discipline. Traditionally, teachers’ SMK could be considered as equating with the number of courses he/she has taken in the subject, or the amount of teaching experience he/she has in the subject. Research has indicated that teachers with good SMK have more knowledge of related concepts, and methods of connecting one concept with another. Further to this, limited subject matter knowledge also results in low confidence in teaching science (Appleton, 2003, 2006; Harlen, 1997; Harlen & Holroyd, 1997). Thus, the level of complexity of one’s subject matter knowledge structure is a critical factor in how easily knowledge structures influence classroom practice and embodies the content fundamental to the development of PCK.
Experience and reflection – foundations of PCK

Student teachers’ lack of classroom teaching experience must inevitably influence what their PCK might look like compared to that of experienced science teachers. However, in order to catalyze the development of PCK it seems reasonable to suggest that recognition of the parts may well enhance development of the whole. Hence, PCK as the transformation of these different elements of knowledge relies on a dynamic relationship between each. Further to this, as alluded to above, PCK needs to be considered in relation to practice: “The best strategy might be to combine a theoretical and empirical analysis to generate as complete a picture of PCK as possible and yet keep it grounded in classroom practice” (Marks, 1990, p. 11).

Magnusson et al. (1999) stressed that the development of PCK is determined by the content to be taught, the context in which the content is taught and the way the teacher reflects on his/her teaching experiences. Reflection therefore emerges as another important element for student teachers in developing expertise in their practice and is central to them accepting more responsibility for their actions (Calderhead, 1981, 1993; Korthagen, 1993; Loughran, 2002; Munby & Russell, 1993; Shulman, 1987; Van Manen, 1995; Wallace & Oliver, 2003). It could well be argued then that teacher educators need to provide opportunities for student teachers to examine, elaborate and integrate new knowledge and beliefs about teaching and learning into their existing knowledge and beliefs: “This goal can be addressed through activities such as observing, analyzing and reflecting upon one’s own or another’s teaching” (Magnusson, et al., 1999, p. 122) if PCK is to become a real goal in learning about science teaching. This study therefore considers how stimulating student teachers’ reflections on their own classroom experiences might influence their understanding of the complex relationship between their teaching, subject matter content and the context to foster possibilities for the development of PCK. The research question being examined then is: “What elements of professional knowledge do student teachers’ recognize in their practice and how does such recognition influence (or not) the development of PCK?” How each of these elements (PK, SMK, CK) is (or is not)
recognized is then central to how the interaction between these “knowledges” impacts the possible development of PCK.

Method

Participants in this study were four student teachers, three female and one male all between 20-25 years, in the final year of a four and a half year pre-service program (Maths/Science for primary and secondary school). The program is structured such that there is a mix of two years of different science courses, two years of pedagogy courses and half a year of practical work in the school context, all spread out across the whole program.

The student teachers involved in this study volunteered to participate in a specific research project: Journey of knowledge in physics. This project aimed to inspire school students’ interest in science and technology, and to provide student teachers with possibilities to regularly teach and learn science in a school setting. When they agreed to participate in the project they had finished all their science courses, three were elementary courses in physics, and were studying general pedagogy. They had also been out in schools for in all, ten weeks of individual practical training, to teach science. Within the project, the student teachers planned their lessons and taught, without any interference from the classroom teacher (or teacher educator). They did not draw upon a packaged curriculum, but were free to choose the content of the specific lessons themselves. They planned and taught all their lessons in pairs which was part of the learning about teaching procedure designed to offer participants the opportunity to collaborate and share ideas and experiences. During the year they taught specific physics topics, e.g., electricity, mechanics, temperature, light and sound to three primary school classes with students aged 9 to 11 (see table 1 for a description of the individual lessons). The student teachers were not physics graduates but were encouraged to choose physics topics because they experienced the subject themselves as complex and difficult. Some expressed a lack of confidence in and a negative
attitude towards the subject and even admitted that they planned to drop the subject in their future profession.

The use of video-recording of participants’ teaching as a prompt for stimulated recall interviews (Meade & McMeniman, 1992) was a major methodological approach employed to enhance reflection. Stimulated recall has been used in several studies to facilitate student teachers’ and teachers’ learning from their experiences (Brown & Harris, 1994; Calderhead, 1981; Davis, 2003; Freitas et al., 2004; Mead & McMeniman, 1992; Stough, 2001). As Jensen (2002) noted, it is a powerful way to elicit information about student teachers’ personal views of their own teaching and therefore an important way of encouraging participants’ reflection on their own practice. Therefore it was chosen as a major data source for this study.

**Data collection**

Over the course of a year, the four student teachers taught physics, in pairs, once a week. They planned the lessons themselves, and their teaching was to a large extent based on an approach whereby each lesson contained some form of experiment.

The student teachers were consistently observed throughout the year as they taught a range of topics. Two topics in particular (3 lessons each, six lessons in total per pair) were video recorded. These topics were chosen partly as they are often considered as difficult and abstract and partly for practical reasons (not in the beginning and not in the end of the year). The first topic concerned electricity in which the students worked with how to light up lamps with different intensity, how to connect bulbs and batteries in series and in parallel, how to make torches, how to construct light switches and how to find out which materials do/do not conduct current. The second topic concerned temperature whereby the students conducted experiments on the thermal conductivity of different materials e.g., by putting them in the freezer or lowering them into boiling water. They also boiled water, with and without salt, to explore the concept of boiling point.
The aim of video recording was to use it as a concrete tool for stimulating the student teachers' reflection on the lessons including the way they communicated with their students and their actions in the classroom. Subsequently, these video recordings were used for stimulated recall interviews with the student teacher pairs (i.e., Stimulated recall 1: Lessons 1, 2, 3; Stimulated recall 2: Lessons 4, 5, 6; see Table 1 below).

<table>
<thead>
<tr>
<th>Jenny + Julia</th>
<th>Lessons 1, 2, 3 (electricity)</th>
<th>Stimulated recall 1</th>
<th>Lessons 4, 5, 6 (temperature, heat)</th>
<th>Stimulated recall 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>David + Tina</td>
<td>Lessons 1, 2, 3 (electricity)</td>
<td>Stimulated recall 1</td>
<td>Lessons 4, 5, 6 (temperature, heat)</td>
<td>Stimulated recall 2</td>
</tr>
</tbody>
</table>

Table 1: Data sources and topics

During the stimulated recall interviews, each pair of student teachers studied their video recording together with the author. The student teachers were invited to stop the tape and comment on any critical incidents (Tripp, 1992) in their teaching. A critical incident or “special event” was defined as something that caused them to reflect on their teaching, for example, an event connected to their activity and their interaction with the children during their teaching; how they experienced the lesson, their feelings, attitudes and intentions. These critical incidents then became the basis for in-depth examination and analysis of their pedagogical actions. Each stimulated recall interview lasted for about three hours and was semi-structured, hence there was a protocol of questions (e.g., why did you experience the situation as critical? How did you feel about the situation? Why did you ask or respond to students’ questions in such way? etc.), but it also allowed the researcher to ask clarifying questions in order to explore the student teachers’ reflections as they stopped the tape. Hence, methodologically, the stimulated recall sessions were designed to explore that which student teachers
themselves perceived as important components of their own knowledge for teaching and opened up new possibilities for exploring how these “changed” during classroom practice. In so doing, it was anticipated that responses would offer insights into the foundation for (or otherwise) of their PCK.

**Analysis**

Data obtained from the stimulated recall sessions were analysed in order to produce thick descriptions (Geertz, 1973) of student teachers’ reflections. All stimulated recall interviews were transcribed verbatim. Data were analysed in terms of specific examples of reflections particularly related to the three knowledge bases (SMK, PK and CK) and those that might be suggestive of the development of participants’ PCK.

It is clear in the literature that there are of course other elements that have been suggested as contributing to PCK (e.g., knowledge of curricula, how to assess students’ understanding of science and scientific literacy), but in this study, analysis focused on the three most commonly acknowledged knowledge bases (PK, CK and SMK) as they were the most indicative and dominant elements apparent in these student teachers’ reflections.

Data coded as predominantly Pedagogical Knowledge (PK) included specific reflections on the teaching activities and how these student teachers interacted with their students during their teaching, for example, consideration of teaching procedures and strategies, questioning techniques, and so on. Data coded as predominantly Contextual Knowledge (CK) included reflections connected to students’ behaviour and the school context, for example, the cooperation between the students in the classroom and different factors connected to the school context. Data coded as predominantly Subject Matter Knowledge (SMK) included student teachers’ own conceptual understanding, participation in the scientific discourse and an understanding of the structure and the nature of the discipline of physics.

To establish the validity of the coding, inter-coder reliability was conducted based on the application of the descriptors above of the three knowledge bases (PK,
SMK and CK) to the transcripts. Only those reflections coded in the same way by the author and a second researcher were accepted as valid data for analysis. All of the quotations used in the following section (Results) are therefore indicative quotes based on the dominance or tendency of a given knowledge base (PK, SMK or CK) to be the central thrust of the data.

A limitation with analysis based on ‘separate knowledge bases’ as described above is that given the complexity and intermingling of participants’ knowledge, thoughts, ideas and practice in the process of teaching, although analysis assumes that the knowledge bases are completely separate and distinct, in reality they are combined in a complex web. There is then an inevitable ‘mixing of knowledge’ as student teachers reflect on their practice not through the three separate and distinct knowledge bases but through their examples of their critical incidents of practice. The boundary between the three knowledge bases in the discussion of critical incidents by the student teachers can therefore not be seen as always being separate and discrete, but rather as a choice between competing possibilities with the most dominant feature attracting most attention in terms of possible analysis and interpretation. Therefore a difficulty in analysis is in seeking to interpret the data according to the most dominant feature of a given incident whilst acknowledging that it may not necessarily be that knowledge alone. This aspect of the study therefore offers interesting glimpses into the transformative nature of PCK almost regardless of analytic classification and interpretation.

Results

As the data in this section suggests, through the stimulated recall sessions participants’ recognized, and in some instances emphasized, the three knowledge bases both separate entities and also in concert with one another. As the data offered in this section illustrates, the way each of the knowledge bases is explained by the participants as well as the interplay between the three knowledge bases suggests that, through reflection, transformation into PCK might well be occurring.
A focus on the need for Pedagogical Knowledge (PK)

The student teachers emphasized the need for pedagogical knowledge particularly in relation to how they handled their teaching in the classroom such as planning, preparing and deciding on the teaching methods to use and what physics materials to include in a lesson. They often felt tied to their plan and the need to keep up with the physics content that “needed to be covered”. They commonly expressed frustration at not having enough time to carry out their plans.

Jenny: But you are fairly focused here as you feel you should do both heat and cold. You do not want to start anything else …

They could see the importance of being flexible and fair in how they dealt with students’ questions and the importance of not answering too quickly, but to wait for the students to try to answer themselves. They were also aware that students found it difficult to write, but they still wanted them to practice making hypotheses and giving details of their findings. They discussed how they tried to stimulate the process of writing laboratory reports:

Julia: They [students] seemed to think that it is more fun only to talk about what they had found. There was always a big sigh as soon as they were going to write.

Tina and David also reflected on how the class was conducted and what to do to maintain students’ attention. Among other things, they realized that they should not plan too many activities in one lesson but rather split them up over two lessons. They further reflected on the lack of available time and how insufficient instructions could negatively affect students’ patience and concentration. They recognized aspects of their pedagogical knowledge in terms of preparing for questions and dealing with unforeseen events in the classroom.

Jenny and Julia highlighted the role of communication as a tool for developing students’ learning abilities. They emphasized the use of different teaching methods and ways of explaining phenomena to guide students towards a better understanding; something which requires an act of transformation and might therefore be suggestive
of a transition toward PCK as their pedagogical knowledge is influenced by the need to better help in understanding everyday phenomena. Jenny claimed that “the more ways you can explain a concept, the better the students understand the explanations” and that she as a teacher must be able to explain in several ways – which highlights not just the PK but hints at a mix with SMK and CK as well.. In summary, all participants emphasized planning, performing and evaluation in relation to their teaching of experiments and their interviews made clear that the development of their pedagogical knowledge was an important aspect of their understanding of being a science teacher.

**A focus on the need for Subject Matter Knowledge (SMK)**

SMK includes knowledge of subject content, and an understanding of the structure and the nature of the discipline of physics. The interface between SMK and PCK was critical in the process of how to transform the physics content which again raises several interesting questions concerning the relationship between subject matter understanding and the subsequent development of PCK. These student teachers, Tina in particular, emphasized the importance of having strong subject matter knowledge to manage and to feel confident in her teaching:

Tina: I felt that I did not know what I was talking about. One student suddenly asked me if the fluorescent lamps were connected in series or in parallel. And I was supposed to explain that. I thought they were connected in parallel, but I was not sure. You can really see how I am thinking, trying to find the answer. I felt … ah … let us continue with something else. I did not want to discuss things that I did not understand.

All of the student teachers drew attention to their own understanding of subject matter knowledge. They argued that during their university courses they had learnt different scientific concepts, laws and formulas but this did not necessarily mean that they understood the content.

Tina: But I wonder if you really understand when you are not able to write it down in words? I thought I understood, but when I tried to formulate it in other words, it did not work, and then I raised the question “have I
understood?” In other words, the content should be formulated in my own words. It should not be copied from our university literature. At the university we have learnt very much, but we are not able to apply it. In an assignment when you have to formulate and describe your knowledge on the paper you are really tested.

The student teachers stated that they used upper secondary school physics text books, in order to develop their own understandings to see which words were used and to know the content at an adequate level. From this perspective, it could appear as though the student teachers had therefore started to move beyond SMK to PCK because although they used textbooks for their own understanding, they were also using textbooks to get a feel for the level of students’ understanding and the need to pitch the material at the students’ level. However, they all stressed that they found their university courses to be abstract and did not introduce the physics of everyday life, which they considered a disadvantage for their own subject understanding. The importance of having appropriate subject matter knowledge was further discussed by David and Tina, in reflecting on an event when a short circuit was caused by a pupil connecting a lamp to a battery. On this occasion, David had difficulty in explaining why there was a short circuit and Tina’s uncertainty as to how lamps in the ceiling were connected showed that she also lacked a deeper understanding of the ideas.

Jenny and Julia discussed how they used a formula to calculate the boiling point for salt water, but during the experiment they had to explain why water with and without salt had different boiling points and it caused them problems. They also talked about a lesson where they discussed the relationship between colour and temperature. They informed the students that black clothes were warmer than white in the summer, but when one pupil wanted an explanation; they were confused and could not answer the question.

Jenny: This thing about colours is difficult even to us and I feel somewhat uncertain. I mean, what exactly absorbs heat and so on. I can perhaps accept it when I read it, but to explain it … I cannot recognize that we have discussed that in our university courses. Perhaps it would have been easier having a metaphor or picture in my own head. We both felt confused about this question and we looked at each other. Actually we were grateful that we
were interrupted by a teacher who knocked at the door. Then we did not have to answer the question.

Each of the student teachers experienced a gap between the subject matter knowledge they had gained at the university and the physics they taught in school. This gap emanated partly from their difficulties in transforming their subject matter knowledge and in relating theory to practice, largely derived from a lack in their own subject matter knowledge. The relationship between student teachers’ subject matter knowledge and their teaching ability, self-confidence and attitudes towards science was clearly evident. For each of them, good subject matter knowledge led to confidence in teaching that subject. Students’ questions sometimes led to feelings of frustration and discomfort when they could not answer them. This meant they were eager to have a better understanding of the physical science required to teach their students well but that such knowledge, although based in the subject matter, needed to be understood beyond the subject matter as propositional knowledge alone.

**A focus on the need for Contextual Knowledge (CK)**

Contextual knowledge includes such things as teachers’ knowledge of students’ abilities and learning strategies, students’ attitudes about school science topics, the social and cultural environment and students’ prior knowledge of the concepts to be taught. The student teachers argued that such contextual knowledge was crucial to their success in teaching. They discussed the need to experience how the classroom context influenced their ability to teach and learn science. At one level, the need to be familiar with tasks and unwritten rules of the school that influenced their teaching was important, for example, in relation to classroom management:

> Julia: After a lesson, we pointed out the necessity of raising a hand for attention. But you are a bit careful in the beginning and you are mainly focusing on what to do regarding the subject.

A different type of “rule” was that of evaluating and checking students’ knowledge. Julia and Jenny discussed how and why they asked questions, and which questions they asked in order to respond to the rule but also to become more familiar with how to help a pupil. Julia described her experience of certain students shouting for help, even though they did not need help, and how she gradually learned to sort out the differences. The students’ relationships with each other and the group dynamics in the classroom were also discussed. Tina discussed her uncertainty about the demands
required of her as a teacher. She also noticed that she did not give the same amount of
time to the girls as to the boys:

Tina: I discussed with these girls only one time. It is really terrible when you feel that you do not have time for everybody. I am in the back row the whole time. I am not at the front. Perhaps it is because the boys sit at the back and shout all the time. The girls in the front did not ask for help or said one word during the whole time.

Jenny and Julia drew attention to their relationship with the students and how they experienced differences between boys and girls. They found that the girls dared to say more, and asked more questions when they were alone than when the boys and the girls were all present in a group. Julia described the girls as being more creative. Both stressed that it was difficult to learn about a context, which to a large extent depended on the individuals forming it. In a classroom with 24 students, all individuals were different:

Julia: There were a lot of different factors in the classroom that you must learn to recognize.

In summary, the student teachers recognized well the role that classroom context played in influencing their teaching. They could see the importance of group dynamics and the need to know their students, their ideas, abilities and interests and they emphasized the importance of being aware of the different factors that influenced the classroom climate, particularly in relation to students’ special problems and needs.

**Recognizing the role of reflection**

Through the team teaching, stimulated recall reflections and the collaboration the student teachers were able to highlight issues and situations that were important to them in shaping their understanding of their own practice. These approaches were important aspects of this study because they were intentional ways of making student teachers’ thinking explicit to one another and the researcher, thus offering access to the
reasoning underpinning their actions. By reflecting on their practice in this public manner, it was possible to see how these participants were in fact recognizing and responding to different elements (SMK, PK and CK in particular) of the knowledge of teaching.

Tina: You learn a lot through sitting here and reflecting on what you do and how you communicate.

David: Yes it has been invaluable to see how you react on different situations and what you might improve and do in different ways. It really should be included in the physics courses to reflect on what you need to teach physics.

Tina: Yes you realize that a lot of unexpected situations happen and you need to understand that you always can do things better. It is not the pupils that are slow year after year. You have to reflect on the fact that it might be your explanations that are not clear enough.

By seeing their own teaching again through the video recordings, these student teachers were able to frame and reframe their practice (Schön, 1983, 1987) and therefore gain new insights into what they were doing and how. Reflecting in this way created new possibilities for them to make the tacit in their practice explicit and to begin to consider how the different knowledge bases on which their teaching was based influenced their developing orientation (Magnusson et al., 1999) to science teaching. How this developing orientation might be a foundation for the development of PCK is considered in the next section.

**Transformation: The foundations of PCK**

As outlined earlier, Gess-Newsome (1999) described two extremes, or two end points of a continuum, that helps to explain the development of PCK: an integrated model and a transformative model. Despite the lack of classroom experience of the student teachers, the transformative argument appears to best explain their journey in the development of PCK. As the data illustrates, it may appear as though the processes of collaboration, teaching and reflection as implemented in the research outlined in this
paper enhanced the transformation of student teachers’ knowledge to develop their PCK. In their reflections the student teachers emphasized the three different knowledge bases in different ways as important in shaping their teaching.

Several times the student teachers had to combine the three knowledge bases to handle experiments that did not go as planned and/or face difficulties in answering unforeseen questions. For example, Jenny and Julia carried out an experiment in which the students were to learn about those materials that conducted heat. The students stuck drawing pins into small pieces of butter on a silver knife, a stainless steel knife, a wooden knife, a plastic knife and a glass test tube and then lowered them into hot water. The students were expected to observe the order in which the drawing pins fell into the water as the butter melted. However, the drawing pins did not fall off in the expected order and so students did not draw the “right” conclusions. Jenny commented on their “failed experiment” with the drawing pins, the unanswered questions that were raised due to the experiment and how they desperately searched for an explanation of why the drawing pins did not fall off in the expected order. The student teachers often sought to access the knowledge bases not so much as separate and distinct elements but in a transformed manner. They stated that they needed more work with representations and experiments and activities that could be used in the primary science classrooms to handle students’ difficulties in understanding certain topics.

Tina: When we come out in school and try to find synonyms and similarities to the physical phenomena, perhaps it was not totally correct … we are sometimes afraid of simplifying it for the students.

Further to this, David and Tina discussed their need to develop a repertoire of experimental methods and how such methods might influence students’ learning. They recognized that a teacher must be able to explain phenomena in many ways, as well as being able to connect and relate abstract phenomena to everyday life. A lack of subject matter knowledge made it difficult to relate phenomena to everyday situations, but subject matter alone was not sufficient. Different knowledges needed to be
transformed, but to encourage this transformation through student teachers’ practice, they needed to be confronted with real classroom situations to reflect on, and learn from these concrete examples. For example, Jenny quickly recognized how, through teaching, her knowledge of circuits changed.

Jenny: From the beginning I did not understand how the light bulb was constructed. But when we started to discuss it with the pupils it appeared to me how it worked. I had to draw it on the white board and then I had to observe it more carefully. I had not studied it in theory but it appeared to me during my teaching.

It is reasonable to suggest that the way in which the different knowledge bases for teaching were recognized by these student teachers as changing through experience was clearly apparent and is an indication that Gess-Newsome’s (1999) notion of PCK as coming out of the different knowledge bases is supported.

Tina: I feel that I have learnt more physics during the project. Even if this has been on a very low level, I have been forced to reflect and find synonyms to difficult concepts. When we have walked around in the classroom to help the pupils we have learnt a lot about how they think and act.

Further to this, in some instances, such recognition was borne of being both a teacher and a learner and was therefore a catalyst for further developing these participants’ orientation toward science teaching and learning and therefore appears a likely pathway toward the development of PCK.

Jenny: When Julia explained to the pupil that the metal was cold because it leads the heat away from your hand, I realized something that I had not understood before.

It could well be argued that these student teachers were reconsidering how to both access and use these knowledge bases of teaching and in so doing, their orientation to
science teaching and learning was changing and moving beyond the constituent parts so that it might be foundational to the development of PCK. It appears as though the way their knowledge interacted in practice was evolutionary and dynamic and as separate compartments of knowledge SMK, PK and CK were, of themselves, insufficient to manage practice alone; hence the importance of transformation.

Tina: You feel that when you can transform a difficult concept to an everyday concept, and when you see that the pupils really understand, then you realize that you have found the intersection between the content knowledge and the pupils’ learning. You mix the both parts; I mean the difficult things and the easy ones and in the same way you grasp the ideas.

As it has been suggested that PCK might exist at something more than an individual level, an interesting aspect of this data set is embedded in the sharing of experiences of teaching (team teaching) and in the stimulated recall sessions. These student teachers’ data hints at the foundation for PCK as being influenced through the sharing of experiences and understandings of practice. By teaching together, listening to one another, questioning, reviewing and learning together, their reframing of practice suggests that the knowledge of teaching somehow takes on new and different significance across the group as opposed to being at an individual level alone.

Jenny: As when a child asked us *why* the black T-shirt was warmer than the white one, it would have been easier if we have had not only a correct explanation of the absorbance, but instead a picture in our heads and different explanations and metaphors. When he asked the question we were lost and we just looked at each other.

Jenny: We discussed it later but we could not find a good way to explain it, I mean the light was caught and it got warmer, but why? Was it due to the material in the clothes? We realized that only having content knowledge on a high level and being able to count on absorbance was not enough to teach why the black T-shirt was warmer. We also needed some good explanations and methods to represent the ideas.
Hence, as a consequence of sharing experiences a reconsideration of what it meant to understand the particular concepts as a learner and a teacher emerged in ways that intimate a change in knowledge from the “what” to the “how” and learning about the “how” is embedded in practice and is the essence of a pathway to the development of PCK as a transformational process.

**Discussion**

It is reasonable to suggest that in several situations the student teachers expressed their need to have their knowledge bases as a transformed unit. However, the process of transformation was not always evident. They had a repertoire of teaching methods and experiments, but they did not fully manage to present the content in a way that promoted students’ understanding. These student teachers had passed their exams in physics courses, which should indicate that they in some way had acquired the subject matter knowledge. They had also passed their exams in most courses of pedagogy which similarly indicates that they had acquired a repertoire of teaching methods. Yet, the data indicates that in teaching, they faced several problems. As already highlighted in several studies (Appleton, 2003, 2006; Harlen, 1997; Harlen & Holroyd, 1997) it may appear as though these student teachers’ limited subject matter knowledge also resulted in low confidence in teaching science. However, it might well be suggested that their ways of seeing what they think (e.g., recognizing important aspects of their learning to teach) and thinking about what they see helped theses participants to reframe their practice in ways which was new to them. It may appear as though the way they conceptualized their difficulties in verbalizing their knowledge, connecting their knowledge to everyday life, and relating theory to everyday situations helped them to go beyond their initial needs and concerns to “give the right answers’ in order to shape their learning about teaching. The data also illustrates that it is crucial to move beyond the individual elements of knowledge bases in order to identify and develop student teachers’ conceptualization of their teaching (create an orientation toward science teaching and learning) in order to enhance their students’ learning.
Whether knowledge for teaching is integrative or transformative has implications for research as well as for practice. To promote student teachers’ development of PCK, teacher educators must develop deeper understandings of student teachers’ perceptions of the knowledge needed for teaching in relation to classroom practice. For such an understanding, careful attention must be paid to student teachers’ personal stories of how they experience what it is to actually teach.

In the present study, PCK was considered as a complex entity built on definable knowledge bases. In relation to the two extremes of Gess-Newsome (1999), this data suggests an evolving position directed towards the transformative model. However, as the components of knowledge function as parts of a whole, a lack of coherence between components can be problematic in developing and using PCK (Magnusson et al., 1999). Also an increased knowledge of a single component may not be sufficient to effect change in practice. As the components will interact in a highly complex way, it is important to understand not only the particular components of PCK, but also to understand how they interact and how their interaction influences thinking about, as well as the act of teaching.

By examining, analyzing and modelling the concept of PCK in teacher education practice, it is more likely that science teaching will be seen by student teachers as a “specialized and sophisticated practice, rather than simply comprising a variety of teaching procedures to make students’ learning of science more fun” (Loughran et al., 2006, p. 222). The process of identifying, developing and transforming the elements that constitute the “knowledge base of teaching”, and how they are related, might be a way to emphasize PCK in teacher education programs. Therefore, it seems clear that teacher education programs need sophisticated approaches to teaching about teaching science if they are to encourage a transformative vision in learning to teach science. (Teacher educators may well need to portray and explicate aspects of their own PCK when teaching about science teaching).
Although the use of only two pairs of student teachers in the study might be acknowledged as a limitation, the strength of an in-depth examination is that it permits a deeper insight into student teachers’ ideas and concerns. Hence, it might be argued that deep qualitative studies are crucial if we are to learn about student teachers’ learning to teach in order to improve practices of teacher education. Yet Cochran-Smith and Zeichner’s (2005) concern for more scientific research in teacher education also requires the need to go beyond the specific to the generalizable. The present study has identified how some of the knowledge needed for teaching, for example, elements of subject matter knowledge, pedagogical knowledge and contextual knowledge are readily identified by student teachers as influencing their practice and how the dynamic interplay between these is central to moving beyond them as individual and separate and distinct domains. If the development of PCK in student teachers can reasonably be described as a transformative process, then clearly it is important that large scale studies of the process of PCK development in student teachers need to be encouraged.

Conclusions and implications for pre-service teacher education

Although numerous studies have been conducted to explore student teachers’ learning to teach, the influence on teacher education practice has in most cases been relatively weak. This study indicates the importance of engaging science student teachers in projects with a substantive focus of reflection of their own teaching of science in order to help them make insightful shifts in their thinking about their orientation toward science teaching and learning and hence, initiate the development of PCK. In terms of teacher education, it is also important to be reminded that PCK constitutes more than the sum of its parts (Magnusson et al., 1999), and so teaching and program structure need to be responsive to this point. One way of so doing might be for pre-service programs to design specialized courses which link SMK, PK and CK and their impact on teaching practices, in order to pay careful attention to student teachers’ needs and concerns; and then to purposefully push beyond these. Further to this, if pre-service teacher programs are to facilitate the professional development of student teachers, teacher educators must understand the processes by which student teachers grow
professionally and, the conditions that support and promote this growth. Therefore it is crucial that teacher educators, in developing their pedagogy of teacher education, seek to find ways of incorporating such practice into their teaching about teaching in ways that challenge student teachers’ learning about teaching in ways that are based on their own recent and real experiences of teaching.

For student teachers to be able to build on, and challenge students’ conceptions of science, it is necessary to obtain deeper understandings of the subject content and pedagogy within a context, but also how they interact in classroom teaching. These are all fundamental conditions to developing PCK. Student teachers bring to their teacher education a subject matter understanding very different from the kind of conceptual understanding that they will need to develop conceptual understanding in their future students (Mellado, 1998). To foster the development of student teachers’ professional knowledge into the amalgam that is PCK, they need tools to help them attend to issues in their classroom practice. They need opportunities to practice instructional processes in the actual lessons that they plan, conduct and evaluate so that “they can learn from review and discussion of each other’s lesson, as well as from peer-review and discussion of their own lessons” (Morine-Dershimer & Kent, 1999, p. 44). As this study illustrates, team teaching and videotaped lessons are useful ways of helping them “unpack” the complexity of the classroom and promote opportunities for careful reflection on their teaching.

The research outlined in this paper was intended to draw serious attention to the way in which student teachers’ shared teaching experiences might be portrayed and understood in order to demonstrate the importance and usefulness of the knowledge produced. Hence, creating possibilities for student teachers to recognize that learning about teaching also comprises the development of the sophisticated knowledge of practice that is PCK requires real possibilities for them to build on the dynamic interplay between (at least) SMK, PK and CK through their practice. For this to occur, embedded learning through experiences of teaching is essential, however, reflection on such experiences is crucial.
References


From lesson plan to new comprehension: Exploring student teachers’ pedagogical reasoning in learning about teaching

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Abstract
The research reported in this paper is based on an exploration of the ways in which student teachers learn about the issues and concerns that shape their own professional learning. Shulman’s process of pedagogical reasoning and action was used as a conceptual framework to systematically elucidate different critical incidents that student teachers experienced and to then apply it as an analytic framework for developing deeper understandings of the complex task of learning to teach primary science. Primary science student teacher participants (n = 22) were stimulated to reflect upon critical incidents in order to facilitate identifying their teaching concerns and teaching needs. The data collected consisted of: (A) the results from questions to the student teachers before the lesson; (B) questions to the school pupils; and, (C) written answers to a questionnaire and audio-recordings of group discussions concerning participants’ answers to the total data sets (A, B & C). The results indicate that by helping student teachers to focus on critical incidents in their learning to teach they come to question their practice more deeply and through such reflection, gain new insights into teaching as being problematic.

Introduction
Learning to teach is a complex process and an ongoing concern in the learning to teach literature is the need to help student teachers move beyond notions of teaching as the delivery of information, and begin to critically reflect on, and seek to actively develop, stronger links between their teaching, their students’ learning and, importantly, their own learning to teach (see for example, Berry, 2004; Chin, 1997; Feiman-Nemser, 2001; Heaton & Lampert, 1993). As the literature makes clear, this is a difficult transition for student teachers because their “apprenticeship of observation” (Lortie, 1975) has created a strong sense of experiencing teaching as telling. The
apprenticeship of observation combined with the fact that teaching as telling tends to prevail in their teacher education classes (Russell, 1997; Korthagen et al., 2001) means that, for many student teachers, coming to understand teaching as being problematic and therefore moving beyond expectations of learning to teach as being “told how to do teaching” is a constant challenge. However, facilitating such a change is crucial to a pedagogy of teacher education (Loughran, 2006) and the practices and processes highlighted in this paper help to inform the ongoing development of our thinking of teaching about teaching.

Student teachers are often interested in knowledge that is practical and can be applied in the classroom. Further to this, it could well be argued that student teachers do not always manage to make explicit connections between teachers´ actions and the pedagogical theories that inform practice. For student teachers the theoretical knowledge (subject matter as well as pedagogy) might not always be experienced as immediately useful in addressing their problems in practice. However, through teaching experiences that are reasoned and reflected, it is reasonable to suggest that student teachers might recognize their knowledge needs and, thus, bridge theory and practice in a meaningful way. Zeichner (1995) argued strongly that student teachers´ critical awareness must “grow out of” their own experiences “by drawing attention to certain elements of their practice” (p. 17). Zeichner (1995) further stressed that student teachers´ own issues and practices become the starting place for making more transparent the inherent dilemmas of practice. Therefore it might be reasonable to suggest that a pedagogical reasoning, which moves from specific observations within the student teachers’ teaching practice (through which patterns, regularities and hypotheses can be explored) to some general conclusions about student teachers´ teaching concerns, might tell us something about student teachers’ learning about teaching.

In the study that is described in this paper, one way of so doing has been to focus student teachers’ attention on incidents within their teaching experiences that they experience as ”critical incidents” (Tripp, 1993, 1994) and to invite them to reflect on
these incidents in order to identify their concerns for learning to teach. Hence, it is suggested that when student teachers are encouraged to analyze their own teaching practice in order to better understand what, why and how they do it, they may also become more empowered to seek new ways of conceptualizing their practice. According to Tripp (1993) there are thus two stages to the creation of critical incidents: first some phenomenon is observed and noted (produces a description of what happened), then, secondly, the critical incident is created through reflection on what the incident meant, which means moving out of the immediate context in which the incident occurred. A critical incident is produced by the way we look at a situation and is then an interpretation of the significance of an event (Tripp, 1994). Hence, the specific content of a critical incident can strongly differ between individuals depending on the subjective meaning that is attributed by the person. Therefore, as the student teachers generate the incidents themselves (through their reflections) the level of criticality and the interpretation of the incident then has to be understood from the interpretive framework that the individual student teacher uses to give meaning to his/her practice.

To take something as a critical incident is a value judgement we make, and the basis of that judgement is the significance we attach to the meaning of the incident. …we can read anything that happens in a critical fashion. (Tripp, 1994, p. 8)

By encouraging student teachers to reflect on their teaching experiences in order to recognize and focus on critical incidents it is anticipated that they might then question their practice more deeply and begin to see into the problematic nature of teaching. There are examples of this being the case. In the context of science teaching Nott and Wellington (1995) used critical incidents to help student teachers see into their teaching (activities; experiments; demonstrations) and their students’ learning (students saying or doing unexpected things; questions which the student teacher could not answer; etc.). Maureen and Griffin (2003) examined the effectiveness of using critical incidents in a supervised field experience in order to develop student teachers’ reflective and critical thinking skills. Their results showed that reflecting on critical incidents increased student teachers’ orientation toward growth and inquiry. Woods
(1993) used the term ‘critical event’ to refer to events that had consequences for personal change and development in challenging one’s claims to be a teacher and Watts et al. (1997) explored ways in which children’s questions provoked critical incidents for teachers about both the nature of science and the processes of teaching and learning. Further to this, reflection on critical incidents can help make explicit for student teachers their specific teaching concerns such as knowledge of difficulties in the teaching (Van Driel et al., 2002) as well as their more general pedagogical content concerns (De Jong, 2000), described as concerns about transforming the academic knowledge into teaching activities. Therefore, in focussing on critical incidents discovered by the student teachers themselves, and pedagogical reasoning about these incidents (e.g. with peers or educators) it is possible to help student teachers see to reframe pedagogic situations (Schön, 1983) and to develop more sophisticated understandings of what it means to teach.

**Student teachers’ needs and concerns: Influences on learning to teach**

Long ago, Fuller (Fuller, 1969; Fuller & Bown, 1975) highlighted the importance of student teachers’ concerns and how they shift during teacher preparation. Fuller & Bown (1975) posited three distinguishable stages of concerns that were characteristic of teachers. The first stage involved survival concerns. Those were concerns about one’s adequacy and survival as a teacher, class control, being liked by pupils and being evaluated. The second stage included teaching situation concerns which were about limitations and frustrations in the teaching situation such as methods and materials. The third stage reflected on concerns about pupils, their learning and their social and emotional needs. The experience of becoming a teacher involved coping with all three stages. In recent times there has been some debate about the applicability of such stage based models (Burn et al., 2000, 2003; Richardson & Placier, 2001). However, despite these differences, there is a recognition that teacher educators still need to be cognizant of student teachers’ needs and concerns because one way or another, they inevitably influence what they are “ready to see and respond to” in a given pedagogic situation.
As noted earlier, reflection has developed a great deal of currency in teacher education programs. Many studies support the view that pre-service teachers should become reflective practitioners in order to develop their practice beyond the technical alone (Calderhead, 1988, Korthagen, 1993; Loughran, 2002; Munby & Russell, 1993, Schön, 1983). Studies into reflection illustrate how beginning teachers often experience tensions between their beliefs and their actions in the practice of teaching (Van Manen, 1995). Therefore, it could well be argued that the earlier student teachers become aware of their needs the earlier they may begin to systematically study their practice and test their beliefs in practice (Bryan & Tippins, 2005). Hence, it is reasonable to suggest that helping student teachers identify, analyze and address their concerns is important in helping them to modify their images of “self as teacher” and therefore, their understanding of teaching more generally (Veenman, 1984).

Sanford et al. (1998) examined the concerns expressed by novice teachers in relation to their perceived lack of preparation for dealing with classroom problems and Watson (2006) reached a similar conclusion. Adams and Krockover (1998) identified beginning science and mathematics teachers’ concerns and how they influenced their views about the effectiveness of their preservice teacher education program. Common to many such studies is the view that as student teachers, they lacked experience in planning and managing teaching activities. In a study by Swennen et al. (2004) student teachers were most concerned about matters such as selecting and teaching content, motivating pupils to learn and adapting to the needs of different pupils and less concerned about matters that were not central to the immediate task of teaching. Talanquer (2007) noted that concerns that influence student teachers’ understanding of learning about practice relate to student teachers’ ability to: meet the cognitive and social needs of their students; plan instruction; use teaching methods; conduct their teaching and the limitations and frustrations that arise as a result.
Pedagogical reasoning and action

As many of these studies illustrate, concerns about learning to teach highlight the importance of pedagogical reasoning and how that influences approaches to teaching. Shulman (1987) discussed what he considered were the processes underpinning pedagogical reasoning and argued that particular actions were necessary if teachers were to transform their personal comprehension of subject matter into forms that might be comprehensible to students. Pedagogical reasoning though is not as simple as just thinking about teaching. According to Shulman (1987) and Wilson et al. (1987), pedagogical reasoning comprises a cyclical process. Teaching begins with comprehension whereby teachers first need to understand the subject matter themselves and also understand how the ideas within their discipline are interrelated and connected. Comprehension also comprises an understanding of the aims and purposes of teaching. Following comprehension is transformation in which teachers transform their content knowledge into forms that are pedagogically powerful and adaptable so that the content might be understood despite the diversity of students’ learning styles. Instruction follows transformation and involves such things as organizing and managing the classroom, explaining, interacting effectively with students, discussing and providing effective teaching. Evaluation follows instruction and that includes checking for students’ understanding and misunderstanding, as well as the formal testing and evaluation that teachers do to provide feedback and grades. Interestingly, evaluation is also directed at one’s own teaching, at the lesson and the materials employed in those activities. In that sense it leads directly to reflection. Reflection is what a teacher does when she/he looks back at the teaching and learning that has occurred, reconstructs, re-enacts and recaptures the events, the emotions and the accomplishments. Finally then, the process of pedagogical reasoning cycles back to influence new comprehension as a result of the learning achieved through experience. Therefore, through acts of teaching that are reasoned, new comprehension of the content, students and the processes of pedagogy emerge.
This model of pedagogical reasoning offers synergies with ways of considering student teachers’ needs and concerns and how they might be explicaded through critical incidents to enhance learning about teaching through reflection on practice. In the study described in this paper, the process of pedagogical reasoning was not explicitly taught to student teachers but was used as a methodological framework to design a research project in order to systematically elucidate different critical incidents that student teachers recognized within their teaching experiences.

**Research design**

The research reported in this paper is based on the assumption that if a student teacher is encouraged first to identify and further to reflect on critical incidents in their own practice, they might then conceptualize aspects of their practice that they need to address in order to meet their explicaded pedagogical concerns. The following research questions formed the basis from which an organised and structured research project was constructed to appropriately respond to the overall purpose of the study:

- What critical incidents influence student teachers’ pedagogical reasoning in learning to teach?
- What teaching concerns do student teachers recognize in their own practice as they reflect on their learning to teach?
- What teaching needs do the student teachers formulate in order to manage their identified teaching concerns?

During the process of planning, conducting and evaluating a science lesson, primary science student teacher participants (n = 22) were stimulated to reflect upon critical incidents in order to facilitate identifying their teaching concerns. Structural features of the study setting included:
1. teaching a science lesson with a special target group (young students aged 4-11);
2. a special setting – a Science Learning Centre – and teaching in small groups (2–3 student teachers teaching together); and,
3. group discussions about their experiences of teaching

As noted above, the aim of the study was to identify critical incidents that primary student teachers experienced during their teaching in order to explicate their different teaching concerns in learning to teach (primary science). The process of pedagogical reasoning and action (Shulman, 1987) was used to systematically elucidate different critical incidents that student teachers experienced in order to develop deeper understandings of the complex task of learning to teach primary science.

**Conceptual framework**

As suggested above, in using critical incidents to “unpack” student teachers’ pedagogical reasoning it may well be that new comprehensions of “purposes, subject matter, students, teaching, and self” (Shulman, 1987, p. 15) might be articulated in student teachers’ learning about teaching. Shulman’s pedagogical reasoning model (see Figure 1 for a schematic representation which also includes data collection methods and points) therefore offers an analytic frame for exploring that which underpins student teachers’ actions. At the same time, through using this theoretical framework it is also possible to highlight (for participants) the problematic nature of practice. Through actions that are reasoned and reflected (together with peers and educators) student teachers might therefore also see into the complexities of teaching and learning in ways that foster their moving beyond the technical in their learning to teach.
Figure 1: The process of pedagogical reasoning and action used in the study.

Setting of the study

The setting of this study was a primary science teacher education program in a Science Learning Centre. The Science Learning Centre offers a lot of teaching and learning for pupils aged four to eleven who attend the centre to experience science lessons as an additional component to their regular schooling. The lessons normally include different experiments in the hope that attendees will experience science as something interesting. The intention is that pupils attending the Science Learning Centre will be stimulated to work in a problem-based manner, putting forward hypotheses, documenting their observations and discussing their results. The student teachers who participated in this study were in a three-and-a-half-year pre-service primary teacher programme; one year was given to maths and science. The entire programme qualified the student teachers to teach in pre-school and primary school. During their second and third terms they had different basic courses in mathematics, physics, chemistry and biology, to prepare them for teaching in pre- and primary school. At the time of the present study, they were in the end of their third term completing a compulsory part of
their science method course involving planning and conducting a lesson with a group of pupils in the Science Learning Centre. The first term of their teacher education was intended to give them an insight into general education. The second and the third terms contained fundamental courses of science. Hence, they had finished their science courses and were supposed to have a relatively good portion of subject matter knowledge in science. The school aged pupils were registered by their teacher to attend the Science Learning Centre as a special occasion beyond their regular schooling. The student teachers worked in pairs or trios (n = 10 groups) and the themes of the lessons concerned a range of scientific phenomena related to an everyday context. The student teachers were free to choose both their teaching topics, and the peer(s) with whom they would work. However, they were to choose a topic either in physics or chemistry that involved problem solving and experimentation. The duration of lessons was approximately two hours. Table 1 summarizes information of the participants and the content of their lessons.

**Table 1:** An overview of the student teachers, students and lesson content.

<table>
<thead>
<tr>
<th>Student teachers</th>
<th>Students</th>
<th>Lesson Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anna, Julia</td>
<td>4-5 years</td>
<td>Experiments on gases</td>
</tr>
<tr>
<td>Nora, Rita</td>
<td>5-6 years</td>
<td>Experiments on gases</td>
</tr>
<tr>
<td>Klara, Johanna</td>
<td>6 years</td>
<td>Experiments on gases</td>
</tr>
<tr>
<td>Mette, Stina</td>
<td>6 years</td>
<td>Experiments to concretize density.</td>
</tr>
<tr>
<td>Sara, Sophie</td>
<td>6 years</td>
<td>Experiments on gases</td>
</tr>
<tr>
<td>Tina, Jane, Lisa</td>
<td>10-12 years</td>
<td>Experiments of electricity, to connect light bulbs and to build a switch</td>
</tr>
<tr>
<td>Lotta, Hanna</td>
<td>11 years</td>
<td>Experiments of electronics, to design a house, installing lamps and an alarm</td>
</tr>
<tr>
<td>Peter, Simon</td>
<td>11 years</td>
<td>Experiments on gases, surface tension, to fire wool of steel, volcano and to build a rocket</td>
</tr>
<tr>
<td>Jane, Chris, Emma</td>
<td>11 years</td>
<td>Experiments to concretize air and gases</td>
</tr>
<tr>
<td>Maria, Karin</td>
<td>10-11 years</td>
<td>Experiments of electronics air and gases</td>
</tr>
</tbody>
</table>
In order to gain insight into the student teachers’ experiences, and to further enhance their understanding of teaching and learning in science, different qualitative methods were used. As the study consisted of 22 student teachers the intention was not to generalize across student teachers as a population but rather to examine in rich detail these participants’ learning about science teaching in this setting.

Data collection

The data collected consisted of three main sets (see Figure 1). The first data set (A) comprised the results from questions to the student teachers before the lesson. The second data set (B) was questions to the school pupils and the third (C) was written answers to a questionnaire and audio-recordings of group discussions concerning participants’ answers to the total data sets (A, B & C) as well as student teachers’ spontaneous reflections in the seminar. The intention of conducting a group seminar after the lesson was to situate participants in a social context to stimulate their reflection and to explore their personal stories about how they experienced different critical incidents within the process of teaching, and their identified concerns associated with those incidents.

Data set (A) was collected before the lesson as the student teachers completed a questionnaire about their comprehension of the subject, how they planned to transform it and how they expected their students to experience the content. Data set (B) was drawn from the school pupils who completed a questionnaire based around four questions: What have you learned today?; Why do you think you have made the things you made today?; Would you be able to do this in another way?; and, How would you prefer to learn more about this? All the questions were answered individually by the students, but in the case of the very young students, the questions were answered with the help of their teacher. Data set (C) involved a number of instruments. The seminar began with an individual questionnaire and then the student teachers were encouraged to discuss their answers about: their planning and teaching; what they learnt; how they learnt it; and, their views about their own professional attitudes. The individual written
questionnaire contained questions such as: What did you do with the group and how did you prepare the lesson?; and, How did you experience the lesson? There were also questions designed to encourage them to reason about their interaction with their school pupils: How did you experience the response from the students?; Did anything go wrong, surprise you or make a deep impression on you?; How did you feel instructing a group of students? Some questions concerned their own efforts during the lesson for example: What things made you satisfied/less satisfied with your teaching?; What would you do if you had the possibility to redo the lesson? Finally they were stimulated to reflect on their own learning and their professional development: What have you learned during the project?; and, In what way can you take responsibility for your own development as a teacher? Then, the student teachers in groups of five to six participated in a group seminar. As the study consisted of 22 student teachers, in all there were four group seminars.

During the group seminar, each pair of student teachers presented their experiences and further discussed different incidents that they experienced as critical. The role of the researcher during the seminar was to lead the seminar and ask clarifying questions and to probe for more expansive details concerning incidents that the participants considered as critical. In that way the seminars were designed as semi-structured group interviews (Cohen et al., 2000) allowing both the researcher and the student teachers the flexibility to discuss specific issues as they arose. The discussions during the seminar, stimulated by the questions before, the pupils’ feedback and the individual questionnaire, were audio-recorded and transcribed for later analysis.

The researcher (who also was a teacher educator), was not responsible for assessing these student teachers within the course, but was responsible for planning the project and conducting the group seminars. The researcher had been involved with these student teachers during their previous coursework which meant that the researcher had a relationship with the student teachers. Given the qualitative nature of the study, this relationship could be viewed as both a strength and weakness. The researcher was never positioned as an unbiased seminar leader; rather, she was personally engaged
with all of the participants which might have influenced the manner in which she interacted with the participants during the group discussions. But on the other hand, as the research was built out of the student teachers’ personal reflections during the seminar these relationships afforded opportunities to which a less involved researcher might not have had access. The participants in the group interviews and the researcher were comfortable talking with one another. Although the seminar mainly considered the answers from the different questionnaires, the group discussions flowed freely, allowing participants to explore their own ideas.

**Data analysis**

The written answers to the three questionnaires (A, B & C) were one form of distinct data sets. The group discussions in the seminars were transcribed verbatim and qualitatively analyzed to form a separate data set. Analysis was based on coding the transcriptions to systematically elucidate specific incidents which the student teachers experienced as ‘critical’. These critical incidents caused them to reflect, not only on what happened but also on how they might manage such incidents next time. In such way, their reflection facilitated identification of their concerns for teaching (contributed to their new comprehension) and further conceptualized aspects of their practice (teaching needs) that they needed to address in order to meet their explicated pedagogical concerns.

The data analysis started with a content analysis (Miles & Huberman 1994) where data from all three data sources were read repeatedly in order to identify recurring themes and produce thick descriptions (Geertz, 1973) of what events and emotions that the student teachers experienced during the process, from planning through to conducting the lesson. The primary mode of analysis was the development of categories from the raw data into a framework that captured key themes and processes judged to be important by the researcher. According to Miles and Huberman (1994) this kind of content analysis facilitates the production of *core constructs* from textual data through a systematic method of data reduction (selecting and simplifying from the entire data),
In the data reduction, data were coded for recurring themes and illustrative examples of (1) critical incidents and their related (2) concerns for learning to teach and (3) teaching needs that the student teachers emphasized (critical incident $\rightarrow$ concern for learning to teach $\rightarrow$ teaching need). Concerns in this context were defined as issues that worried the student teacher and/or that they felt anxious about. Needs were defined as things to be done or formulated actions that might resolve a situation. To establish validity of coding, another researcher read the transcriptions in order to highlight reflections that illustrated critical incidents, concerns for teaching and teaching needs. Reflections that were discerned by both researchers then became the accepted coded data for further analysis.

**Results**

The following results are examined according to the three research questions. Hence, the result section presents (1) examples of critical incidents, leading to identification of (2) concerns for learning to teach and finally (3) teaching needs in order to respond to the identified concerns. The teaching needs and concerns that the student teachers recognized as a result of their explicated critical incidents offer insights into the nature of their pedagogical reasoning and are important not only for understanding student teachers’ perceptions of their knowledge of teaching, but also how that knowledge is interpreted.

**What critical incidents influence student teachers’ pedagogical reasoning in learning to teach?**

Given the qualitative nature of the analysis, some parts of discussion are embedded in the presentation of results. The student teachers reflections on their experiences during
the process, from planning through to conducting the lesson were grouped into two overarching themes of critical incidents:

- Critical incidents connected to classroom management
- Critical incidents connected to pupils’ attitudes and learning

**Critical incidents – connected to classroom management**

The student teachers’ limited experiences of teaching made them emphasize a number of incidents connected to classroom management as critical. Mostly those incidents concerned limitations and frustrations in the teaching situation such as methods, time planning and materials but also their own [lack of] sufficient preparations or subject matter knowledge. Critical incidents connected to classroom management most notably emerged when an experiment failed or when they were asked questions by their pupils, or their accompanying teachers, that they were not able to answer due to their own lack of explanations. Peter and Simon described a critical incident during their lesson when their experiment of burning steel wool “failed”. Through this incident, apart from becoming conscious of the value of “testing” experiments in advance, they recognized the problematic nature of teaching and how through a failed experiment discussion about the nature of science and scientific experiments could be examined.

Another important issue connected to classroom management concerned student teachers´ own comprehension of the subject being taught. According to the definition of Shulman (1987), comprehension means that teachers should first understand the subject matter for themselves and also understand how the ideas within their discipline are interrelated and connected. In their pedagogical reasoning, the student teachers emphasized not only the aim and the content of the lesson, but also their own comprehension and self-confidence of the content to be taught. Several of them stressed that they did not feel confident in their subject matter knowledge which also influenced their way to ask and respond to questions. In the group seminar, Jane stressed that she did not want to ask too “open” questions or initiate a discussion about
electricity because she was afraid that she would not be able to explain all phenomena that the pupils might be interested of. They also stressed the importance of being positive and engaged as a teacher.

They further claimed that their science courses at the university had been too advanced for them to actually understand the content and that sometimes the pupils knew more than they did which they experienced as critical. They stressed that a lack in their own understanding made it difficult for them explain concepts for the pupils. This corresponds to Harlen & Holroyd (1997) who found that in general, science background, subject matter knowledge, attitudes and confidence to teach were closely related. As such, Tina referred to a critical incident when she was teaching electricity and recognized that her own content knowledge was insufficient. During her teaching she had difficulties in explaining why a short circuit was caused by a pupil who connected a lamp to a battery. She also found difficult to explain to another pupil why the light bulb became warm. Stina noted how in her experiments on density in which students dropped stones, balloons, macaroni and pasta into water, that the pupil asked why certain things floated and others sank. For Stina this was a critical incident which made her reflect on her own comprehension of the concept of density.

Stina: The macaronis sank but the piece of pasta floated. The students explained it by saying that the macaronis were heavier … but it was not. We could not explain it and we were quite frustrated. We rushed forward. Next time we will select the materials better, but also being more prepared concerning our content knowledge.

Several of the student teachers emphasized incidents that emanated from their difficulties in transforming their subject matter knowledge and in relating scientific theories to a relevant primary school practice. Some of them stressed that they experienced a gap between the knowledge they had gained at their university courses and the knowledge they needed to teach in the Science Learning Centre. Another critical incident connected to classroom management concerned the student teachers´ use of scientific language which sometimes led to pupils’ misunderstanding. Mette and
Stina experienced a critical incident concerning their use of the concept of density. During the experiment they used raisins that moved up and down as gas bubbles “stuck to them”. When a child asked why, they had difficulty in explaining without using the word density. This incident made her reflect on how easy it was to use a language of adults that pupils do not recognize.

**Critical incidents connected to pupils’ attitudes and learning**

Simon and Peter reflected on their pupils’ answers and initiated a discussion in the group seminar about pupils’ attitudes and learning of science. One of the boys in their group said that he had learned that if they burnt the steel wool, rust was created and it became heavier. Even if this was not a scientifically correct explanation, at least the boy had learned that steel wool became heavier when it was burnt and, that the burning process created another compound. The boy also wrote that the reason why they did experiments was that they should “learn something new and not only the normal things that they learned in school”. Only one pupil answered that she was able to learn science in school.

In general the pupils appreciated the experiments and some of them also wrote that they should continue doing experiments at home, invent new experiments and teach their parents. The student teachers found these responses both encouraging and challenging in terms of the implications for their understanding of their pupils and their expectations for extending their learning about science. Sara and Johanna were surprised by the creativity of the pupils and that the six year old pupils were so capable of making experiments and solving problems. Sara and Sophie found it critical as they experienced that the pupils knew more science than they had expected:

Sophie: The thing we feared happened! They knew more than we had expected and we had not planned enough things to do. We thought that our questions would initiate a lot of discussions, but when some of them already knew the answers and shouted it out there were no need for discussions. To fill out the time we had to improvise with a game with matches in a square, but then we realized that we did not know the right answer. We felt terrible.
Jane, Chris and Emma experienced a critical incident when they did a demonstration with baking powder and a balloon and expected the pupils to ask why the balloon blew up. They had prepared answers to a lot of “why-questions” but they did not get any. They had a preconceived notion that pupils were curious by nature and always asked questions about “how and why”. During their demonstration they found out that this was not always the case which made them aware of the need to consider more carefully how to stimulate questioning. It also appeared to be a central assumption of the student teachers that pupils liked doing experiments but before doing their teaching, they did not differentiate between experiments as fun and experiments as engaging in learning science content. Hence, another critical incident that many emphasized was linked to the realization that not every pupil experienced experiments as fun and so they questioned their initial aims. They came to think about doing experiments as needing to be something more than fun (although being fun was still important), but also for their pupils to learn something about the content from doing the experiments.

All student teachers highlighted that the pupils’ evaluations made them identify important aspects from their own teaching. A lot of pupils had written that they learnt a lot but they did not know in what way they could use that knowledge in the future. Peter emphasized that this made him see the importance of giving the pupils good motives for learning science.

What teaching concerns do student teachers recognize in their own practice as they reflect on their learning to teach?

Within their pedagogical reasoning the student teachers recognized several teaching concerns as a result of their explicated critical incidents. The teaching concerns that the student teachers felt anxious about were grouped into three overarching questions:
• How do we adjust instruction to meet the pupils’ learning needs and prior conceptions?
• How do we stimulate the pupils’ interest and give them good motives for learning science?
• How do we develop our learning about teaching primary science?

How do we adjust instruction to meet the pupils’ learning needs and prior conceptions?

Shulman (1987) described the act of instruction as involving the organization and management of classroom teaching, explanations, effective interaction and discussions with students. With respect to instructional strategies, the student teachers’ identified a concern that mostly pertained to their pedagogical content knowledge (Shulman 1986, 1987); how to adjust instruction to meet the pupils’ prior conceptions. Maria and Karin emphasized the importance connecting concepts to the pupils’ everyday world in order to make it concrete for them:

Maria: It can be hard for them to understand how the current and the electrons function when you are not able to see it with your own eyes. Working with practical experiments such as designing houses with lamps is a good way to make it all concrete.

Several student teachers emphasized the concern for knowing how to be well prepared for the pupils’ questions but also for being able to explain phenomena. Deep subject understanding and knowledge of metaphors and analogies appropriate to particular concepts were perceived as important in transforming content knowledge in ways that might be meaningful for the pupils. Lotta and Hanna stressed that the more they knew about the subject, the more self-confident they felt. Many of the student teachers came to recognize that knowledge of pupils’ common misconceptions in science and knowledge of the appropriate level of subject matter were important in shaping a pedagogic situation, i.e., that simply delivering the content, or making experiments fun were different from engaging pupils in meaningful science learning.
Mette: We used the experiments to get a chance to listen to their discussions and explanations to get an insight into their conceptions and misconceptions. As they [pupils] shared their ideas with each other while discussing the experiments we had a perfect opportunity to know more about their thoughts and that we found out as being very helpful later when we discussed the experiments.

Emma: We have realized that you have to use different explanations. If a pupil has a good preconception, perhaps he/she does not need a very detailed explanation. Therefore it is important not only to be able to find the appropriate explanations but also to know something about pupils’ different conditions.

Rita indicated that things that were very clear to her were not always clear to her pupils. She said that in pre-school it was important to create pictures in the pupils’ heads to help them understand and to “avoid misconceptions”. Some thought that the use of scientific language “frightens the students”. Others believed that it was important for the students to hear scientific language at an early age to be better prepared for future learning in science.

**How do we stimulate their pupils’ interest and give them good motives for learning science?**

Most of the student teachers described their teaching aims as being to stimulate their pupils’ interest. However, they emphasized the connection between their own self-confidence in and attitudes towards teaching and their ability to stimulate the pupils. As a result of their concern for giving the pupils good motives for learning science, the student teachers emphasized the importance of choosing experiments that the pupils recognized and that were close to their everyday experiences. As such, Klara and Johanna used a metaphor of baking bread when they did experiments with the pupils 6 years old about how to create carbon dioxide. Lotta and Hanna described how they used the analogy of water in a tube to explain the concept of current. Rita described how she used a demonstration with a balloon to explain how carbon dioxide was created in a bottle with aspirin and water. When the gas went up in the bottle the balloon expanded.
Several student teachers stressed the importance of encouraging pupils to discuss science but also how the way they acted in the classroom influenced the pupils’ attitudes and interest. Therefore, during their group discussions they emphasized the importance of being open-minded to the pupils’ ideas, flexible and creative.

Mary: I think it is important to listen to the pupils and try to figure out what they like and dislike. I mean, pupils are different and it is not always about only making the content simple, it is about teaching in ways that stimulate pupils’ interest and learning and that is not always easy.

During the group seminar it was emphasized that all pupils have different abilities, interests and learning needs and that they, as teachers, had to be flexible and creative when unexpected things happen all the time. Rita stated that she wanted to make her pupils conscious of the science around them and Jane emphasized that she wanted to develop pupils’ conceptions of electricity and technology in order to give them a good base to build upon in the future and to develop as good members of the society. The student teachers also emphasized the importance of making pupils better understand both what and why they were learning science. As such, in the study the evaluation of students’ response was based on monitoring pupils’ answers and other approaches to checking for understanding such as how the pupils had experienced the teaching.

_How do we develop our learning about teaching primary science?_

In their pedagogical reasoning all student teachers emphasized their concerns for learning how to teach primary science and what factors that influenced that learning. Through their shared experiences in the seminar, they came to recognize different issues that could shape their own professional learning. For example, Johanna reflected on different factors that influenced her professional knowledge:
Johanna: It is interesting to listen to the young pupils’ hypothesizing, reasoning and explanations. They are not afraid of saying what they think and listening to their discussions helped me to gain insight into their thinking, which has learned me a lot about my own teaching. It has also helped me to know how to talk to them in order to be more “understandable” and to give the pupils an adequate challenge. I am sure that my content knowledge has been influenced as I was forced to repeat the content for myself and to transform it to an appropriate level.

The student teachers emphasized the need – as teachers – to review, reconstruct and critically analyze their own and the class’s performance. They considered it to be important that as teachers, they needed to develop a positive attitude toward gathering and understanding pupils’ thoughts and ideas and to therefore be competent in stimulating pupils’ creativity. They also stressed the importance of transforming the theoretical knowledge gained in university courses into a relevant teaching practice as well as displaying sincerity, enthusiasm and joy. Anna and Julia emphasized the importance of reflection in order to think about how their approaches might differ in the future. They also stressed that it was good to work in groups and to learn from hearing what their peers had planned, what they have done and how it has worked.

Peter stressed that it was important to be curious about doing new things. In general the student teachers thought it was instructive when they received questions from pupils and when unexpected things happened in their lessons – again hinting at recognition of the problematic nature of teaching. To be open-minded and flexible for new ideas and thoughts was identified as important factors for their learning how to teach. During the seminar the student teachers also emphasized the importance of evaluation as a tool for their professional development. They stressed the importance of getting feedback from peers and pupils about their own teaching, for example in planning their lesson or the materials employed in the activities. Through their pupil’s answers they realized that they did not always experience the lesson in the same way as they had expected. The pupils’ experiences of the lesson made them aware of those
parts of the lesson that were consistent or inconsistent with their aims; they begin to see alternative perspectives on the teaching and learning situation which is suggestive of reframing (Schön, 1983).

**What teaching needs do the student teachers formulate in order to manage their identified teaching concerns?**

As a central feature of enacting a change is bound up in the ability to see an issue requiring attention (Loughran, 2006), the pedagogical reasoning used in the study also helped the student teachers to recognize their teaching needs. These teaching needs were of different nature. Some aimed at improving the technical effectiveness of the specific teaching experiences and others aimed at addressing more general objective issues applying to many different situations. The four overarching teaching needs are presented and discussed below:

- need for good content knowledge in order to explain phenomena to their pupils and to connect scientific concepts into an everyday situation
- need to have a large repertoire of experiments and activities
- need for knowing about the pupils’ earlier experiences, general classroom organization and learning needs
- need for knowing how to be self-reflective

Within their pedagogical reasoning, all student teachers stressed the need for good content knowledge in order to feel more confident in a teaching situation and for knowing how to explain phenomena to their pupils. The student teachers also emphasized the need to put scientific concepts into an everyday situation for their pupils so that they might better understand different phenomena. Further to this they emphasized the need to have a large repertoire of experiments and activities with the majority of student teachers emphasizing their intentions of explaining phenomena and beginning to recognize the problematic nature of teaching. To adjust instruction to meet the pupils’ conceptions the student teachers highlighted the need for knowing
about the pupils’ earlier experiences and specific learning needs. Better knowledge of pupils’ common [mis]conceptions and general elements regarding classroom organization and management, student evaluation and classroom communication (e.g. cognitive, social and developmental theories of learning and how they apply to pupils in their classroom) was also emphasized as important issues. Finally, almost all student teachers emphasized the need for knowing how to reflect and the need – as teachers – to review, reconstruct and critically analyze their own and the class’s performance.

Discussion

Veenman (1984) suggested that knowledge of the problems faced by beginning teachers may provide important information for the improvement of pre-service and in-service programmes. This study of primary science student teachers has used a range of methods to gain insights into student teachers’ pedagogical reasoning and therefore their developing understanding of the nature of teaching. As a consequence, and as the data and analysis above illustrates, the student teacher participants in this study came to see that teaching science required much more than simply delivering the knowledge of science to their pupils. The study illustrates how student teachers use their teaching experience to create need to know that might encourage a reconsideration of the teacher as teller role (Russell, 1997; Korthagen et al., 2001), often emphasized by many student teachers. Hence, the strength of the data was in student teachers’ own personal stories of situations which they experienced as critical and which caused them to reason about aspects of teaching and learning science that they had not explicitly questioned previously. As such, experiences of critical incidents might also serve as catalysts for change.

Shulman’s (1987) pedagogical reasoning framework was used as a methodological framework in order to better understand student teachers’ learning about teaching through connecting the phases of planning, conducting, evaluating and reflecting on a lesson. Initially, science content was “the major issue” for many, but through their experiences their views of success in teaching shifted to acknowledging and
responding to the problematic nature of practice. They grasped the importance of genuinely interacting with their pupils rather than only talking at them. In explicating their concerns about teaching and learning situations they began to reframe situations in ways that created (for them) deeper understandings of their role as teachers. Even though an experienced teacher might have considered the incidents that the student teachers emphasized in their discussions as “small problems”, for the student teachers those incidents turned out to be very worrisome. Thus, their discussions led to the identification of several concerns for learning to teach and further teaching needs that they considered important in informing their future practice; and therefore the development of their “new comprehension” of teaching.

The results support Shulman’s (1986) and others (e.g., Van Driel et al., 1998) view that subject matter knowledge may well be a prerequisite for effective teaching but also illustrates that subject matter knowledge alone is not in itself sufficient. Hence, in learning to teach, being able to meet student teachers’ concerns is important, but moving beyond them is crucial in helping them see teaching as something more than the transmission of information. Tripp (1993) argued that understanding of what it is one does and how one does it come together when there is a sharp focus on learning from experience. Further to this, and important in learning to teach, critical incidents may also promote an increased awareness of the variables that impact teaching and learning (Griffin, 2003). Learning about teaching requires risk taking and student teachers need opportunities to take risks and to learn from their critical incidents in positive ways. Loughran et al. (2006) argued that opportunities for student teachers to experience a sense of frustration matters if they are to move beyond being comfortable with tips and tricks alone (that is to see and feel the problem in order to decide to do something about it).

Appleton (2002) advocated the need for primary science teachers to go beyond only using “activities that work”. To develop high quality science teaching in pre- and primary schools and for teacher preparation to serve an important role in that process, student teachers need to be encouraged to recognize their concerns and to move
beyond them if they are to see teaching as a complex process. The results of this study highlight the importance of listening to student teachers’ personal stories to consider the difficulties that they face within the teaching process so that they might do as Veenman (1984) suggested, begin to identify, analyze and address their teaching concerns. In so doing, they might be “forced” to modify and reconstruct their images of self as teacher and see into the complex process of learning about teaching.

Conclusions and Implications for teacher education

As indicated in this study, Shulman’s model (1987), as described in figure 1, provides opportunities for deeper analysis of student teachers’ activities within the process of their learning to teach. Encouraging student teachers to share their experiences, to interpret, value and learn through reflection on the critical incidents they experience, can contribute to new insights into their professional development. The close relationship between these participants’ critical incidents and their identified teaching concerns raises important questions about the nature of subject matter courses and how these might be shaped to take into account student teachers’ concerns about content “in teaching”. Clearly, an implication from this study is for pre-service courses to pay careful attention to student teachers’ critical incidents and teaching concerns. If pre-service teacher programs are to facilitate the professional development of student teachers, teacher educators must understand the processes by which student teachers grow professionally and, the conditions that support and promote this growth.

Another interesting issue raised through this study is that of a pedagogy of teacher education. It is too often the case that studies (such as this) draw attention to particular aspects of learning or teaching or teacher education but do not link those outcomes to the ways in which the teaching of teacher education is conducted. This study makes clear that by helping student teachers focus on their critical incidents, by empowering student teachers to trust in the authority of their own experience (Munby & Russell, 1994) and, by linking those experiences with concrete aspects of their own pedagogical reasoning, that student teachers can direct their own professional
development. In that sense, it is crucial that teacher educators, in developing their pedagogy of teacher education, seek to find ways of incorporating such practice into their teaching about teaching in ways that are based student teachers' own recent and real experiences of teaching. Therefore, the method employed in conducting this research can also be viewed as an approach to teaching about teaching and therefore also offers possibilities for teacher educators to apply in appropriate ways in their teacher education programs.

References


Appendix 3 – Paper 3
Primary science student teachers’ and their mentors’ joint learning through reflection on their science teaching

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Abstract:
This paper focuses on what and how primary science student teachers and their mentors learn from planning and reflecting together on each other’s science lessons for pupils aged 7 to 9. The student teachers had had training in scientific knowledge, but only brief experience of teaching. The mentors were well experienced in the pedagogy of teaching and mentoring, but did not feel confident about their science content knowledge and the teaching of science. During a four-week school practicum, two lessons of each of two student teachers and their two mentors were video recorded and later reflected on in a stimulated recall session. During their reflections, the student teachers and the mentors gave concrete examples of their development of subject matter knowledge, pedagogical knowledge, instructional knowledge and knowledge of pupils.

Introduction
There is little doubt that the complexity of teaching highlights the need for more extensive research into the relationships between the different elements that constitute teacher knowledge, and how these are developed during pre-service teacher education. The learning opportunities that arise for student teachers during their school-based practice have long been investigated and acknowledged. As outlined in the research on experts’ and novices’ relations (e.g., Berliner, 1986, 2004), expert teachers and novice teachers differ in the ways they interpret classroom life. In this context, mentoring and the development of pedagogical content knowledge (PCK; Shulman, 1986, 1987) are well explored in the research literature. However, no connections exist in the literature between research on mentoring and research on science PCK, and little is known about what science PCK develops in the context of mentoring. In the field of primary science, a deeper analysis is lacking of what and how student teachers and their mentors can learn from their common experiences and reflections (Clarke, 2006). This
leads to the question of how school-based experiences can be used to stimulate professional reasoning on science teaching for student teachers and their supervising mentors.

In this study we explored the knowledge student teachers and their mentors develop while working together in a primary school context. We used Shulman’s (1986, 1987) notion of the knowledge base of teaching as a framework to articulate what elements of knowledge impact on the student teachers’ and their mentors’ teaching. We highlighted the importance of providing student teachers with opportunities to observe and interact with mentors in school-based pre-service teacher education in order to enable them to critically examine their own and their mentors’ teaching experiences. The aim of this project was to investigate the interaction between mentors and student teachers and to gain insight into their joint learning processes in order to improve their science teaching and accordingly develop their pedagogical content knowledge. The project was guided by the following research questions:

1. What knowledge do student teachers develop from their mentors while jointly planning and reflecting on each other’s science lessons?
2. What knowledge do mentors develop from student teachers while jointly planning and reflecting on each other’s science lessons?
3. What knowledge do student teachers and mentors develop from pupils while jointly planning and reflecting on each other’s science lessons?

**Conceptual Framework**

*The knowledge base of teaching primary science*

The theoretical background framing this study is that of research into teachers’ professional knowledge, which characterizes teaching as a complex cognitive skill. Van Driel, Beijaard, D., & Verloop (2001) highlighted that teachers’ craft knowledge consists of teachers’ knowledge and beliefs about their own teaching practice and refers to the integrated set of knowledge, conceptions beliefs and values that teachers
develop in the teaching situation. In 1986, Shulman raised the question about the knowledge bases needed for teaching and how a teacher should use the content to build on analogies, metaphors, examples and demonstrations in order to promote pupils’ understanding. Shulman (1986, 1987) introduced the term pedagogical content knowledge (PCK) to draw attention to the value of the special amalgam of content knowledge and knowledge of general pedagogy that a teacher needs to be the best possible teacher. Various scholars have further developed conceptualizations of PCK (e.g., Appleton, 2003, 2006; Gess-Newsome, 1999; Hashweh, 2005; Loughran, Mulhall & Berry, 2004; Van Driel, Verloop & de Vos, 1998) as an academic construct representing specialist knowledge of practice. As such, PCK has become a way of understanding the complex relationship between teaching and content through the use of specific teaching approaches (Van Driel et al., 1998).

Although there is no universally accepted conceptualization of PCK there seems to be consensus that PCK is to be distinguished from subject matter knowledge (SMK), on the one hand, and from general pedagogical knowledge, on the other. It is reasonable to suggest that PCK goes beyond SMK as it refers not only to the subject matter but to the teaching of a subject in ways that promote pupils’ understandings. Hence, a teacher needs to have a deep knowledge of this topic (SMK), as well as an orientation towards teaching the topic to pupils in a specific context. Bishop and Denley (2007) highlighted that rather than seeing PCK as a different “type” of knowledge, it could be viewed as a sophisticated process of combining knowledge bases together for particular contexts in relation to pupils, topics or other factors. This view was supported by Hashweh (2005) who described PCK as a collection of “teacher pedagogical constructions”, a form of knowledge that preserved the planning and wisdom of practice resulting from teaching a certain topic several times. These constructions are topic specific and result not only from planning but also from the interactive and post-active phases of teaching.

The interface between SMK and PCK raises several interesting questions, mainly concerning the relationship between the quality of teachers’ understanding of subject
matter and the consequence of their understandings and beliefs for their development of PCK. Magnusson, Krajcik, and Borko (1999) developed a model of PCK for science teaching in which “orientations towards science teaching” impacted on what PCK might be. The authors emphasised that PCK was the result of a transformation of knowledge from other domains. They used the term “orientation” to represent a general way of viewing, or conceptualizing, science teaching. Knowledge and beliefs in this area guide a teacher’s instructional decisions about the organization of activities, the content of pupils’ assignments, the use of textbooks and curricular materials, and the evaluation of pupils’ learning. As these components may interact in very complex ways, teachers need to develop knowledge of all aspects of pedagogical content knowledge (Magnusson et al., 1999).

Research on primary student teachers’ learning to teach (Appleton, 2006; Nilsson, 2008; Skamp, 1997), emphasize the importance of primary science student teachers’ framing and reframing of their practice (Schön, 1983, 1987) in order to gain new insights into what and how they perform teaching. We also know from research that primary school teachers have limited science knowledge (both SMK and PCK), resulting in low confidence about teaching science (Appleton, 2003, 2006, Harlen, 1997). Osborne and Simon (1996) found that primary teachers’ lack of ability, confidence, and enthusiasm for science resulted in the use of less stimulating methods, and that the teachers did not respond effectively to pupils’ questions. Palmer (2006) emphasized that subject matter knowledge and science pedagogical knowledge increased teachers’ confidence in primary science teaching. Harlen (1997) found that teachers’ expressed low confidence in teaching science was linked to a lack of understanding of scientific ideas. This was confirmed by Carlsen (1991), who found that the less the teacher knew, the more often classroom discussions appeared to be dominated by the teacher. Further to this, the less competent the teachers were, the more difficult it was for them to follow the pupils’ lead and to explore their ideas.

As Van Driel et al. (1998) stated PCK refers to teachers’ interpretations and transformations of subject matter knowledge in the context of teaching. PCK is, then, a
fruitful tool to understand what knowledge comes out of teaching practice. Magnusson et al. (1999) stressed that the development of PCK is determined by the content to be taught, the context in which the content is taught, and the way the teacher reflects on his/her teaching experiences. Reflection, therefore, emerges as another important element for student teachers in developing expertise in their practice, and is central to them accepting more responsibility for their actions (e.g., Calderhead, 1981, Loughran, 2002).

**The role of mentoring in teacher education**

School-based teacher education requires mentors to share their expertise with student teachers in a context of cooperative learning. But although the view of the cooperating teacher as a mentor or a coach to the novice is a common one, little systematic research has been conducted on the nature of this mentoring role (Putnam & Borko, 2000). The mentoring process is generally described in terms of roles (e.g., trainer, partner assessor, and adviser; Jones, 2001). Normally, the mentor’s role is that of an expert proposing instructional approaches to the student teachers and encouraging their professional growth (i.e., their development of PCK) through reflection on the process. Halai (2006) identified a mentor’s roles as those of expert-coach, subject specialist, critical friend, and learner. Furlong and Maynard (1995) asserted that a mentor requires “special skills in order to help students in the systematic enquiry. It is only through such enquiry that students can establish themselves a rational basis for their professional action” (Furlong & Maynard, 1995, p.179) Grimmett and Ratzlaff (1986) explored mentors’ expectations of their work as co-operating teachers helping the student teachers to orientate themselves in the school, providing a source of instructional strategies, and providing feedback and evaluation were emphasized. Carroll (2005) highlighted that, by discussing and modelling his or her own teaching, the mentor helped the novice to learn about certain important aspects, such as planning appropriate learning activities and considering pupils’ prior knowledge and experiences of the topic.
Most studies in which the aim was to document and understand the relationship between mentors and student teachers concern a relationship often defined in terms of power, where the authority lay with the mentor. However, reports from studies on mentors’ and beginning teachers’ relationships imply that this relationship can also enhance the professional development of the experienced teacher. Clarke (2006) reported on a study of cooperating teachers who were provided with the opportunity to reflect on their advisory practice. In a stimulated-recall approach, the teachers had the opportunity to reflect on what was important about their practice, providing an authentic account of the ways in which they reflected upon their work as school-based teacher educators (Clarke, 2006). Tauer (1998) reported on a study in which experienced teachers mentored student teachers. Both the mentors and the student teachers spoke of different responses to the mentoring process, such as professional and personal growth and reinforcement of existing beliefs and practices. Book (1996) noted that “supervisors have begun to realize that their role in supervising student-teachers has enabled them to learn more about teaching because in helping novices improve, they articulate more explicitly what they know and believe about teaching” (Book, 1996, p. 202). Lazarus (2000) referred to a study in which mentors stated that the mentoring had a positive effect on their own teaching and gave an opportunity to re-evaluate their teaching. The presence of student teachers as observers made the mentors more aware of what they were doing in the lessons.

In this study, we examined mentor-student teacher relationships incorporating the learning of both the mentor and the student teacher. The focus was on systematic exploration of the nature and substance of the interactions between two student teachers and their mentors in a primary school setting. Our goal was to identify factors influencing not only the student teachers´ but also the mentors´ development of professional knowledge about primary science teaching. We aimed to connect research on mentoring with research on the knowledge base of teaching, which, as argued above, has not been done in previous research.
Method

Participants
A qualitative case study approach (Cohen et al., 2000; Stake, 2000) was used to examine what student teachers and their mentors learn from planning and reflecting together on each other’s science lessons. Cohen et al. (2000) described the purpose of a case study as to portray, analyse, and interpret situations through accessible accounts; it may be described as interpretive or subjective. Case study methods provide a systematic way of looking at events, collecting data, and analyzing and reporting the results.

In the present study, the two (out of 40) primary student teachers and their mentors were randomly selected and asked to participate in a research project. The student teachers and mentors (all females) agreed to participate. Only two pairs were chosen owing to the resource-intensive nature of the data collection required for the analysis. In the end of the third term of their three-and-a-half-year pre-service teacher education (of which the second and the third term focused on maths and science), the two primary student teachers participating in the study had a four-week practicum in primary schools. During the four weeks, the first author, who was also a teacher educator, was present both when the two pairs planned the period (planning sessions) and during two lessons of each of the student teachers and mentors (eight lessons in all). It was made very clear that the outcome of the study would have no influence on the assessment of either the student teachers or the mentors for their teaching qualifications. They were all informed that the aim of the research was to investigate the learning resulting from their interactions. During the year, the student teachers had taken four basic courses (of eight weeks each) in mathematics, physics, chemistry, and biology, but they had no prior experiences in teaching science. The aim of their four weeks of school practicum was to give them an opportunity to use their scientific knowledge in a primary school context; for this reason, they were told to teach science as much as possible.
Each student teacher was mentored by a female teacher who had at least 20 years’ experience in primary teaching, but had minimal experience in teaching science and had no education in science. The student teachers were at different schools in different districts, and both classes consisted of pupils between 7 and 9 years of age. The first student teacher and her mentor (ST1, M1) worked with the subject area of space and the universe; they included experiments on air, light and gravity. The second student teacher and her mentor (ST2, M2) focused their teaching on activities and experiments with water. Even though those issues had been involved in the student teachers’ courses they were not familiar with the teaching of those subjects. Concerning the two mentors, M2 had worked briefly with water but was not familiar with experimental work. M1 had, several years ago, only briefly taught about the universe but had very little experience with experimental work either.

Collection of data
Two weeks before the school practicum started, the first author, who was also a teacher educator (from now on referred to as the observer), was present when both pairs planned their lessons for the whole period (i.e., science content, teaching methods). The planning session (1) was designed to give the student teacher and the mentor an opportunity to discuss the content to be taught, teaching methods, and practical issues such as time-planning, school routines, and pupils. During this planning session, the role of the observer was to document but not to interfere with the interaction between the mentor and the student teacher. During the following four weeks of school practicum, the observer documented (video recorded) two consecutive lessons of each of the four participants. The student teacher and the mentor were present during each other’s lessons, but only one was responsible for the lesson. Immediately after the taping of each lesson, the observer conducted a (2) “stimulate recall session” (Brown & Harris, 1994; Calderhead, 1981; Meade & McMeniman, 1992) with both participants (using the entire tape of the lesson as stimulus). Jensen (2002) noted that stimulated recall is a powerful way to elicit information about teachers’ personal views of their own teaching, and, therefore, an important way of encouraging participants’ reflection on their own practice. The aim of video recording
in the classroom was to stimulate the student teachers’ and the mentors’ reflections on the lessons, including on the way they communicated with the pupils and their actions in the classroom.

During the stimulated recall sessions the student teachers and the mentors were invited to stop the tape and comment on any critical incident (Tripp, 1993) in their teaching. In this way, the agenda for these sessions was set by the participants and not by the observer. A critical incident or “special event” was defined as something that caused them to reflect on their teaching, for example, an event connected with their activity, their interactions with the pupils and with each other during their teaching, how they perceived the lesson, and their feelings, attitudes, and intentions. These critical incidents became the basis for an in-depth examination and analysis of their pedagogical actions. A deeper analysis of what the student teachers and their mentors emphasized in the stimulated recall sessions is presented in the results section.

Methodologically, the stimulated recall sessions were designed to explore things which the mentors and student teachers themselves perceived as important components of their learning processes. Thus, the role of the researcher during the sessions was not to interfere with the discussions, but rather to act as an observer. The participants also wrote a (3) reflection on how they experienced the session, on feelings and reflections that were not mentioned during the session, and on what and how they learned from planning and reflecting together on each other’s science lessons. It was expected that the responses would offer insights into the primary science student teachers’ and their mentors’ joint learning through reflection on their science teaching. All discussions from the planning sessions and the stimulated recall sessions were tape recorded for further analyses.

**Data Analysis**

Data obtained from the planning sessions (1), the stimulated recall (SR) sessions (2), and the written reflections (3) were analyzed using a multi-step iterative process in order to search for statements of the participants’ perceptions of their learning and
teaching of science. Transcriptions from the SR sessions constituted the main data set. Hence, data from the planning sessions and the written reflections were used to triangulate in order to confirm the ideas that emerged during the analysis of the data from the SR sessions. The analysis of the data was done in the following steps: (a) All empirical data from the SR sessions were transcribed in full (by the first author). (b) The data were read repeatedly and examined in order to identify evidence related to the three research questions. The data were then organized according to the three research questions using knowledge elements as codes. Some of these elements were elements of PCK, according to the model of Magnusson et al. (1999) and Van Driel et al. (1998), in particular if participants referred to the pupils’ learning of science content (i.e., knowledge of pupils), or if they discussed the use of instructional strategies to teach science (i.e., instructional knowledge). Since the participants also discussed issues related to their subject matter knowledge and general pedagogical knowledge, these knowledge elements were added to code the data. (c) Representative episodes with respect to the research questions (half of the entire data set) were translated into English. (d) An inductive process followed, in which both authors separately applied the codes (i.e., the two PCK elements mentioned above, plus subject matter knowledge and pedagogical knowledge) to the data concerning each of the three research questions. Emergent examples of transcriptions connected with these four knowledge elements were presented. (e) The coding done by the two authors separately was compared, and the knowledge elements and the related examples of the participants’ learning (Table 1) were discussed until consensus was reached. (f) The knowledge elements were again applied to the entire data set from the SR sessions by the first author. (g) The knowledge elements were also applied to the other two data sources in order to search for similarities, and support for the initial results. (h) To establish the validity of the coding, a third researcher applied the knowledge elements to the full transcripts of the SR sessions. Since the number of participating teachers was small, care should be taken in generalizing from these findings, and assertions treated as tentative.
Results

The results section is organized according to the three research questions mentioned in the introduction; the knowledge elements are used as sub-headings.

Research question 1: What knowledge do student teachers develop from their mentors while jointly planning and reflecting on each other’s science lessons?

PCK element 1: Instructional Knowledge
In their reflections both student teachers stated that the mentors helped them to see, recognize, and interpret critical incidents and situations in their teaching activities which gave them valuable insights into their own actions. In the planning session, M2 showed ST2 how she always connected her teaching to the curricular goals and how she encouraged her pupils to assess themselves according to the goals. The mentors made their student teachers aware of the importance of making the teaching concrete (e.g., including practical experiments) and linking the content to pressing issues, such as climate change and water recycling, in order to make it meaningful to the pupils. ST1 explained that she wanted to stimulate the pupils’ interests of science, hypothesizing and problem solving through the use of experiments and drawings. When explaining their intentions to the mentors, both student teachers needed to reflect on questions concerning what representations of knowledge they could use in the instruction. They had to put their mentors into the science context and discuss experiments with them, which they described as very instructive. One example was how M2 encouraged her student teacher to explain all the experiments to her in the way she would explain to the pupils. In the stimulated recall reflection, when ST1 discussed the instruction with her mentor, M1 made her see the importance of having a clear aim, giving clear instructions and not including too much information:
M1: I am thinking here about how you presented the task. You tell them that they are to draw the planets in different colours, and to put them in their books…but how? It is a bit confusing, and they do not really understand what to do here. It is very messy.

ST1: Yes, perhaps my instructions were not clear enough.

M1: No, I do not think it was that your instructions were unclear, but that you explained so much in the same lesson that they did not know which “picture” to take into account in their tasks.

M2 highlighted the importance for ST2 to build on the pupils´ own ideas, not being steered too much by the answers she expected and to get and give every child a chance to be engaged in the discussion. During their instructions both student teachers practiced to use experiments, demonstrations, mind-maps and role games to concretize different phenomena. As it was close to Christmas, M1 suggested to ST1 the idea to create an Advent Calendar; the pupils opened a box containing an experiment every day from the first of December until the Christmas holidays. This was meant to integrate experiments and Christmas preparations in a natural way, and to stimulate pupils´ hypothesizing, discussions, and creativity. Both student teachers stated that they learned through observing their mentors´ teaching and that their mentors often helped them to see how they asked and responded to questions and dealt with unforeseen incidents during their teaching.

Subject Matter knowledge

Even though none of the mentors were science experts or even had a science training the student teachers stressed that they developed their subject matter knowledge while jointly planning and reflecting together with their mentors. As both student teachers (and the mentors) were supposed to teach the subject matter in a way that promoted pupils´ understandings, deep knowledge and understanding of the specific topics were required. In the stimulated recall sessions both student teachers stressed that they learned a lot about their own subject matter knowledge when they had to explain to their mentors what and how they wanted to teach. Further to this, as the mentors
sometimes expressed that they felt insecure of the science content, the student teachers often had to explain scientific concepts for the mentors.

ST2: I learnt a lot about surface tension and density when I planned the water experiments together with the mentor. As she (the mentor) was not used to do all these experiments we also planned her experiments together.

In the stimulated recall session M1 noticed that ST1 seemed to feel discomfort when trying to explain the different colours of the planets in space. This recognition initiated a discussion about the importance of subject matter knowledge in order to develop pupils´ thinking. ST1 stressed that she needed to feel confident in her teaching (with respect to her subject matter knowledge) which in turn made M1 to comment on how she managed to interact with the pupils in order to develop their thoughts about why the planets were shining.

M1: Yes I think that you made that perfect to include the students in the reasoning. It was really skilful because it is not very easy to explain why planets shine and I am impressed of how you managed the situation and how you built on the students´ knowledge in order to teach them a deeper dimension.

ST1: Yes I was so happy that I actually knew about those things as the different colours and sizes of the planets and that some of them have rings and some have moons.

M1 further stressed that, in general, deep, but also integrated subject matter knowledge made it easier for a teacher to explore the pupils´ ideas and stimulate their reasoning. This was confirmed by her student teacher.

ST1: Yes, I just heard someone who asked why the planets were shining and another girl explained that it was like a mirror, a reflection. The night before I read an explanation about how the sunlight reflects on the planets and makes them shine. Very quickly then I could come back to the pupils´ reasoning and help them develop their thoughts.
Pedagogical Knowledge

Both student teachers emphasized how their mentors helped them to learn how to handle the pupils, to interpret classroom events, and to manage teaching in a more general way. Both student teachers also referred a lot to how they had learned from working together and observing the mentors´ lessons. This was mainly because the mentor knew a lot about general pedagogy and how to handle different situations in the classroom, such as time-planning, dealing with conflicts, democracy issues and encouraging all pupils to participate in activities. For instance, M1 brought up the following situation:

M1: And what do you do when you have a pupil who wants to make comments all the time.
ST1: Well, if he is not disturbing the others it is OK. But he is disturbing the others and he does not raise his hand...
M1: Yes, but it is a question of democracy in the classroom. You have a responsibility as a pedagogue to invite everyone to participate in the discussion. It is very difficult to judge if a pupil should be allowed to talk or not. When is it OK to talk and when is it not?

ST2 described how her mentor taught her to recognize and interpret pupils´ behaviour, for example, silence and body language, which was very useful in the teaching situation. During a lesson in which ST2 was talking about water, she suddenly diverted from the topic and got frustrated. As her mentor was able to interpret the pupils´ reactions, she helped the student teacher by formulating a question in order to get the pupils back to the topic.
ST2: When Michael wanted to say something and I was not able to interpret his body language, you saw that he wanted attention. I was not able to see that.

M2: No, I think that our focus was a bit different during the lesson.

ST2: Yes...in that situation I did not think of it at all.

M2: It is important to know about these signals and how to read them. You learn to see the signals and how to interpret them. You see someone trying to catch your eye, and how he pulls his hand over the paper or does something else. Then you know that he or she wants to say something. The more experienced you are the better you can read their body language.

Both student teachers emphasized the importance of self-confidence in the teaching situation and that they felt more confident in their role as teachers when working with the mentors. ST2 stressed how the mentor made her aware of her asking of open questions and how she as a teacher should be able to stimulate pupils’ reasoning and give them the possibility to explore their previous conceptions. M2 told her how to encourage pupils with special needs and learning difficulties only through reflecting in how to formulate questions. Especially shy pupils were encouraged to discuss when the questions were of an open character. Too “narrow” questions could result in that a lot of pupils were “lost” on their way to find the right answers but an open question stimulated pupils’ brainstorming. When explaining the different characteristics of posing questions M2 referred to a situation in her own teaching. During her teaching she had asked a pupil “How do you think here?”, and afterwards she told ST2 that it would have been better to ask “How do you know that?” As knowledge is concrete and thoughts are abstract she stressed that it was much more difficult for pupils to explain how they think than how they know. M2 also stressed for ST2 her that the more you as a teacher notice the pupils’ ideas the more they dare to say.
Research question 2: What knowledge do mentors develop from student teachers while jointly planning and reflecting on each other’s science lessons?

PCK element 1: Instructional Knowledge

Both mentors stated that they learned much through working together with the student teachers and from observing both their own and the student teachers’ teaching. Particularly, both mentors stated that they had learned about scientific methods, a lot of experiments and ideas about how to do them, but also the importance of testing the experiments before doing them with the pupils. M1 stated that she did not have any science education and did not have much experience of teaching science. M1 also stressed how she felt stimulated through the science teaching and the way the pupils appreciated the experiments and the discussions, and that she should continue to integrate experiments in her everyday teaching. M1 told that she had dealt with the weather, the phases of water, temperature, and the lives of famous scientists, but not very much with experiments. Although both mentors had been teachers for more than 20 years, this new way of teaching science made them feel like novices. This was brought up by one of the pairs when the student teachers (ST2) stopped the video and commented on how then mentor handled her teaching:

M2: Ah…what am I doing?
ST2: Perhaps for once you are more focused on what you have to say and what you have prepared than on involving the pupils. You are focused on the things that you have planned and you do not see what happens around you.
M2: Yes, and I had prepared it very well, but still I could not grasp the moment. I do not feel confident in the subject, and if it was something I was used to…this would never have happened. So I have learned a lot, and this I will add to all the other knowledge. That is the way to develop as a teacher.

M2 expressed that she could use the methods of hypothesizing and working in a problem-based manner in other contexts, too. She stressed that she now had a perfect opportunity to encourage the pupils to remember their ideas from the experiments, and
that she could use other experiments to get the pupils to talk. In the stimulated recall session ST2 commented on a situation within one of the mentor’s science lessons:

M2: A lot of things happened behind my back. I had in mind that I should mention the words snow, ice and rain because I thought those concepts were important, but it all fell out of my mind.

ST2: Yes, you looked unsafe and it is obvious how the pupils noticed that.

M2: When I have been observing you I have seen how important it is to ask all these investigating questions to stimulate the pupils’ ideas about science. I had it all in my head but I could not get it out. Even though I have a lot of teaching experience I realize that teaching science requires a deeper level of that experience.

ST2: Yes but it is only you who know that you are not doing what you have planned. The pupils can not read your mind. That is what you told me last week.

In the stimulated recall discussion when they discussed the mentor’s teaching (she was reading to the pupils in a newspaper about how a space ship lifted), ST1 noticed how the pupils asked a lot of interesting questions. However, M1 wanted to focus on reading the text and discuss the “take-off” and did not want to be interrupted by all the questions. ST1 commented on the issues that the pupils brought up which made her mentor became aware of that her idea of what was interesting was not always the same as the pupils’:

M1: A lot of scientific concepts could be included here, but I did not want to talk about all these things. I wanted to focus on Christer Fuglesang and how his space ship lifted. I also wanted to focus on the historical aspect, as it is a historical moment. I did not think that all the other things (scientific phenomena) were so important. I must admit that I did not bother about all their questions because I wanted to hold onto my goal with the lesson. I am not sure that I am required to be able to explain those things, either. But the pupils would have loved it, so I should find out and learn about those things so that I can discuss them.
Subject Matter Knowledge

During the planning sessions, neither of the mentors worried about the general preparations of the lessons (e.g., handling group work, pupils’ reactions). Instead, they stated that the lesson could be designed to match the pupils’ interests. However, both mentors expressed insecurity about the science content and about how to explain the experiments. In both cases the student teachers were asked to support their mentors concerning experiments and scientific explanations:

ST2: To illustrate density we could put raisins into natural water and mineral water...but I have already done that experiment several times.
M2: But it is perfect. Then I can do it and you can explain it. I mean, we must help each other. I must find some books so that I can study science. I must copy some experiments and also find explanations.

Both mentors experienced the importance of having appropriate subject matter knowledge; several times during the project, they became aware of the consequences of their insufficient subject matter knowledge (e.g., difficulties of handling unforeseen situations and explaining things that they did not understand themselves). During her lesson, M1 referred to the experiment with the needle in the balloon conducted by the student teacher in the previous lesson. A pupil asked the mentor why the balloon did not burst when they put a needle in the tape. The mentor did not know, and turned to the student teacher for an answer. During the SR session, the mentor commented on how she had learned through the situation:

M1: It was natural for me to ask ST1, as it was she who had planned and conducted the experiment.
ST1: It would have been harder if I had not known the answer.
M1: It is very good. I had never thought about that before. When the child asked me, I realized that this was one I needed to get explained. That’s why I turned to Mary for the answer. Yes, of course the explanation is that the needle was still stuck in the balloon. That is why the air did not go out and the balloon did not explode. But I did not think about it directly.
The other mentor (M2) forgot the formula for water and she had to ask the student teacher, and in the SR session she referred to her feelings. The incident implied that when the mentor felt uncertain of the teaching content, she did not manage to handle the situation, which made her confused. This confusion was brought up and further discussed by ST2 during the stimulated recall session.

When ST1 asked her mentor why she did not respond to a boy’s question about how it was possible to walk on the moon or eat in a space craft, her mentor (M1) came to see how her subject matter knowledge also influenced how she handled the pupils’ questions. She explained to ST1 that if she could not answer a question (mostly because of a lack in her subject matter knowledge), she pretended not to hear them. Further to this, when the pupils initiated a discussion about gravity, she did not pay attention to the question. At this moment ST1 (who had just finished a course of mechanics) explained about the earth’s and the moon’s gravity and how it was possible to walk on the moon. This situation initiated a discussion about the mentor’s subject matter knowledge and M1 expressed that she needed more scientific knowledge to better develop the pupils’ ideas and to stimulate their interest in learning science. M1 further described how she learned a lot about astronomy (e.g. why Venus was warmer than Mercurius) when she listened to how the student teacher and the pupils discussed during the lesson.

**Research Question 3: What knowledge do student teachers and mentors develop from pupils while jointly planning and reflecting on each other’s science lessons?**

**PCK element 1: Instructional knowledge**

As the student teachers and mentors learned how the pupils perceived and understood scientific ideas and methods (knowledge of pupils), they were also forced to consider their teaching and how to find new ways to make the content understandable for the children. During the mentor’s (M1) lesson a pupil opened a box with a balloon, a string, and a straw. The student who opened the box was given the task of making a balloon-rocket that could move with the highest speed possible. This experiment
stimulated the pupils’ discussions, problem solving, and creativity. After the lesson everyone was told to try it at home. The mentor challenged the pupils’ ideas by letting them discuss the differences between the balloon going straight forward or in a loop. The discussion made her see the benefits of asking investigative questions in order to discover how to engage the pupils.

M1: This thing with the loop was something that occurred to me during the discussion with the pupils. What I mean is that it is important to make the pupils think, and to stimulate their problem solving... and I wanted to use the experiments to pose the pupils why questions, and to get an opportunity to listen to their explanations and to develop their thinking.

In her reflections M2 stressed how the pupils’ engagement and joy made her see the benefits with instructions building on experiments and problem solving skills.

**PCK element 2: Knowledge of pupils**

In the SR sessions the student teachers and the mentors emphasized what they had learned about the pupils. As they identified how the pupils’ language, explanations, and questions uncovered their thoughts and preconceptions, they learned how the pupils perceived and understood scientific ideas and methods which were important for their teaching. Both pairs were surprised to observe that the pupils were smart and had a lot of scientific ideas. One pupil (7 years old) explained that salt dissolves in water as it was “friends with the water”. Another pupil (8 years old) explained how rain was created, which made ST2 to reflect:

ST2: When she started to talk about the water molecules I thought, God, how much she knows. She was really right on the button. The water molecules are lumped together and then they fall down. I was not prepared for her to start to talk about molecules.

ST2 also commented on another situation when she learned from pupils’ explanations and questions as she referred to an experiment in which she put an ice-cube in water.
The aim of the experiment was to learn about the phases of water. She expected the pupils to come up with the hypothesis that the ice would melt but they came up with hypotheses and explanations that she did not expect. For example, one girl wrote that there would be more water in the bowl, and another that the water temperature would decrease. However, ST2 had only prepared one explanation and the pupils’ suggestions showed that they were much cleverer than she initially thought.

M1 expressed how she learned about the pupils’ thoughts and ideas of science through posing them different exploring questions connected to the experiments in the advents calendar. In the stimulated recall discussion she referred to a balloon experiment which initiated a discussion when a boy asked why he could hear a sound when the air escaped the balloon. M1 posed the question to the pupils to initiate a discussion. A girl answered that all the air was collected in the same area and it wanted to get out. The discussion continued about how we can hear different sounds. The mentor asked the pupils to whistle, and a girl asked why there were different tones in a flute. From this experience M1 stressed that she learned a lot about pupils’ ponders and ideas.

One of the mentors (M2) described how she used pupils’ experiences of the experiments to encourage them to discuss their initial beliefs, and to “get into their heads”. In that way she could “build” her teaching on their thoughts and feelings:

M2: I never imagined it could be so exciting with a bowl of water and an ice cube. Perhaps it is formulating a hypothesis that makes it so exciting. They are not used to that, and it gives them much more expectations of what will happen. Done differently, it would never have been so exciting.

During their lessons they learned that the pupils considered science interesting, but that it was sometimes difficult to explain a phenomenon if the pupils did not know the important concepts related to it. For example, in one lesson, some pupils did not know the concept of molecule, which led to difficulties in understanding the circulation of water.
Subject Matter Knowledge

On several occasions the mentors and the student teachers expressed the realisation that pupils’ unexpected questions and comments made them aware of the limitations of their own subject matter knowledge in science. They stated that they learned a lot from the pupils’ explanations, and that they used the pupils’ explanations of scientific phenomena as a way to explore their own ideas of specific concepts.

ST1: There you have the girl who explained why the planets shine. She compared it with a mirror that reflects the light. And it was almost the same explanation that I had planned... and another one mentioned that all planets are of different sizes and some have moons and some have rings.

M1: Yes, and I liked when you finished the discussion with the phases of the moon and how the planets circulates around the sun. And when one of the pupils asked how long time it takes for the earth to go around the sun a girl answers one year... listening to them really makes me see how it all is linked together.

Both pairs referred to discussions with the pupils, and emphasized the importance of their own subject matter understanding in order to be able to explain something that was not always evident. ST1 stressed that the science courses on her pre-service program were on a too-high level.

ST1: You think that you will never have to deal with it. But when you get into a discussion about how the nervous system works when a person is out in the space, you realize that it is important to know things about the nervous system and to have a deep knowledge of science.

M1 explained how she used the pupils’ words to explain phenomena and to adapt her explanation to the pupils’ level. The pupils are not familiar with all the scientific concepts, they see things from their perspective and they use their words when explaining, which also helped her to see which words she could use.
Conclusions and discussion

As our findings illustrate, it is clear that the student teachers’ and their mentors’ knowledge and beliefs about their own teaching practice (i.e. the integrated set of knowledge, conceptions beliefs and values developed in the teaching situation), described by Van Driel et al. (2001) as teachers’ craft knowledge were laid down through the processes of planning, teaching, and reflection, as implemented in the research outlined in this paper. In their reflections, the student teachers and their mentors stated that they came to see, and even learned several elements important in shaping their teaching of primary science. It was certainly apparent that the joint learning between the student teachers and their mentors depended not only on their interaction, but also on their interaction with the pupils. Both pairs stated that they learned methods of promoting pupils’ understanding (e.g., how to make science concrete and link it with everyday life and how to do exciting experiments). They also gave examples of how they learned from pupils’ explanations and questions and also became aware their own [lack of] subject matter knowledge. Just as Harlen (1997) stated, our result show the depth of subject matter knowledge affects the ability of the teacher to ask appropriate and meaningful questions. The participants further described their learning from working together and observing each other’s lessons. For instance, one of the mentors (M1) said that this experience had taught her to take a step back and take a broad perspective while observing and reflecting on how the student teacher herself asked and responded to questions and unforeseen incidents. In addition, all participants mentioned learning from seeing and interpreting pupils’ engagement and activities in the classroom. In developing craft knowledge to teach science however, teachers must draw on a range of forms of teacher knowledge, such as the knowledge outlined below (Table 1). Table 1 presents a brief overview of the results and shows specific themes within the four knowledge elements that were noted within and across each of the student teacher-mentor pairs.
<table>
<thead>
<tr>
<th>Type of knowledge</th>
<th>Examples of student teachers´ learning from mentors</th>
<th>Examples of mentors´ learning from student teachers</th>
<th>Examples of mentors´ and student teachers´ learning from students</th>
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| **Instructional knowledge** | - Increased ability to use mind-maps, metaphors, and experiments to make science concrete  
- Finding ways to stimulate students´ discussions and creativity  
- Linking the content with pressing issues to make it meaningful  
- Formulating clear aims and instructions and ask investigative questions | - Learning methods to make science concrete (e.g., including practical experiments)  
- Increased ability to use hypothesizing, experiments, and problem-based learning in order to help students understand science  
- Finding ways to engage the students and to make experiments exciting | - Learning to design and use instructions that engage students |
| **Knowledge of students** | - Learning about students´ characteristics in order to recognize and interpret their behaviour (e.g., silence and body language) | | |
| **Subject matter knowledge** | | - Learning specific subject matter knowledge; becoming aware of the limitations of their current SMK and the consequences of these | - Students difficulties made them aware of the limitations of their own subject matter knowledge and the importance of deep knowledge |
| **Pedagogical Knowledge** | - Learning how to handle different situations in the classroom, such as time-planning, dealing with conflicts, encouraging all students to participate in activities  
- Learning to give the students feedback and building on the students´ own ideas | | |
As Shulman (1986) stated, teachers need knowledge about the subject they teach, but also about pedagogy and about children and how they learn best. This touches the very heart of the question of what it means to know a subject and to teach it in a way that makes it understandable for a child. The present study was aimed at answering the question of what knowledge student teachers and their mentors developed during their joint planning, teaching, and reflecting. We also aimed to discover what knowledge they developed from the pupils.

As highlighted by Bishop and Denley (2007), if we can define the knowledge base needed for teaching, it might assist new teachers’ structure their professional learning and know better how to acquire it. Shulman’s concept of PCK was used to structure this teaching knowledge. The findings reported in the results section above allow us to draw some conclusions about our aim of identifying joint learning of student teachers and their mentors. They practiced to use specific teaching methods to represent subject content and to stimulate pupils’ interests and motivation. The student teachers had better SMK than the mentor, but they had no previous experience of classroom management. Nevertheless, we found that the subject matter understanding of our student teachers was not adequate to answer all the pupils’ questions and to handle unforeseen incidents. The mentors had a lot of teaching experience, but did not always feel confident in their teaching of science.

It might well be argued that the learning environment implemented in this paper (incorporating opportunities for jointly planning, teaching, observing, and reflecting) was effective in promoting student teachers’ and their mentors’ learning processes (i.e., the construction of their professional knowledge). The data also clearly indicate that the pupils played an important part in this construction process. Using the stimulated recall methodology, the student teachers and their mentors were able to highlight issues and situations that were important to them in shaping their knowledge of teaching and their understanding of their own learning. This approach was an important aspect of the study, and was a way of making their thinking explicit for the researchers, thus offering access to the reasoning underpinning their actions.
Much of the work of building student teachers’ and teachers’ PCK must take place in a teaching context. As Berliner (2004) outlined, it takes 5 to 7 years to acquire high levels of teaching skills, where the teacher is no longer surprised by what happens in their schools and classrooms. Berliner (2004) added that this period might be shortened, or be made richer, if some coaching were to take place. Our findings indicate that, in addition to coaching, also planning, teaching, and reflecting with others on teaching practice result in learning, not only for student teachers’, but also for their mentors. Our findings also indicate that even a very experienced teacher can be insecure, surprised, and even perplexed, depending on the content he/she teaches.

Similar to those of Tauer (1998), our findings support the notion that mentoring serves as a catalyst in the experienced teachers’ thinking. This initiates a process of growth or development of the experienced teachers, as they re-examine aspects of their professional lives. To guide student teachers’ learning, mentors need to understand how student teachers think and learn about science teaching. They must also have knowledge about specific strategies of science teaching, pupils’ learning, and the subject matter in order to guide their student teachers in learning to teach science. Providing the student teachers and their mentors with the experience of planning, observing, and commenting on each other’s teaching showed a two-fold advantage for the mentors: 1) they could directly verify and develop their own teaching skills; and 2) they had the opportunity to step back and to reflect on another person’s teaching. Consequently, we conclude that the mentoring process is a reflective experience in which not only the student teacher but also the mentor grows professionally.

**Implications for pre-service teacher education and future research**

The findings of this research demonstrate the importance of thorough subject matter knowledge for the teaching of science in primary school; it was also shown how knowledge of teaching can be enhanced and developed through the interaction between student teachers and their mentors. To create PCK as a central component of primary science teacher education, teacher educators must learn to operationalize
subject matter in a way that makes it teachable to pupils, that is, to blend content and pedagogy with knowledge of children’s minds and ideas. A key mentor attribute enabling joint learning was not to be seen as “controlling”, but to be able to maintain a distance and work alongside the student teacher as a colleague with an open and questioning relationship. Professionalism and clear signs of a mentor’s skills, expertise, and confidence are, therefore, key features of successful mentoring. Even if mentors feel inconvenienced in opening up their own practice, our findings indicate the need to consider that student teachers and pupils can be seen as a catalysts for mentors in clarifying their own thoughts and needs as teachers.

The present findings might contribute to our understanding of the complex notion of PCK in pre-service teacher education, and also of the social and educational dimensions of the relationship between the student teacher and the mentor in the practicum context. The findings demonstrate the need to systematically explore the nature and substance of student teacher-mentor reflection in practicum, but also to investigate the role of the pupils in teaching and learning practices. Thus, for future research deeper studies into pupils’ feedback as well as student teachers’ experiences of teaching might contribute to the understanding of aspects that need to be taken into account in the process of developing the teaching and learning of primary science. To ensure thoughtful interactions, mentors and student teachers need to listen to each other’s ideas and give each other instructive feedback. This study demonstrates that both mentors and student teachers can indeed benefit from such interactions.

**References**


Appendix 4 – Paper 4
How will we understand what we teach? – Primary student teachers´ perceptions of how to develop subject matter knowledge and a positive attitude towards physics

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Abstract
In the research outlined in this paper, it was investigated how different factors, such as practical experiments and subsequent group discussions, contributed to primary student teachers’ development of subject matter knowledge in combination with a more positive attitude towards physics. During an eight-week course, 40 primary science student teachers worked in groups of 13-14 on practical experiments and problem-solving skills in physics. The student teachers were video recorded in order to follow their activities and discussions during the experiments. In connection with every workshop, the student teachers participated in a seminar; they watched the video recording in order to reflect on how they communicated their conceptions in their group. After the eight weeks of coursework a questionnaire including a storyline was used to elicit the student teachers´ perceptions of their development of subject matter knowledge from the beginning to the end of the course. Finally, five participants were interviewed after the course. The results provided insight into how aspects such as self-confidence and the meaningfulness of knowledge became important aspects in primary science student teachers´ development of subject matter knowledge, and into their development of a positive attitude towards physics.

Introduction

We know from research that primary school teachers have limited science knowledge, which results in low confidence in teaching science (Appleton, 2003, 2005, 2006, Harlen, 1997). We also know that primary teachers in particular hold conceptions
about physical phenomena similar to those held by school children, although expressed in more sophisticated language (Cochran & Jones, 1998). The low confidence often results in teaching limited to ‘science activities that work’ (Appleton, 2003) related to science pedagogical content. Further to this, teachers who have little subject matter knowledge have limited options “…especially if they lack confidence to choose activities that work from science topics about which they know little, or to acquire new science content knowledge for themselves” (Appleton, 2005, p. 42). With this in mind, by focusing attention on how student teachers develop subject matter knowledge and positive attitudes as particular aspects of the knowledge base for teaching (Shulman, 1986, 1987), important factors for this development to occur need to be mapped and conceptualized.

In the context of primary science teacher education, research has indicated that primary student teachers often perceive physics as difficult and abstract, resulting in difficulties in transmitting the content to pupils (Nilsson, 2008). During physics courses, student teachers learn to use laws and formulas, but they do not manage to link these formulas to the everyday phenomena that they are supposed to teach in primary school. Research has also indicated that science knowledge is a significant factor that influences primary teachers’ attitudes towards and confidence in teaching science (Harlen & Holroyd, 1997). There is a relationship between primary teachers’ subject matter knowledge and their attitudes, which in turn affects pupils’ understanding and attitudes (Jarvis & Pell, 2006, Osborne & Simon, 1996). In the project that underpinned this study, therefore, the aim was to make physics more comprehensible and attractive for primary student teachers so that they would become able to teach physics in a stimulating way to young children. This required student teachers to develop subject matter knowledge in physics, but also to develop a positive attitude towards what and why they taught. Hence, in the research outlined in this paper, it was investigated how different factors, such as practical experiments and following group discussions, contributed to primary student teachers’ development of subject matter knowledge in combination with a more positive attitude towards
physics. The context of the study was an eight-week physics course with a special course design.

The following research questions formed the basis on which a research study was constructed in order to respond appropriately to the overall purpose of the study:

- What factors do primary science student teachers consider important for their development of subject matter knowledge in physics?
- How do these factors contribute to the student teachers´ development of SMK and a positive attitude towards physics?

The answers to these questions are crucial to the pedagogy of teacher education (Loughran, 2006). Hence, the practices and processes highlighted in this paper contribute to inform the ongoing developments in determining how to involve student teachers in constructing appropriate knowledge of both science and science teaching.

**Subject matter knowledge and the knowledge base of teaching**

In 1986 Shulman focused attention on subject matter knowledge (SMK) by emphasizing that a teacher cannot explain the principles underlying physical phenomena to his/her pupils if he/she does not explicitly understand them. Subject matter knowledge refers to a teacher’s quantity, quality, and organisation of information, conceptualisations, and underlying constructs in a given field of science (Zeidler, 2002). Shulman (1986, 1987) argued further that subject matter knowledge alone was not enough for teaching. The question of how subject matter knowledge was to be transformed caused him introduce the term pedagogical content knowledge (PCK) as a special amalgam of subject matter knowledge and knowledge of general pedagogy. Research has indicated that the development of teachers’ SMK and PCK is related in complex ways, and that both are crucial to good science teaching (Gess-Newsome, 1999b; Hashweh, 1987; Van Driel, Verloop & de Vos, 1998). Gess-Newsome (1999a) began her review of secondary teachers’ knowledge of and beliefs
about the impact of subject matter on instruction by asking, “What do teachers know about the content that they are expected to teach?” (p. 51). She further argued that, “Teachers with a strong conceptual knowledge have a more detailed knowledge of the topic, more connections and relationships to other topics and can easily draw upon these topics in a teaching situation” (p. 62). Hashweh (1987) explored three secondary physics and biology teachers’ knowledge of science, and the impact the knowledge had on their teaching. When teaching topics within their area of expertise, the teachers had more knowledge of related concepts, and methods of connecting one concept with another. For example, given a concept like photosynthesis, the biology teachers knew about misconceptions that pupils were likely to bring to the classroom. The biology teachers also understood which ideas were likely to be the most difficult, and how to use analogies, examples, demonstrations, and models to deal with those difficulties. Teachers’ subject matter knowledge in a field that was not their area of expertise showed more misconceptions and a less organized understanding of the information (Hashweh, 1987). Further to this, Childs and McNicholl (2007) investigated the relationship between secondary science teachers’ subject matter knowledge and their teaching practice (e.g., providing science teaching explanations in the classroom). They defined a “science teaching explanation” as interpreting and retelling scientific explanations in order to promote pupils’ understanding. When the teacher felt confident with her subject matter knowledge, she was better able to match the content of the science teaching explanation (Childs & McNicholl, 2007).

Harlen and Holroyd (1997) designed a study of primary teachers’ subject matter knowledge to evaluate their knowledge about different concepts. Three groups of correct and incorrect conceptions were defined: (i) concepts already understood by the teachers; (ii) concepts of which understanding developed during the interviews; and (iii) concepts that were less commonly understood. It was also determined that a lack of everyday language of physics was at the source of teachers’ inaccuracies.

In a more recent review of science teachers’ knowledge, Abell (2007) systematically reviewed the research conducted into science education since 1960.
Most early studies of science education equated teachers´ subject matter knowledge with the number of science courses taken. However, the findings of later research clarified the character of SMK needed by teachers to include understanding of central ideas, relationships, elaborated knowledge, and reasoning ability (Abell, 2007). Following the review of teachers´ subject matter knowledge in physics, it was concluded that teachers´ misunderstandings mirror what we know about students and an “understanding of how physics teachers understand the structure of the discipline and the relation among concepts remains a largely untapped field of study” (Abell, 2007, p. 1117).

Several researchers have reported that many student teachers do not even have the most basic understanding of their disciplines when they begin their teacher preparation programmes (see, e.g., Cochran & Jones 1998). This was confirmed by Yip, Chung, & Mak (1998), who investigated the subject matter competence in physics of 147 in-service junior secondary science teachers in Hong Kong. Their findings indicated that most teachers were incompetent in subject content knowledge, in particular in mechanics and electricity. A reason for this might be that the scientific concepts primary student teachers are usually exposed to are not representative of or connected with those concepts they are likely to be expected to teach (Cochran & Jones, 1998). As pre-service teacher education is often teachers’ first opportunity to reflect on the actual use of their subject matter knowledge, the importance of such opportunities can not be over-emphasized (Lederman & Gess-Newsome, 1999). Teachers need to understand the structure and nature of their discipline, have skills in selecting and translating essential content into learning activities, and recognize and highlight the applications of the field to the lives of their pupils (Gess-Newsome, 1999a).

**Teachers´ attitudes - Influences on teaching science**

Over the past two decades, the findings of several studies have shown that many in-service and student teachers in primary science have poor science knowledge and a
negative attitude towards science. In this study we considered the meaning of an attitude towards teaching a subject to include the student teachers’ feelings, opinions, beliefs, and appreciations in relation to the subject. The underlying assumption was that attitudes affect behaviour, and that positive attitudes amongst student teachers lead to good learning and, consequently, to good teaching of that subject. Hence, those involved in primary science teaching must not only be knowledgeable with respect to science, but they should also convey a positive attitude towards the subject in order to motivate their pupils.

Only a small minority of primary student teachers like science and have had success in it at school. For most of them, therefore, their choice of a career in primary education is in part a choice not to do science (Schoon & Boone, 1998). Many primary teachers have had little or no success in their own study of science, which influences their attitudes towards and self-confidence in teaching science (Palmer, 2001). Most student teachers have had “boring and irrelevant secondary school experiences that were largely text-based and had limited or no practical work” (Olson & Appleton, 2006, p.129). Many prospective teachers have a reasonable level of everyday knowledge in science, but the knowledge tends to be episodic rather than conceptually organized, which might lead to difficulties in applying the knowledge in new contexts. Jarret (1999) investigated how an inquiry-based method course influenced primary science teachers’ interest and attitudes, and showed that there was a strong relationship between teachers’ interest in science and their confidence to teach science. However, although the findings of a number of studies have indicated that science method courses can be very successful in developing positive attitudes towards teaching science, increased science knowledge by itself will not consistently result in improved self-confidence (Palmer, 2001). For example, Shoon and Boone (1998) reviewed a number of studies in which the effects of science content courses on student teachers’ attitudes were investigated. They concluded that completion of science content courses does not necessarily improve their attitudes, but that those courses that were specifically designed for primary education were more valued than others. Olson and Appleton (2006) advocated method courses that prepared teachers who already had the
attitude, understanding, and skills to successfully begin teaching primary science (e.g., through providing science inquiry activities and stimulating student teachers to discuss how the science content could be explained to children). Osborne and Simon (1996) and Appleton (2006) emphasized that primary teachers’ lack of confidence, enthusiasm, and ability for the subject of science resulted in the use of less stimulating methods, and caused teachers to respond ineffectively to pupils’ questions. Harlen (1997) and Harlen and Holroyd, (1997) found that, in general, science background, attitudes, and confidence to teach were related. The findings of an earlier study (Appleton, 1995) indicated that primary teachers are least enthusiastic about the physical sciences. It might then be obvious that it is important to develop methods of stimulating positive attitudes among student teachers, and to make them enthusiastic about science. Fleer (2006) highlights the notion of “meaning making science education” in order to build a community of practice for early childhood student teachers. Primary student teachers must cross a border from the community of practice known as “early childhood education” to the community of practice known as “science education” during their science learning. If they do not have the framework of the kinds of questions and ideas the children might have while experiencing and discussing science through objects and experiments, then the border crossing will be difficult (Fleer, 2006).

Although research studies seem to raise concerns about teachers’ attitudes and subject matter knowledge, they tell very little about the influence of these factors on teaching and pupils’ learning. The findings also tell little about how student teachers develop usable subject matter knowledge (Cochran & Jones, 1998). Gess-Newsome and Lederman (1993) followed ten student teachers’ conceptions of biology subject matter structure across three science methods courses and during teaching practice. Their results showed that student teachers found it difficult to articulate the relationships between pedagogical ideas and subject matter concepts. The student teachers showed little integration or stability in their subject matter knowledge, and they were nearly unable to show any relationship between content and pedagogy to explain the concepts which they would be teaching. Referring to Shulman’s (1986,
1987) ideas about the knowledge base for teaching, it might then be considered that the student teachers lacked PCK. Consequently, to uncover and make explicit student teachers’ thinking about their learning to teach, a critical reconsidering of what kind of subject matter knowledge primary science student teachers need, and why, is important

Research design

Participants and context of the study
The research reported in this study was aimed at uncovering and articulating student teachers’ perceptions of their development of self-confidence and subject matter knowledge during an eight-week physics course. The special course design, designed by the first author, is presented in Appendix 1. The course took place in the second term of a three-and-a-half-year pre-service primary teacher programme; one year was given to maths and science. The entire programme qualified the student teachers to teach in pre-school and primary school.

Before entering the course, the student teachers had had a term of general pedagogy and a ten-week course in elementary mathematics. During the present course, 40 primary science student teachers, in groups of three to four, worked on practical experiments and problem-solving skills in physics. In the course of the eight weeks, they had four experimental workshops of three hours each, conducted by the physics teacher, in which they were expected to discuss everyday phenomena based on practical experiments. The first workshop dealt with experiments on heat, temperature, density, and heat conductivity. The second workshop dealt with mechanics; the third, optics; and the fourth, electricity. As the group of 40 student teachers was divided in three groups (of 13-14 student teachers), every workshop was conducted three times.

During the four experimental workshops, all four groups of three to four student teachers were video recorded in order to follow their activities and discussions during the experiments. In connection with every workshop, the student teachers participated in a three-hour seminar to watch the video recordings together with their physics
teacher and a science educator (Author 1) in order to reflect on how they communicated their conceptions (and sometimes misconceptions) in the group. The aim of the group discussions on the video-recorded workshops was to contribute to student teachers’ understanding of the specific physical phenomena brought up in the experiments. Hence, during the seminar, the student teachers had the possibility of expressing their knowledge and also of reflecting on how this knowledge was communicated and shared with their peers.

For practical reasons, two groups (of four student teachers each) participated in the same seminar; the video recordings from both groups were discussed. The student teachers were invited to stop the tape and comment on any situation during the workshops that caused them to reflect, e.g., an event connected with their activities or their interactions with each other during the experiments. The tape could also be stopped by the science educator and the physics teacher if they noticed situations that they wanted to discuss with the student teachers (i.e., in order to probe for more expansive details on how the student teachers interacted to solve the different problems). One educator was a physicist, and was also the examiner and the teacher responsible for the course. The role of the physicist during the seminars was mainly to clarify different physical concepts and phenomena for the student teachers. The role of the science educator (Author 1) was to stimulate the student teachers to reflect on and discuss specific issues as they arose during the workshops. This educator had no role in assessing the student teachers. The video seminars were presented to the student teachers as occasions for learning, and they were not examined during the sessions. The grades were set by the physics teacher only after the course was finished; this might otherwise have had an impact on the student teachers’ discussions during the seminars. In addition, the student teachers, the physicist, and the science educator were all comfortable talking with each other, and the discussions flowed freely, allowing participants to explore their own ideas. Every workshop was followed up with a lecture for the whole group of 40 conducted by the physics teacher. To prepare for the lecture, the student teachers were requested to formulate questions for the teacher concerning phenomena and concepts that they found difficult during the workshops.
**Procedures and instructional design**

Underpinning the design of the course is the assumption that the construction of knowledge and attitudes does not happen in a social or a cultural vacuum. Social contexts influence the ideas that individuals construct as they communicate with others. Research on teacher learning has often demonstrated the importance of interactions with peers (e.g., Little, 2002). If student teachers are encouraged to discuss practical experiments with peers, and to reflect on and make explicit how they develop attitudes and subject matter knowledge, they might then conceptualize aspects related to this development in order to develop their knowledge base for teaching.

To provide a deeper insight into the instructional design of the four experimental workshops, they are described in detail here. Every workshop consisted of four different experiments, which were all designed to stimulate the student teachers’ discussions, problem-solving skills, and active learning processes. All the experiments had a very open design, and the student teachers were encouraged to discuss their hypotheses and to come up with proposals of how to conduct the experiments. The first workshop dealt with the concepts of density, heat, and energy. The aim of the workshop was to help the student teachers to develop their knowledge of different concepts (e.g., Archimedes’ principle, density, and specific heat capacity), and also to give practical examples of the principle of energy connected with melting and freezing, and energy and changes of phases. The second workshop dealt with the concepts of forces and motion. The aim of the workshop was to help the student teachers to develop their knowledge about the connections between forces and movement. The experiments covered concepts such as gravity, inertia, mass, velocity, the universal gravitational constant, and acceleration. One experiment was carried out in an elevator of a 22-storey building at the university; the student teachers used a scale to discuss how their weight changed while they went up to the 22nd floor and down again to the ground floor. The third workshop dealt with experiments on light and optics. The aim of the workshop was to help the student teachers to develop knowledge about how light is spread out and reflected. The student teachers were also expected to gain insight into the functions of the eye, the functions of contact lenses and glasses, and the functions of different optical instruments. The last workshop dealt
with experiments on electricity, and was aimed at stimulating knowledge development about principles of the electric circuit. Concepts such as electric current, voltage, and electrical energy were covered, as were Ohm’s law, magnetic fields, electromagnetic induction, and generators.

**Research instruments and collection of data**

To collect data with the aim of capturing the complexity of student teachers´ perceptions of their development of subject matter knowledge and attitudes to physics, a multi-methods design was used (field notes, questionnaire, and interview). During all the video seminars the science educator (first author) made (1) field notes to document comments and reflections made during the video seminars by the student teachers. After the eight weeks of course work, a (2) questionnaire including a storyline (Beijaard, Van Driel & Verloop, 1999; Gergen, 1988) (Figure 1) was used to elicit the student teachers´ perceptions of their development of subject matter knowledge from the beginning to the end of the course. In addition, five questions (Appendix 2) were used to help the student teachers describe their storylines, and to elicit their ideas about their attitudes to the course and to their own learning. Finally, after the course, all 40 student teachers were invited by the science educator (first author) to participate in a (3) semi-structured interview (Cohen et al., 2000) in order to gain a deeper insight into their ideas and perceptions. As it was the end of the term and summer vacation, only twelve student teachers volunteered to participate; five were selected. The main criteria for selecting the student teachers were that their storylines were qualitatively different and that they had written verbose answers to all questions in the questionnaire. In the interviews, the student teachers were first questioned about their experiences of the course. They were then asked to comment carefully on their storylines, and to explain what had caused the high and low points, the directions or changes of direction, and the directions of inclines. Finally, they were asked to further elaborate their answers in the questionnaire.
The storyline method

The storyline method aims to elicit teachers’ stories, i.e., the way teachers make sense of, evaluate, and clarify their own experiences and events in practice. Author 2 et al. (1999) investigated how and under what conditions this method could best be used to elicit teachers’ practical knowledge about relevant current and prior experiences and events in their professional lives. The method was also used by Gergen (1988) to evaluate college students’ feelings of general well-being. As mentioned by Beijaard et al., (1999), a storyline can be qualified as progressive (from a negative to a positive evaluation), stable, or regressive (from a positive to a negative evaluation). Not only the direction of the storyline, but also the incline, contains information on a certain experience or event. In the present study we used the descriptors ‘constant progressive’, ‘progressive with ups and downs’, ‘stable’, and ‘regressive’ (Figure 1).

We used the storyline to trigger the student teachers’ reflections in order to uncover events during the eight weeks that pertained to their development of subject matter knowledge. The student teachers were asked to grade (on a five-point scale where 1 was considered low and 5 high) how their subject matter knowledge in physics developed every week. Hence, the storyline represented student teachers’ evaluations of their level of knowledge of physics on the vertical line of the graph on a 5-point scale, which was plotted in time on a horizontal time scale during eight weeks (Figure 1).
Figure 1: The different types of storyline used in the study

**Level of knowledge**

According to Gergen (1988), information collected using the storyline method can sometimes be too general, or fail to do justice to all details. In the questionnaire (Appendix 1), therefore, all student teachers were asked to clarify their storyline and describe events that influenced high and low points in the graph, in order to identify factors that they perceived as important for their attitudes towards and their learning of physics. All 40 student teachers’ storylines and questionnaires were then analyzed in order to find common issues and categories related to both what and how they learned the subject matter of physics, and categories related to why they learned.

**Analysis**

Data obtained from the field notes, the questionnaires, and the five interviews were analyzed using a multi-step iterative process involving both authors and a research assistant. Data from the field notes became the basis for a descriptive analysis of how
the student teachers perceived the experiments during the four workshops (e.g., related to factors influencing the student teachers’ development of subject matter knowledge in physics). Data from the questionnaires (including storylines) of all 40 student teachers were then used to give an overview and a broad perspective of what the participants emphasized. Next, data from the five interviews were analyzed in greater depth to identify factors and categories concerning the student teachers’ development of knowledge and attitudes, and how these were related.

A. Field notes
The entire data from the field notes were read repeatedly to search for statements relevant to the student teachers’ perceptions of their development of subject matter knowledge and attitudes towards physics (i.e., what, how, and why they learned), and to probe for illustrative transcriptions emphasized by the student teachers concerning the video-recorded workshops.

B. Questionnaires and storylines
The storylines were classified into the categories of progressive constant, progressive with ups and downs, regressive, or stable. The answers to the questionnaires of all 40 student teachers were read repeatedly to get an overview of what they emphasized. This overview was then organized according to the different categories of storylines.

C. In-depth interviews
- The five interviews were transcribed in full. The transcripts were read repeatedly in order to get an overview. Recurring themes and issues related to the two research questions were translated into English (two thirds of the entire data).
- Both authors went through the interviews, and coded for categories and subcategories and how these were related.
- Quotations representative of the categories and subcategories that emerged from the data were selected.
The interpretations and categorizations made by the two authors were compared, and similarities between the two main categories and the subcategories (Table 1 in result section) were discussed until consensus between the authors was reached.

- The main categories and the subcategories were again applied to the full data set by the first author.
- To establish the validity of the coding, a research assistant applied the main categories and the subcategories to the transcripts.

Results

The following section is organized in three parts. The first part (A) presents the results of the field notes. The second part (B) presents the results of the 40 questionnaires (including storylines). The third part (C) presents the results from the five interviews.

A. Field notes

During the discussions in the seminars, the participants often reflected on factors influencing the student teachers’ development of subject matter knowledge in physics related to the workshops. The student teachers, the physics teacher, and the science educator discussed the experiments, and the student teachers stopped the video several times to ask for explanations. Concerning optics, for example, the student teachers had difficulties in connecting the experiment with the lenses with how light is reflected in the eye. They discussed the relation between the lenses in the workshop and the lens in the eye, and asked the teachers for clarification. The electricity workshop was also the subject of much discussion. For example, the student teachers asked about magnetic fields and electric fields, and how they were related, leading the physics teacher to provide explanations and make drawings on the blackboard.

During the discussions in the seminars, the student teachers often mentioned having “aha experiences” as they finally understood things that they did not understand while doing the experiments.
ST: It is when you have to formulate it for yourself that you know if you have understood. That’s why it is so important to sit in the group and explain things to each other.

Several times in the video recordings the student teachers could be seen searching their books for the “right formula”. This was discussed during the seminar; one student teacher observed herself in the video and said,

ST: We are looking for something, but we do not know what. I think that is because we are so used to looking for the right formula.

It was also documented in the video recordings how the student teachers tested and evaluated the different ways of figuring out the volumes of different bodies, and discussed how things float or sink in the water. One mentioned that a person lying horizontally on the water surface would float better than one whose body was vertical. In the seminar, they elaborated on the discussions, and said that if a book were put with the thin side in the water it would sink faster than if it was put in horizontally. One student teacher said the following:

ST: I can imagine a lot of F (force) would push me up.

Another responded as follows:

ST: Yes, we must go the swimming pool and test how much of the body is above the surface, and how much below. It is like lying or standing on ice…the pressure is different.

Several student teachers stopped the video during the seminar, and commented that it was difficult to know if the answers were reasonable as they did not have any experience of doing experiments in this way. One student teacher commented that the concept of density was abstract, and that they were looking for a formula to calculate density; the physics teacher explained the connections. The student teachers also discussed how they did calculations in the wrong way, leading to incorrect results.
ST: In this discussion we lose track of what we are actually doing. We forget that it is a real world that we are living in, because we are so focused on finding the right formula and theory. If we had only thought about it as a real situation, we would have seen what was reasonable, and what not. Here we really lose track of what we are doing, and it is so evident in the video.

There was much discussion of how the student teachers interpreted the experiments in different ways from what the physics teacher had expected. The physics teacher commented as follows:

Physics Teacher: When I said this to you I thought you understood it directly, but when I see you in the video recording and now during our discussion, I realize that you didn’t. It is like if I went to the shop to buy a digital camera. I would not know all the terms the salesman used, but I would guess that he thought I understood everything. Only after I had brought my new camera home would I realize that I had not understood how it worked. I now realize that it can be the same with physics.

There was much discussion of the scale in the elevator. Forces, pressure, feelings in the body, acceleration, and velocity were discussed. These discussions stimulated the physics teacher to write Newton’s three laws on the blackboard. He spent a lot of time in the video seminar discussing the three laws in relation to the experiments conducted in the workshop.

ST: I did not understand the formula F=mxa, but now when I think about standing in an elevator on a scale, I see the formula in a different context.

**B. Questionnaire with storylines**

Of the 40 storylines, 60 % were labelled *progressive constant*, 37.5 % were *progressive with ups and downs*, 2.5 % were *stable*, and none were *regressive*. The student teachers labelled as *progressive constant* mentioned in their answers to the questionnaire (Appendix 2) that they had learnt a lot, but some things were more difficult than others. Some referred to *why* they needed to learn physics, and said that they were motivated because they thought that it was important to really know the
things that you were going to teach. Some also said that as it was a long time since they had studied physics, they felt a bit unsure in the beginning, but they had learnt a lot during the course, and had become much more assured. All expressed the belief that the workshops were good as they forced them to look deeper into the real content and to discuss it with their peers. Some commented that the experiment in the elevator was particularly good as they could use their bodies in order to learn about the forces and acceleration.

The workshops sometimes caused the student teachers some problems because they did not manage to do the experiments or measurements in the right way. At the same time, some mentioned that it was important not to be “given” the knowledge, but instead to work actively to construct their own knowledge. Several student teachers said that the variation in teaching methods was good, and that the course gave them a lot of ideas about how to teach physics in their future primary teaching. Everyone said that their attitudes towards physics had improved, and that they were now more curious about things that they did not know about before. They also stressed that the group seminars after the workshops gave them a better picture of how things were linked. They also emphasized that the physics teacher’s use of metaphors in his explanations during the lectures clarified several things. For example, when they talked about electricity they referred to water. Several also mentioned that they had realized the importance of starting with physics in primary school, and that they appreciated the discussions of how the content could be useful in primary teaching. Also, it was found to be important for the student teachers’ development of subject matter knowledge that it could be seen what happened in the experiments.

The student teachers labelled as progressive with ups and downs emphasized that they had learnt a lot, but sometimes they said that they felt uncertain of their own knowledge in difficult discussions. The ups and downs depended mostly on the content in the workshops, and on the fact that some things were more difficult than others. Several had not studied physics since secondary school, which caused them some problems. In addition, some said that the experiments were difficult because of
their open design, and that their prior knowledge was not always sufficient. These situations caused “downs” in their storylines, but when they worked in the group and discussed the experiments in the video seminars, their storylines improved, and they felt much more confident. Some emphasized that the video recordings were very good because they helped them to recognize if they were doing the right things. Several said they had expected the course to be boring, because this had always been their view of physics, but the workshops and the various methods made it interesting, and even entertaining. They realized that they could do experiments using plain materials and still get a good idea of how phenomena worked in practice. Some said that their biggest “up” in the storyline was the workshop with the elevator. One student teacher mentioned that the “ups” were when she was helped in her own thinking in the discussions during the workshops and, especially, during the seminars, when they discussed things with the teachers.

ST: For me it is important to progress in my way of thinking that I get a piece of a puzzle and can go further with the help of others. The teachers gave us some fuel in the discussions, and that helped us to advance further in our own thoughts.

They also mentioned their “ups” during the seminars, when they had the opportunity to discuss how they could use the knowledge with small children. One student teacher said that she had a “down” during the workshop on electricity because she did not know what to do. She also experienced a “down” in the first workshop; a lot of calculating was required, which caused her great difficulty. Another student teacher commented on her “ups”, such as when she felt that she could use the knowledge for her own teaching and when she had ‘aha’ experiences in the seminars and during the lectures. Whether they were well prepared for the workshop also seemed to have a beneficial effect on the student teachers’ storylines. The most positive aspect of the course seemed to be that they had started to understand the everyday physics and to get ideas about how to teach physics in primary school.
The one student teacher whose storyline was *stable* said she had studied physics at university so she felt that she knew quite a lot. She estimated her physics knowledge before and after the course to be about the same, but “refreshed”.

As for their attitudes (Question 4, Appendix 2), all 40 student teachers mentioned in their written questionnaire that their attitudes towards physics had changed during the course. Most referred to their secondary school physics as the cause of a negative attitude towards physics when they started the program, but they said they felt more positive about it at the end.

**C. In-depth interviews**

During the interviews the five student teachers were expected to elaborate on the answers they gave in the questionnaire, and comment on their storyline. Two main categories and several sub-categories of student teachers’ learning were highlighted in the data. These are presented below in Table 1.

**Table 1.** An overview of main categories and sub-categories

<table>
<thead>
<tr>
<th>Main Categories</th>
<th>Sub-categories</th>
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| Student teachers’ learning of subject matter knowledge for themselves | • Connecting theory with practice through experiments, everyday phenomena, and problem solving  
• Discussing subject matter with a person with more knowledge, or explaining it to others |
| Student teachers’ learning of subject matter knowledge for primary teaching | • Meaningful knowledge  
• Self-confidence |

The following is organized on the basis of transcriptions related to these categories. Figure 2 presents a compilation of the storylines of the five student teachers interviewed. ST 1, 4, and 5 were ‘progressive with ups and downs’ (P.U.D), ST 2 was ‘progressive constant’ (P.C.), and ST 3 was ‘stable’ (S).
Student teachers’ learning of subject matter for themselves

*Connecting theory with practice through experiments, everyday phenomena, and problem solving*

All five student teachers emphasized the importance of the different practical experiments as a way to connect theory with practice. However, the experiments had a twofold influence on the student teachers. If they succeeded in doing the experiments, they said that their knowledge had increased.

ST 2: I have always liked practical work, and I think I learn from experimenting; I learn more from doing things than from only reading about them. I mean, if you have really done something, it is easier to remember.

But if they failed in doing the experiment (e.g., because of unclear instructions or a lack of prior knowledge), they got frustrated, and even panicked, which influenced their knowledge development. Hence, prior knowledge to build on was also mentioned.
by the student teachers, especially as the experiments had an open design without direct instructions. The need to be well prepared for the workshops was emphasized by all five student teachers. Another issue connected with the experiments was the difference between doing an experiment in practice and only reading about it or thinking about it.

ST 3: I get such an understanding through testing in practice, studying and experimenting, and not always looking for the mathematical connections. For example, I sat on a chair with weights in my hands; when I kept my hands out I turned slower, and when I held them closer to my body I turned much faster. This is really a good way to understand. Of course, I know how to predict this, but only calculating does not give me the same understanding as if I experience it myself.

ST 3 mentioned that once she started to learn the physics she understood what she did not know, and also what she needed to know. The more she read, the more questions arose. She said that finding out how things worked in practice was a bigger challenge than working them out on paper, using formulas and calculating. She mentioned that she had quite good basic knowledge and that she, unlike the others, started at level four on her storyline. In the first workshop, she had good prior knowledge, and was familiar with the units and formulas. She described how her storyline decreased, mostly because she realised that she could not always use the formulas and numbers to explain the different phenomena. She said further that she did not want to use formulas only, but wished instead to focus on her own understanding. She got confused when she had to create formulas based on the experiments at the workshop, and she started to wonder what knowledge she actually possessed:

ST 3: Throughout the whole course I tried to avoid only building my knowledge on mathematical terms and formulas; instead, I wanted to understand the physics itself, and that caused me some problems. I mean, it was hard for me to understand the words and explain the why instead of calculating with a formula and getting the right solution.
ST 1 emphasized the importance of realizing why formulas are needed and what they actually stand for. In the interview she described how she at first did not manage to see the connection between numbers and formulas and what they really stood for when applied in an everyday context. ST 4 mentioned that during the workshops she found that something which she thought she understood turned out to be more difficult. She described how her storyline decreased at the end of the course because the last workshop was so difficult and created a lot of new questions, and that she suddenly realised that she did not know everything as well as she thought she did. ST 3 said that she had always liked to count and think about different problems, but perhaps she had not always understood what was behind all these numbers and formulas. Further to this, ST 4 stressed that if you do not understand the units you will also have difficulties understanding the results and explaining the results in words. When she was forced to do things in practice and to actually use the units while presenting the results, she became able to relate this to things she recognised. ST 5 referred to the experiment with the elevator, and said that it helped her to think logically as she recognised much from her earlier experiences. ST 4 also referred to the elevator:

ST 4: The elevator was not difficult, because it was something we had all experienced before. I mean, everyone has been in an elevator, and it was easy to connect the experiment with the body when we felt very heavy just when it started to go up and very light when it stopped. Everything was clear, and if you really see things like that it is much easier to learn about the concepts of forces and other things.

All five student teachers stated that the experiment in the elevator helped them to experience the forces and acceleration with their bodies. Some also said that it was easier to understand acceleration while observing on the scale how they became heavier. They also said that they laughed a lot, which they perceived as important for their learning. ST 5 suggested other experiments, such as floating in a swimming pool, to improve understanding of the concept of density. They all emphasized that if you experience the phenomena yourself it is easier to understand.
Discussing subject matter with a person with more knowledge, or explaining it to others

The discussions during the video seminars were mentioned by all five student teachers. They said that these discussions gave them the possibility to reflect on what they did during the experiments, and to compare each other’s results. They also mentioned that it was good to explain things to each other as it helped them to understand their own thoughts. However, all emphasized the importance of having someone more knowledgeable in the discussions to explain difficult concepts. Also the lecture that the teacher gave after each workshop was brought up as an important factor for the development of subject matter knowledge:

ST 1: The seminar and the lectures were very good as we had to reflect on what we did, and we discussed all the experiments. Otherwise, you do the experiments and then put them behind you. Also, I think that it is important to sit with your peers and discuss. Then you have the opportunity to explain things to each other and hear each other’s thoughts. And you realise that you normally have the same answers even though you formulate them differently. The group discussions were also good as we saw each other’s successes, but we also saw each other’s mistakes; I learned a lot.

ST 3 highlighted that discussing things with her peers gave her an idea of what was difficult for her. Trying to analyze others’ thoughts and what things they considered difficult helped her to gain an insight into her own difficulties and how they could be dealt with. She mentioned the conversations in the seminars as important for her development of subject matter knowledge. ST 5 said that the discussions in the evaluation seminar made her realise how things were connected. She also found it good to discuss things with the others in the group, because their explanations helped her in her own thinking. ST 1 told that when she had to explain phenomena to her peers she was forced to put her own knowledge into words. ST 3 described how the need to convince others forced her to reflect on her own knowledge. She referred to an occasion during a workshop when all members of the group were agreed, except one girl, who had a totally different opinion.
ST 3: It was not difficult for us to find arguments, but to convince the other person was not that easy. I don’t know if we managed, but we really tried to express ourselves, and that helped us to be clearer in our own thoughts. I think it is important not only to work alone, but also to work in a group and discuss your experiences. I don’t think that you can get very far if you only work alone.

Some student teachers also referred to the video recordings in the seminar. ST 1 highlighted an incident during the seminar when they watched a video recording:

ST 1: One girl did not understand anything throughout the whole workshop, and then suddenly she understood. It was really cool to watch her, because it was so evident that something really became clear for her.

In sum, all five student teachers mentioned that their storylines increased when the content was connected with everyday experiences; the evaluations in the seminar were also important, and gave a lot of ‘aha’ experiences. In addition, the student teachers highlighted the shift from understanding a thing to explaining it to others.

Student teachers’ learning for primary teaching

Meaningful knowledge

Almost all of the student teachers said that they were more motivated when they felt that the knowledge was meaningful to them and could be used in their future teaching. Discussions about concepts that might be meaningful for primary children, and about how they could be explained, were also considered useful by the student teachers.

ST 2: I also consider it important that we be able to use the experiments in our own future teaching, and that the things we do are meaningful for us as teachers, giving us insights into how we can teach the subject later. I mean….you have to think of that even when you are studying physics as a subject.
ST 3 mentioned that the discussions in the video seminars gave her the possibility to get an insight into the work of the other groups, which was a good preparation for her future teaching. Seeing what others found difficult helped her to think about what school children might find difficult. She stressed that memorizing laws and formulas was not meaningful in her primary teaching, so she was forced to understand the phenomena in order to be able to give the children meaningful explanations.

ST 3: I wanted to understand it from a different viewpoint, and understand the theory and the explanations and not only the mathematics and the formulas. That is the type of knowledge I will need when I have to explain it to the children. Then it is not enough only to describe things using formulas; you need to know why things happens as they do.

ST 5 said that because children have so many questions, she needed a lot of knowledge in physics in order to promote their understanding. ST 5 also emphasized the importance of the subject matter knowledge being meaningful for primary teaching:

ST 5: Another thing that I think is important for my own learning is that the knowledge that we gain in the course is usable in the school context in which we are supposed to teach young children. We can not use formulas, difficult words, or calculations with the small children. The physics we learn must be practical and concrete, but also meaningful and usable in our future teaching.

ST 3 referred to the experiments in mechanics, and mentioned that those experiments could easily be discussed with children (e.g., what would happen with the body when you accelerated and slowed down a car); because children recognise these things, the phenomena could effectively be referred to and be perceived as meaningful by the children.

**Self-confidence**
All five student teachers highlighted self-confidence in their subject matter knowledge and in their ability to teach science as an important aspect in managing their teaching of primary physics. ST 2 mentioned that she felt confident when they discussed the
experiments in the seminar. She said that without instruction from the teachers, several things would have remained unclear. She also emphasized curiosity and self-confidence as important aspects both for developing subject matter knowledge and for teaching. She mentioned that the group discussion in which she was supported by her peers was important for her self-confidence. While doing the experiments, she became more and more interested, and a lot of questions were raised:

ST 2: Those questions and experiences made me more curious, which I am sure influenced my motivation and helped in my learning. The curiosity and the self-confidence are really very important, and my attitude has changed a bit: I have become more curious and hungry for knowledge because so many new questions arose during the workshops. The more you learn, the more you want to learn.

Carrying out experiments that were easy to connect with everyday situations helped ST 1 to understand the phenomena, which made her more self-confident; she felt that this also influenced her ability to teach primary science. ST 3 claimed that her self-confidence was closely connected with her knowledge. The better she knew a topic, the more confident she would be in teaching it.

ST 3: The third workshop was optics. I think I was quite calm there because it was not very difficult. I have glasses and I know a lot about lenses, and I have also worked with cameras and have done photography, and so on. After that my storyline did not really have any more valleys; instead, it continued to go up. I got a lot of self-confidence because I felt that I was in control. I felt happy, and that I really would manage all those things. So self-confidence is very important for knowledge to develop. You must feel safe.

She also mentioned that she sometimes thought that she understood a thing because she knew the concept or the formula, but that when she wanted to use her knowledge to explain it to the others she realised that she did not possess the knowledge she thought she had. This influenced her self-confidence, causing a “down” in her storyline.
ST 3: But then, suddenly, my story-line fell into a real valley. This was when I started to read before the fourth workshop. My father is an electrician, and so is my brother, and I have been working with electric circuits and connections since I was a little girl. No problems. So before the workshop I felt that I was going to manage everything, and then I started to read it through and suddenly I started to feel that everything was very difficult.

ST 4 described how the course changed her attitudes towards physics, and mentioned that she had started to see physics everywhere, which also was important if she was to stimulate children’s interests and learning.

ST 4: So the positive feeling is very important. I have always liked physics, but this course has made me like it even more. I feel that I need a lot of knowledge of physics if I am going to teach small children, because I know that children have so many questions. It is an interesting subject, and doing experiments is a very good way to learn. Positive feedback from the teachers is very important, too, as people often perceive physics as very difficult and boring.

ST 5 described how she started to understand the content after a while and get into the physics way of thinking when they discussed a lot about the workshops in the group. Various factors (e.g., group discussions, practical experiments, lectures improved her understanding greatly, and a lot of gaps were filled for her. This, she claimed, was connected with her attitudes towards the subject, which she said were important not only for her development of subject matter knowledge, but also for her self-confidence and her ability to teach science in her future profession as a primary teacher.

Conclusions and discussion

A range of methods was used in this study of primary science student teachers in order to gain insight into student teachers’ development of subject matter knowledge that became meaningful for them in their teaching of primary physics. As a consequence, and as the data and analysis described above illustrate, the student teachers came to see that different factors were crucial for this development to occur. In many ways, the findings highlight the importance of helping student teachers to uncover and make
explicit their own thinking about their learning about teaching. It is reasonable to suggest that perceptions of, and attitudes towards, science and the teaching of science to young children also influence knowledge development among primary student teachers. For primary student teachers to cross the border (Fleer, 2006) and become able to teach physics to young children, they need to develop knowledge about what and why they teach. For this purpose, they need to learn what sort of questions and conceptions young children might have with respect to science. The results of this study highlight the importance of listening to student teachers’ personal stories in order to map and conceptualize important factors for this development to occur. In primary teacher education, it is our assumption that student teachers must perceive science knowledge as meaningful and usable for themselves. This is firstly because primary teachers are generally more focused on teaching children than on teaching the subject matter; and secondly because the young children require a different way of teaching physics than children in secondary education. As the student teachers mentioned, primary science teaching requires teaching without formulas, with a stronger focus on phenomena and the “science teaching explanations” (Childs & McNicholl, 2007).

The student teachers in the present study were stimulated to learn physics in different ways, and all stated that their attitudes towards the subject had become more positive. They emphasized that it was important in the process of learning to become aware of what you know and what you don’t know, but also why you know. The subject matter knowledge was not considered by the student teachers to be something a person can get and then deliver in the classroom. The development of subject matter knowledge was rather explained as a dynamic process depending on several different factors. ST 1 mentioned, for example, that she had developed theoretical knowledge during the course about things that happen in everyday life, things that she would never have reflected on otherwise. She said that she had always thought that physics was difficult, but that once she started to understand the connections, it became very interesting. In the terms of Fleer (2006), she had crossed the border and she had started to see physics everywhere.
S1: Before this course I thought that physics was difficult, but now I have discovered that it is possible to do something nice and practical with it. I thought that it would be difficult to do something with the children, but now I have seen that it is possible to do a lot of physics with them. This has made me more motivated to learn, which, of course, must result in better knowledge development. Attitude is important, but also the way in which the knowledge might be used in real school practice.

Appleton (2002) advocated the need for primary science teachers to go beyond only using “activities that work”. To develop high-quality science teaching in pre- and primary schools and for teacher preparation to serve an important role in that process, student teachers need to be encouraged to recognize factors that they consider important for developing subject matter knowledge and for their learning to teach science in an appropriate way to primary pupils. In explicating their views about learning situations, the student teachers found themselves viewing their learning and their role as primary science teachers in new ways. The development of subject matter knowledge is strongly connected with attitudes, self-confidence, and perceived meaningfulness. However, student teachers’ personal stories are crucial to understand the difficulties that they face during their complex journey from learners to teachers.

**Implications**

The results of the present study concern both student teachers’ development of subject matter knowledge and other particular aspects of the knowledge base for teaching (Shulman, 1986, 1987) that they consider important in order to teach primary physics. As the data and analysis described above illustrate, the student teachers participating in this study came to see that also self-confidence and the meaningfulness of knowledge were important aspects in their own thinking about how to teach primary physics. Almost all the student teachers stressed the importance of confidence in their ability to teach science. An important issue for the pedagogy of teacher education (Loughran, 2006) might then be to cultivate a more positive attitude by developing student teachers’ confidence to teach science effectively. In so doing, science teacher educators must design course programmes that empower student teachers to see
themselves as learners of both science and science teaching, and that also involve them in constructing their own science understandings (Koch, 2006). As Appleton (2006) indicated, lack of confidence in the adequacy of their science knowledge might result in a limited development of science PCK.

The results of the present study are applicable to teacher education programmes, as it is important that these programmes ascertain the views of the student teachers. Although numerous studies have been conducted to explore student teachers’ development of subject matter knowledge, the voices of the student teachers have been relatively silent. There is an emerging need for researchers in science teacher education to explore the perceptions of student teachers in order to support them in constructing meaningful knowledge of both science and science teaching.

References


## Appendix 1. Course design

<table>
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<tr>
<th>Weeks 1-2</th>
<th>1. Heat &amp; Temperature</th>
<th>Workshop 1 in groups of 12-14 student teachers, lasting 3 hours <em>(physics teacher)</em></th>
<th>Video seminar on workshop 1 in groups of 12-14 student teachers, lasting 3 hours <em>(physics teacher and researcher/science educator)</em></th>
<th>3-hour lecture for all student teachers based on student teachers’ questions on workshop 1 <em>(physics teacher)</em></th>
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<tbody>
<tr>
<td>Weeks 3-4</td>
<td>2. Mechanics</td>
<td>Workshop 2 in groups of 12-14 student teachers, lasting 3 hours <em>(physics teacher)</em></td>
<td>Video seminar on workshop 2 in groups of 12-14 student teachers, lasting 3 hours <em>(physics teacher and researcher/science educator)</em></td>
<td>3-hour lecture for all student teachers based on student teachers’ questions on workshop 2 <em>(physics teacher)</em></td>
</tr>
<tr>
<td>Weeks 5-6</td>
<td>3. Optics</td>
<td>Workshop 3 in groups of 12-14 student teachers, lasting 3 hours <em>(physics teacher)</em></td>
<td>Video seminar on workshop 3 in groups of 12-14 student teachers, lasting 3 hours <em>(physics teacher and researcher/science educator)</em></td>
<td>3-hour lecture for all student teachers based on student teachers’ questions on workshop 3 <em>(physics teacher)</em></td>
</tr>
<tr>
<td>Weeks 7-8</td>
<td>4. Electricity</td>
<td>Workshop 4 in groups of 12-14 student teachers, lasting 3 hours <em>(physics teacher)</em></td>
<td>Video seminar on workshop 4 in groups of 12-14 student teachers, lasting 3 hours <em>(physics teacher and researcher/science educator)</em></td>
<td>3-hour lecture for all student teachers based on student teachers’ questions on workshop 4 <em>(physics teacher)</em></td>
</tr>
</tbody>
</table>
Appendix 2. Questions posed in the questionnaire

1. Put into words your knowledge development in the storyline. Do you have any peaks or valleys, and why? How do you consider your knowledge development at the end of the course compared to when it started? What was easy and what was difficult, and why?

2. How did you perceive the design and the methods of the course?

3. How did you view the four workshops (good, bad, easy, difficult)?

4. What was your attitude to physics before the course, and did this attitude change during the course?

5. What factors during the eight weeks were most important for your development of subject matter knowledge in physics?