Examining science teachers' pedagogical content knowledge in the context of a professional development program

Wongsopawiro, D.S.

Examining science teachers' pedagogical content knowledge in the context of a professional development program

Title: Examining science teachers' pedagogical content knowledge in the context of a professional development program

Titel: Een onderzoek naar de pedagogische vakkennis van bètadocenten in de context van een professionaliseringsprogramma

ICLON, Leiden University Graduate School of Teaching

Print: Proefschriftmaken.nl || BOXPress, Oisterwijk
Cover design: Gerda Visser-Wijnveen
Lay-out: Proefschriftmaken.nl || BOXPress, Oisterwijk
ISBN/EAN: 978-94-90383-07-7

Examining science teachers' pedagogical content knowledge in the context of a professional development program

Proefschrift

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus prof.mr. P.F. van der Heijden,
volgens besluit van het College voor Promoties
te verdedigen op dinsdag 24 januari 2012
klokke 16.15 uur

door

Dirk Soenario Wongsopawiro
geboren te Paramaribo
in 1971

Promotiecommissie

Promotor

Prof. Dr. J. H. van Driel

Overige leden

Prof. Dr. N. Verloop, Universiteit Leiden

Prof. Dr. P. J. den Brok, Technische Universiteit Eindhoven

Dr. F. A. Henze-Rietveld, Radboud Universiteit Nijmegen

Dr. ir. F. J. J. M. Janssen, Universiteit Leiden

Voor Archibald Marshall

Table of Contents

Chapter 1. General introduction

1.1. Introduction

Teachers are the most important factor in student learning (National Research Council, 1996). They determine what is taught in the classroom and how it is taught, making them a critical factor in students' learning (Abell, 2007; King & Newman, 2000). In early days, research on science education focused on science teachers who needed to be well-qualified and passionate in their field of expertise. Over the years, however, it became evident that the possession of expert content knowledge was no guarantee of 'good science teaching'. Science teachers should not only have good subject matter knowledge (SMK), but should also possess pedagogical knowledge (PK). Successful science teachers should get students engaged to help them understand the natural world, to apply scientific principles, and consider careers in the sciences (NRC, 1996). Research in science education has determined that successful science teachers must have strong subject matter knowledge, a good understanding of the nature of science, and be able to translate scientific concepts into meaningful learning experiences for their students (Feiman-Nemser, 2001; Gess-Newsome, 1999b). Recent studies have claimed that science teachers should have a deep understanding of scientific concepts, knowledge of students as learners, knowledge of instructional strategies, knowledge of assessment strategies, and knowledge of curricular resources, thus placing teachers' knowledge at the heart of science education research (Darling-Hammond, 2008). The process of learning to teach means learning how to systematically organize knowledge so that it can be drawn upon and applied to new situations (Berliner, 2001). To understand the knowledge that is needed for science teaching, Shulman (1986, 1987) introduced the concept of pedagogical content knowledge (PCK) as a unique form of knowledge for teaching that makes a content domain understandable for learners. Effective teachers need to develop knowledge with respect to all of the aspects of pedagogical content knowledge and with respect to all of the topics they teach (Magnusson, Krajcik, & Borko, 1999, p. 115). To understand science teaching, it is of pivotal importance to investigate the nature of the PCK of in-service science teachers and how that knowledge guides their teaching: 'A real and serious issue in teaching is the ability to capture, portray, and share knowledge of practice in ways that are articulable and meaningful to others' (Loughran, Berry & Mulhall, 2006, p. 15). A deeper understanding of the nature of the PCK of in-service science teachers provides important insight for science teacher educators as they design their programs for student-teachers (Abell, 2008). Barnett and Hodson (2001) noted that teaching remains a complex enterprise where teachers continually need to adjust their instructional strategies to ensure student learning. Explicating teachers' professional knowledge in the form of pedagogical content knowledge, and sharing it with colleagues or student-teachers, could be the main key to effective professional development of in-service science teachers (cf. Wallace & Louden, 1992). A model of successful teaching practice could inform teachers' professional development (PD) programs. The development of such models can be achieved by carefully investigating and analyzing the practice of in-service teachers (Barnett & Hodson, 2001; NRC, 1997). In this thesis we investigated the pedagogical content knowledge of experienced in-service science teachers in a professional development setting. In this specific context we followed in-service teachers who designed and taught lessons to improve their teaching. We were able to investigate how in-service teachers drew upon their pedagogical content knowledge to plan and conduct their lessons. In this program teachers used an action research approach to improve their teaching. With the use of this approach, we were also able to investigate how their PCK developed as a result of participating in a PD program that aimed to improve their teaching. Investigating what the PCK is that teachers draw upon and how this PCK develops could help us to understand how this particular form of knowledge is actually used in classroom settings.

Understanding the nature of teacher pedagogical content knowledge and how its components are drawn upon when teaching can be accomplished through an investigation of in-service teachers (Berliner, 1986; Shulman, 1986). In this thesis, we investigated how PCK components were used and developed as in-service teachers participated in the professional development program aimed at improving classroom teaching. Investigating in-service teachers' pedagogical content knowledge allowed us to deepen our understanding of what 'good science teaching' is and how it may actually occur in a classroom setting. Our investigations also informed us how we could develop research on teacher knowledge more vigorously.

1.2. Teacher knowledge

Teachers' knowledge and beliefs give meaningful consistency to experiences, thoughts, feelings and actions within a certain context (Posner, Strike, Hewson, & Gertzog, 1982). Feiman-Nemser (2001) notes that teacher knowledge develops as teachers learn to make concepts understandable to their students. Teacher knowledge is closely related to individual experiences and contexts and, therefore, unique and practical to the individual teacher (Verloop, Van Driel, & Meijer, 2001). Teachers' practical knowledge includes the teachers' knowledge about the content, their beliefs about their own teaching practice, and their teaching experience (Van Driel, Beijaard, & Verloop, 2001). The development of the knowledge is a process where teachers try new ideas, refine old ones, and engage in classroom problem-solving (Wallace, 2003). Through experience, teachers develop a knowledge that regulates their own teaching (Carter, 1990). Teacher practical knowledge has been researched and described in numerous research studies (Abell, 2007; Doyle, 1985; Grossman, 1989; Lee, Brown, Luft, & Roehrig, 2007; Lee & Luft, 2006; Magnusson et al. 1999; Meijer, 1999; Van Driel, Verloop, & de Vos, 1998), yet little evidence has been found to determine how this knowledge actually guides decisions in classroom teaching (Calderhead 1996; Black & Halliwell, 2000). There is general agreement, however, that teachers' practical knowledge guides their actions in the classroom (Lantz & Kass, 1987, Verloop, 1992). Van Driel et al. (2001) argue that the concept of practical knowledge 'refers to the integrated set of knowledge, conceptions, beliefs, and values teachers develop in the context of the teaching situation'(p. 141). Teachers' practical knowledge is action-oriented (Beijaard & Verloop, 1996) and person- and context-bound (Johnston, 1992; Stigler, Gallimore, & Hiebert, 2000). It includes tacit and integrated knowledge (Beijaard & Verloop, 1996). In discussing the concept of PCK, Shulman (1987) noted that successful teachers are able to transform their knowledge of scientific concepts into a form of knowledge that can be understood by learners, by integrating their knowledge of learners, representations, instructional strategies, assessments, and curricular resources to create meaningful learning opportunities that make connections between lesson content and students' experiences.

1.2.1. Pedagogical content knowledge

PCK is a central component of the teachers' practical knowledge and is based on both subject matter knowledge and pedagogical knowledge (Van Driel et al., 1998, 2001; Van Driel, De Jong, & Verloop, 2002). Teaching experience also influences the development of PCK (Clermont, Borko, & Krajcik, 1994). Shulman (1986, 1987) expressed the need for a theoretical formulation to identify the different components of teachers' teaching capabilities, as well as the conditions for developing them. He classified teachers' knowledge into content knowledge (subject matter knowledge), pedagogical knowledge, and pedagogical content knowledge. Pedagogical content knowledge was introduced as a concept that represents the kind of knowledge that teachers use in their classroom teaching. Thus 'understanding the development of teachers' subject matter knowledge and PCK is critical for our success in science teacher education' (Abell, 2007, p. 1133).

Lee Shulman (1986, 1987) described PCK as a unique form of knowledge for teaching which is based on subject matter knowledge, knowledge of potential student learning difficulties, and students' prior knowledge of specific concepts, as well as the most effective models, analogies, illustrations, explanations, and investigations to make the concept understandable for students. In his work Lee Shulman explained that PCK conceptualizes 'the ways of representing and formulating that subject that makes it comprehensible to others'(Shulman, 1986, p. 9). In 1987, Shulman rephrased his definition of pedagogical content knowledge as a 'special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding' (p. 8). In his understanding, teachers use both their content knowledge and their pedagogical knowledge in a blended way to promote student learning. Although Shulman's view has been widely used, many scholars have interpreted it in different ways resulting in different PCK models over the years (Grossman, 1990; Marks, 1990; Magnusson et al., 1999; Hashweh, 2005; Fernández-Balboa & Stiehl, 1995; Koballa, 1999; Cochran, DeRuiter, & King, 1993, Kind, 2009).

For the purpose of this study, we selected a model of PCK for our research. Magnusson et al. (1999) proposed a PCK model, which has been widely used to understand science teaching. After Schulman (1987) and later Grossman (1990), they posited that in order to teach a certain content, several types of knowledge (including subject matter knowledge) are transformed into the pedagogical content knowledge suitable for teaching. The Magnusson et al. (1999) PCK model has been discussed by other scholars (Abell, 2007, 2008; Kind, 2009; Friedrichsen & Dana, 2005). Some scholars have used the PCK components derived from the Magnusson et al. model in their studies (Henze, Van Driel, & Verloop, 2008; Kaya, 2009; Justi & Van Driel, 2006; De Jong & Van Driel, 2004). In their review studies, Abell (2007) and Kind

(2009) explained that this model is useful for studying the PCK of science teachers. In the following section, we briefly outline this PCK model which we used for our study.

1.2.2. Magnusson et al. (1999) model of PCK

Magnusson et al. (1999), who described PCK as 'the transformation of several types of knowledge for teaching' (p. 95), proposed a model to study science teachers' pedagogical content knowledge. This model is derived from earlier models proposed by Shulman (1986) and Grossman (1990). Magnusson et al. (1999) defined five components of PCK: (1) orientations toward science teaching; (2) knowledge and beliefs about science curriculum; (3) knowledge

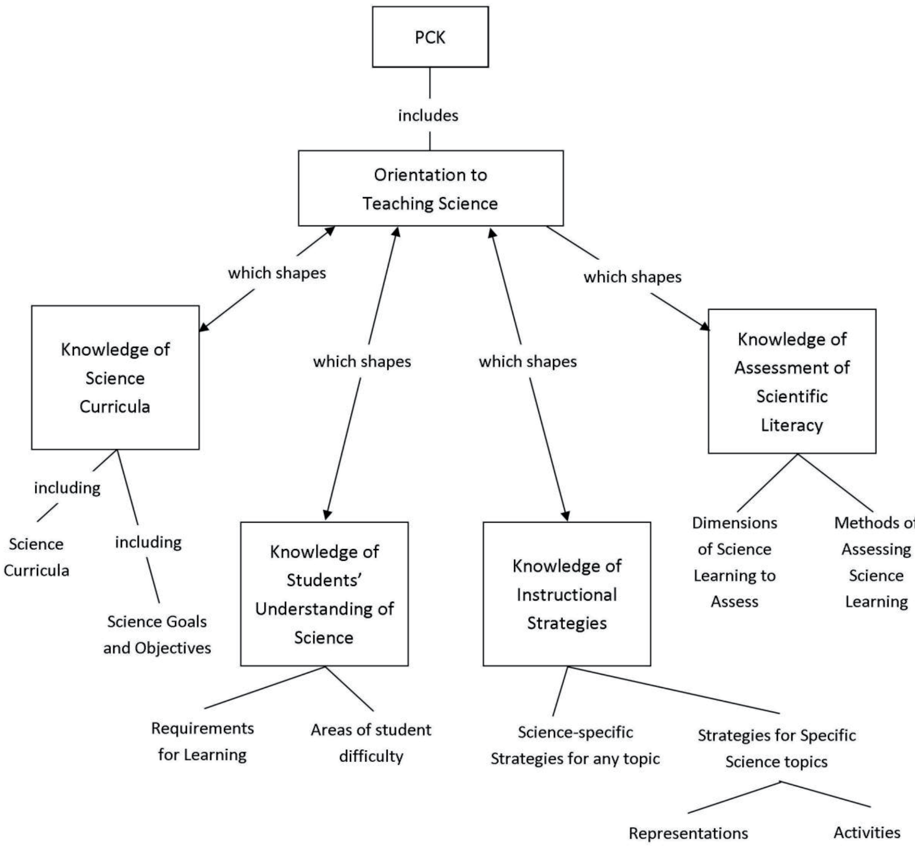


Figure 1.1. PCK model for science teaching (Magnusson et al., 1999, p. 99).

and beliefs about students' understanding of specific science topics; (4) knowledge and beliefs about assessment in science; and (5) knowledge and beliefs about instructional strategies for teaching science (p. 97). Magnusson et al. (1999) explained that the orientations of science teaching serve as a map that guides other PCK components (see Figure 1.1).

We explain the PCK components from the Magnusson et al. (1999) model using other literature for each component:
(1) *Orientation toward teaching science[1]:* Magnusson et al. (1999) described the orientation to science teaching as 'the knowledge and beliefs possessed by teachers about the purposes and goals of teaching science at a particular grade level' (p. 97). They then expanded that by saying 'the orientations are generally organized according to the emphasis of instruction' (p. 97). Teaching orientations act as 'conceptual maps' guiding the decisions about learning objectives, implementation of curricular materials, and evaluation of students' learning (Magnusson et al. 1999, p. 97). Some scholars have argued that the orientations towards teaching science have not been studied well (Friedrichsen & Dana, 2003, 2005; Friedrichsen, Van Driel, & Abell, 2011; Talanquer, Novodvorksy, & Tomanek, 2010). Friedrichsen and Dana (2005) explained that studying orientations can be complicated since teachers hold multiple goals when teaching. They also noted that teaching orientations are still a 'messy concept'. Some scholars used other terms such as 'preconceptions of teaching' (Weinstein, 1989;1990), 'approaches to teaching' (Trigwell, Prosser, & Taylor, 1994), or 'conceptions of teaching' (Hewson & Hewson, 1987; Hewson, Kerby, & Cook, 1995; Lemberger, Hewson, & Park, 1999; Lyons, Freitag, & Hewson, 1997; Meyer, Tabachnick, Hewson, Lemberger, & Park, 1999) to study teaching orientations.

(2) *Knowledge of science curricula:* This type of knowledge refers to the teacher's understanding of the goals and objectives for student learning

1 Orientation toward teaching science is sometimes referred to as 'orientations to teaching', 'science teaching orientation' or 'teaching orientation' in the text.

and the scope and sequence of the scientific concepts. Knowledge of science curriculum consists of two categories: (a) knowledge of goals and objectives; and (b) knowledge of specific curricular programs (Magnusson et al. 1999, p. 103). Abell (2007) argued that most curricular studies have not focused on teachers' knowledge of the curriculum, but rather focused on teachers' ranking of the importance of science goals (p. 1129). Some studies have focused on inquiry-oriented curricula. Jones and Eick (2007) studied changes in teachers' PCK when they introduced an inquiry-oriented curricular program. Some studies have argued that more research is needed to understand how teachers' knowledge of the curriculum is being used in practice (Furio, Vilches, Guisasola, & Romo, 2002; Jones & Eick, 2007; Kesidou & Roseman, 2002; Schneider & Krajcik, 2000).

(3) *Knowledge of students' understanding of science:* This PCK component includes: (a) knowledge of the requirements for learning which refers to the prerequisite knowledge for learning specific scientific knowledge; and (b) knowledge of areas of student difficulty which refers to knowledge of those science concepts that students find difficult to learn (Magnusson et al., 1999, p 105). In her handbook chapter, Abell (2007) found that studies focused on teachers' knowledge of student understanding reported general views of teaching (p. 1127). Halim and Meerah (2002) found that teachers were unaware of students' misconceptions and had inadequate subject matter knowledge. De Jong and Van Driel (1999) found that more teachers were becoming aware of the students' learning difficulties after they reflected on their lessons. Abell (2007) noted that, overall, teachers lack knowledge of students' conceptions, but that this knowledge improves when teachers gain more experience.

(4) *Knowledge of assessment:* This component of PCK consists of two subcomponents: (a) 'knowledge of the dimensions of science learning to assess' which refers to knowledge of aspects of students' learning that are important to assess within a particular unit or lesson; and (b) 'knowledge

of methods of assessment' which refers to knowledge of ways to assess those specific aspects of students' learning. The knowledge of methods of assessment includes knowledge of specific instruments, procedures, approaches or activities that can be used during the assessment.

(5) *Knowledge of instructional strategies*: This component has two kinds of knowledge: (a) knowledge of subject-specific strategies refers to the ability to use general teaching approaches in broad applications; and (b) knowledge of topic-specific strategies includes ways to represent concepts and engage students with instructional strategies to facilitate student learning of specific concepts in science (Magnusson et al. 1999).

Many other scholars have used this model to study the development of the PCK of science teachers who taught a particular topic (Henze et al., 2008; De Jong, Van Driel, & Verloop, 2005; Lankford, 2010). Both Abell (2007) and Kind (2009) noted in their review studies that the Magnusson et al. (1999) PCK model seems to encompass what is needed in science education and is most useful for research on teachers' knowledge. Science education research based on this model can further our understanding of how teachers draw upon their knowledge and beliefs to teach effectively. Many questions still remain that need to be investigated. Questions remain such as: How is an orientation actually linked to the other PCK components? How can the PCK of science teachers be typified in a professional development setting? How do the specific PCK components develop? or How are the components linked to the teachers' practice? More research is needed to deepen our understanding of PCK. Many studies have focused on the PCK of pre-service teachers in a teacher training program, however, few studies have used professional development programs as a specific context where the PCK development of in-service teachers is investigated and monitored. This thesis reports on four studies aimed at improving our understanding of pedagogical content knowledge in practice using the Magnusson et al. (1999) PCK model. In particular, we examine the different components when teachers are participating in a PD program to improve their teaching using classroom action research as a vehicle to reach their goals.

1.2.3. Professional development programs

Professional development plays an essential role in the improvement of student learning (Desimone, 2009). Many professional development programs equip teachers with new activities to be implemented in their classrooms. However, many of these programs have proven to be unsuccessful for a variety of possible reasons. First, the traditional top-down approach encourages teachers to be passive participants exposed to new ideas of 'learning experts'. This has been unsuccessful because it fails to take teachers' practical knowledge into account (Van Driel et al., 2001; Haney, Czerniak, & Lumpe, 1996; Klinger, 2000). Second, teachers do not implement the suggested strategies according to the intentions of the learning experts (Wallace & Louden, 1992). PD developers often neglect to take the teachers' practical knowledge into consideration when planning and developing their program . This practical knowledge includes the content knowledge, pedagogical knowledge, and beliefs of practising teachers. Teachers' practical knowledge has a major influence on the way they respond to professional development programs (Verloop, 1992). Specifically, professional development programs that focus on students' learning often deepen teacher's content knowledge and their knowledge of ways to transfer this knowledge to students (Cohen & Hill, 2000; Kennedy, 1999; Wiley & Yoon, 1995). Successful professional development programs offer effective strategies assisting teachers to promote students' learning. One of the principles of an effective math and science professional development program is to encourage in-depth understanding of core concepts, instead of minimal breadth coverage of the topic. Through an in-service PD program, teachers might deepen their own understanding of content knowledge and learning to transfer their knowledge to their students. To serve students' learning, teachers transform their own content knowledge developing several components of pedagogical content knowledge. PCK development is a product of planning, teaching, and reflecting.

Professional development programs are often used by reform-minded teachers as an opportunity to find novel ways of addressing content. Some scholars have cautioned that educational reform should not only focus on teachers' content knowledge, but should also consider the cognitions, beliefs, and attitudes of the participants (Haney et al., 1996). Most PD programs do not take specific classroom problems into consideration, nor do they focus on the teacher's individual interest in gaining new knowledge and skills. The failure to take teachers' own interests into consideration dooms the PD programs to fail. The focus of a PD program should be on teachers' learning (Ball & Cohen, 1999). Recently, professional development programs have not only focused on the teachers' content knowledge, but incorporated their pedagogical growth as well (Bell, 1998). Some PD programs focus on specific content knowledge instead of general knowledge, or a specific way of teaching a certain topic. In the PD model of Bell and Gilbert (1996), the teachers were encouraged to take students' gaps in knowledge into consideration. In the last decade several studies have been published on effective professional development, teacher learning, and teacher change (Carey & Frechtling, 1997; Cohen & Hill, 1998; Loucks-Horsley, Love, Styles, Mundry, & Hewson, 2003; Richardson & Placier, 2002). In a professional development setting, teachers reflect on their personal practical knowledge. Some research has focused specifically on the effects of professional development on improving teachers' content knowledge (Van Driel et al., 2001). Several PD programs have been studied to learn about the use of pedagogical content knowledge and the change in teachers' beliefs (Bell & Gilbert, 1996; NRC, 1996, Lumpe, Haney, & Czerniak, 2000).

1.2.4. Teachers' professional development

To understand teachers' professional development it is necessary to understand the underlying learning processes and the conditions that support teachers' learning (Clarke & Hollingsworth, 2002). To understand these processes, researchers should identify when, where, and how this learning occurs. Models for teachers' professional development can focus on these processes and are extremely helpful in research. Different models of teachers' professional development have been proposed over the years. While some solely focused on teachers' learning outcomes, others also took the learning processes into account. Professional development models have played an important role in changing teachers' knowledge aiming at improving student learning outcomes (Abell, 2007). Guskey (1986, 2002b) proposed a linear model of teacher change, assuming that a professional development program causes changes in a teacher's practice, which in turn leads to changes in students' learning and therefore results in changes in teachers' knowledge, beliefs, and attitude after reflection (see Figure 1.2: Guskey's model of change, 1986).

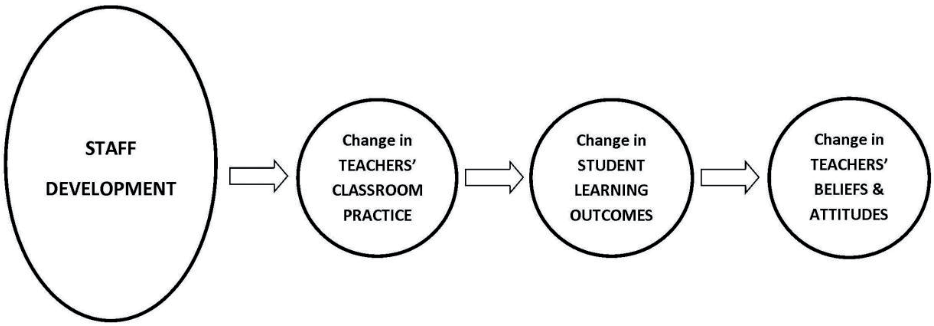


Figure 1.2. A Model of Teacher Change (Guskey, 1986, p. 7)

Other researchers, however, pointed out that teacher learning is not a linear process, but a complexity of processes where teachers are engaged in active and meaningful learning. Sprinthall, Reiman, and Thies-Sprinthall (1996) proposed a non-linear interactive model and argued that there is a close relationship between changes that occur in students' scientific conceptions and changes occurring in the conception of the teacher. Furthermore, changes in the way a teacher teaches also involves a conceptual change in the teacher's pedagogical knowledge (Posner et al., 1982). Although a number of studies have focused on the professional development of teachers, the individual professional development processes have not been studied extensively (Hashweh, 2003; Zwart, 2007). Clarke and Hollingsworth (2002) provided an interconnected model of teachers' professional growth (IMTPG), where changes in teachers' knowledge are seen as a result of active and meaningful learning. *'Teacher growth becomes a process of the construction of a variety of knowledge types (content knowledge, pedagogical knowledge, and pedagogical content knowledge) by individual teachers in response to their participation in the experiences provided by the professional development program and through their participation in the classroom'* (Clarke & Hollingsworth, 2002, p. 955). In this thesis, we define teacher learning as both a change in teachers' cognition (e.g., knowledge and beliefs) and their behaviour (cf. Zwart, Wubbels, Bergen, & Bolhuis, 2007).

The Clarke and Hollingsworth model (2002) describes domains which are not identical to Guskey's linear model (1986), but it incorporates the complexity of the process of teachers' professional growth. This non-linear model can be used as both an analytical and a predictive tool. It can also provide a theoretical background, for example by using the various domains in designing professional development programs. This model has been used as an analytical tool to study teachers' learning in secondary schools (Justi & Van Driel, 2006; Zwart et al., 2007). In the present study we used this model to measure teachers' growth. We studied how each of the PCK components changed when in-service teachers devoted time and effort to preparing, implementing, and reflecting on their teaching of science. The IMTPG was proposed by Clarke and Hollingsworth (2002) to investigate changes in four different domains. Underpinned by empirical data, the authors established four different domains: (1) the Personal Domain, which includes the teacher's knowledge, beliefs, and attitudes; (2) the External

Domain including external resources, information, or stimuli; (3) the Domain of Practice involving professional experimentation; and (4) the Domain of Consequence including salient outcomes such as students' motivation, changes in students' behaviour, or students' developing new ideas. The authors found evidence that a change in one domain causes changes in other domains. Through processes of enactment and reflection, the model suggests possible pathways for change resulting in growth networks, which in turn represent the professional growth of a teacher (see Figure 1.3). An enactment is a specific action of a teacher based on a certain belief or knowledge, such as providing students with microscopes to study the structure of cells. Reflection is seen as 'active careful consideration' (Clarke & Hollingsworth, 2002, p. 954) such as reflecting on a classroom experiment.

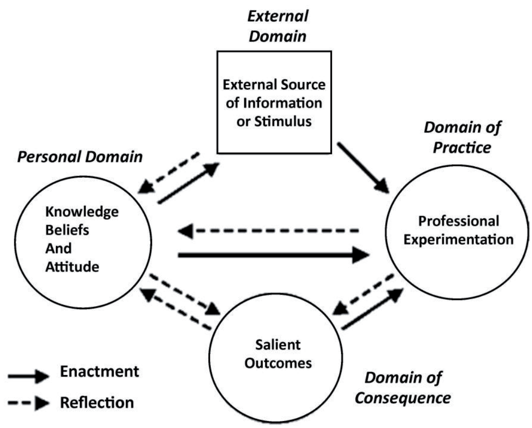


Figure 1.3. The Interconnected Model of Teacher Professional Growth (Clarke & Hollingsworth, 2002, p. 951).

1.3. The context of the study

This study was conducted within a professional development program for in-service teachers called the Mathematics and Science Partnerships program (MSP program). With support of the National Science Foundation, this partnerships program was designed to educate and support K-12 mathematics and science teachers. The MSP is a program for the different states of America; each state administers its own program, monitors progress, and documents its effectiveness, while working with the U.S. Department of Education. All MSP projects are funded by the states and report to the federal government on an annual basis. The MSP program is focused on teacher knowledge and student learning. The Mathematics and Science Partnerships program aims to improve teacher quality. The intent of the program is to increase the academic achievement of students in mathematics and science by enhancing the content knowledge and teaching skills of classroom teachers. The goals of this three-year grant-aided program were threefold: (1) to increase teachers' content knowledge; (2) to increase teachers' pedagogical (content) knowledge; and (3) to increase the teachers' use of action research. Each year a cohort of mathematics and science teachers participated in professional development activities. The partners in this particular project included the Regional offices of Education (ROE), local universities, school districts, and teachers in Southern Illinois.

1.3.1. The MSP program

During one year teachers were encouraged to conduct an action research project within their own classroom. This program started each year with a two week summer workshop called the summer institute. During the first week of the workshop, the teachers were taught how to conduct action research in the classroom. In that first week the teachers also attended mathematics and science presentations from university staff concerning 'best practices in school'. At the end of the first week the teachers had to choose a science or a math topic to focus their action research on. In the second week the teachers were able to study the literature about their topic, to study 'best practices' about teaching that topic, and to work out an action research plan. After those two weeks the teachers were asked to plan lessons based on their action research plan. In the following year, the teachers had to conduct their action research in the classroom. During that year, they met with the academic staff who functioned as their mentors and their critical friends (Ponte, Ax, Beijaard, & Wubbels, 2004). The teachers kept a progress report, an online reflective journal, and collected students' artifacts throughout the year. At the end of the year they turned in their progress report, including the lesson plans, and their students' artifacts. Some teachers took part in an interview after completing their action research. This study included three cohorts of teachers from three consecutive years.

1.4. Design and focus of the study

To study the pedagogical content knowledge of in-service teachers, we used both quantitative and qualitative approaches to study the different components of PCK. The main question of this thesis is: *What is the pedagogical content knowledge of science teachers when they prepare and conduct lessons as part of a specific professional development program to improve their science teaching and how does this PCK change when they participate in a PD program?*

To answer this question, we devised four research questions:

1. What are the orientations of science and mathematics teachers to teaching science or math in the context of a professional development program?
2. How can in-service science teachers' pedagogical content knowledge be typified at the end of a professional development program to improve their teaching?
3. What are the possible pathways that lead to changes in science teachers' pedagogical content knowledge in a professional development program?
4. What is the relation between the teachers' concerns, their orientations towards science teaching, and the inquiry-based instructional levels of inquiry when they design and conduct lessons?

Four studies were conducted using both quantitative and qualitative approaches to answer these research questions.

1.5. Relevance of the study

Research on PCK has long been the focus of numerous science scholars. Over the years many models of PCK have been introduced and used in both research and teacher education programs. We tried to contribute to this research by investigating what PCK looks like when teachers engage in a professional development program. In the last three decades, researchers have proposed PCK models with distinct components in each model. The Magnusson et al. (1999) model has often been used as a model to investigate pre-service teachers' PCK. Understanding PCK can lead to understanding what 'good science teaching' is all about and how we can foster teacher education programs which focus on developing PCK of pre-service science teachers.

1.6. Outline of the study

In the first study (aimed at the first research question; see Chapter 2) we investigated the orientations of 107 in-service science and mathematics teachers. Orientations towards teaching are seen as an overarching conceptual map that 'shapes' the other PCK components and are therefore pivotal in PCK research (Magnusson et al., 1999). Understanding these orientations can actually broaden our understanding of how teaching orientations influence other PCK components and the teachers' practice. Using triangulation of the teachers' action research plans, their lesson plans, and their reflective journal, we compiled data from three different sources to investigate this phenomenon. In this study we used a mixed-method approach to identify the various orientations and to describe these orientations. Using hierarchical cluster analyses (HCA) and principal component analyses (PCA) we tried to determine the teachers' orientations when they engage in the planning and implementation of an action research project in their own classroom.

In the second study (aimed at the second research question; see Chapter 3), we investigated the relations between the different PCK components, using the teachers' concerns and the purposes of teaching, when the teachers prepared and conducted improved lessons. In this study we used the teachers' interviews together with their action research progress reports to collect data. Using a qualitative approach we determined how teachers' concerns, teaching purposes, and the different PCK components were related to one another.

In the third study (aimed at the third research question; see Chapter 4) we investigated how the PCK components changed when the teachers engaged in action research. We triangulated the teachers' interviews, their progress reports and their reflective journals to determine the changes in their PCK. Using the interconnected model of teachers' professional growth (Clarke & Hollingsworth, 2002) we investigated how each of the knowledge components changed through processes of enactment and reflection.

In the fourth study (aimed at the fourth research question; see Chapter 5) we investigated the content of PCK in relation to inquiry-based teaching. We investigated the inquiry-based levels of instructions of science teachers in relation to their concerns, and their teaching orientation when planning and conducting inquiry-based instructions in their lessons. Teachers' progress reports, their lesson plans, and their reflective journals were used as data sources for this study. We used the model of Bell, Smetana, and Binns (2005) to determine the level of inquiry of 24 science teachers. To understand what kind of inquiry and why these teachers use inquiry to teach certain science topics, we investigated what orientations and concerns these teachers have when teaching science as inquiry.

In Chapter 6 we try to answer the main research question. We discuss the findings of the four studies in order to answer how the PCK components were related and how they changed. Finally we discuss all the findings and we make some recommendations for future research. In this chapter we also discuss the robustness of the model of Magnusson et al. (1999). For each study we used different cohorts of the MSP program. For the first study, we used all the participants of three cohorts. For the second and the third study, we used twelve science teachers from the first and the second cohort, and for the fourth study we used the third cohort of the MSP program (see Figure 1.4). We selected different data sources to answer the specific research questions of each study.

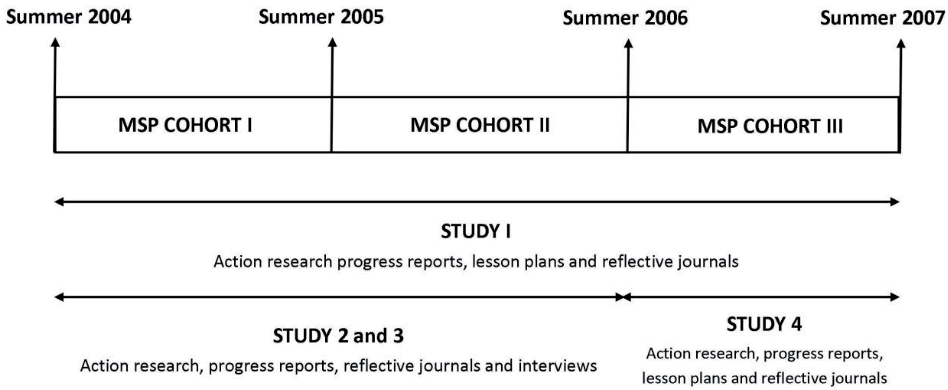


Figure 1.4. Outline of the studies in three cohorts

Chapter 2. Understanding orientations towards teaching of mathematics and science teachers in the context of a professional development program

Abstract

This study was designed to identify and characterize in-service teachers' orientations towards teaching math or science when they participated in a Summer Institute to plan action research to improve their teaching. Teachers' goals play an important role in determining their orientations towards teaching. Using resources such as teachers' plans and reflective journals during the Summer Institute, we were able to identify four major goals that determined their teaching: teaching content knowledge, teaching skills, teaching inquiry, and motivating students to learn math or science. We found three main orientations towards teaching: content-driven using student-oriented activities, content-driven using teacher-oriented activities, and skills-driven using student-oriented activities. Within these main orientations towards teaching we found that teachers have different emphases in their orientations.

Keywords: orientations toward teaching, pedagogical content knowledge

2.1. Introduction

Teachers' knowledge and beliefs play an important role in the planning and conducting of classroom teaching (Talanquer et al., 2010). Scholars have argued that teachers hold strong beliefs about teaching and learning (Abell, 2007). These beliefs 'lie at the very heart of teaching' (Kagan, 1992, p. 85). Research is therefore needed to understand the knowledge and beliefs teachers use for planning and conducting their lessons. Teachers' knowledge and beliefs have been the scope of interest in understanding their action and practice. For years, educational researchers studied pedagogical content knowledge as part of the knowledge base of teaching, aimed to help students gain a good understanding of specific subject matter (Lee & Luft, 2008; Loughran, Milroy, Berry, Gunstone & Mulhall, 2001; Loughran, Mulhall & Berry, 2008; Nilsson, 2008; Friedrichsen, Abell, Pareja, Brown, Lankford, & Volkmann, 2009; Henze et al., 2008). According to Gess-Newsome (1999a), 'PCK that helps students understand specific concepts is the *only* knowledge used in classroom instruction' (p 12) that influences the decision-making of classroom teaching. In the often cited PCK model of Magnusson et al. (1999), teachers' orientations towards teaching are based on their knowledge and beliefs of goals and purposes of teaching (Magnusson et al., 1999; cf. Grossman, 1990).

Teaching orientations play a critical role in the pedagogical content knowledge of teachers (Friedrichsen & Dana, 2005). Magnusson et al. (1999) argued that teaching orientations serve as 'conceptual maps' that guide a teacher's instructional decisions about the organisation of curricula, classroom activities, student assignments, classroom materials, and the evaluation of students' learning, and thus shape the development of teachers' PCK. Borko and Putnam (1996) state: 'attempts of experienced teachers to teach in new ways are highly influenced by what teachers already know and believe about teaching, learning, and learners' (pp. 684-685).

In this empirical study we focused on the construction of orientations towards teaching. Abell (2007) argued in her review that although orientations play a critical role in distinguishing the quality of teaching, these orientations have not been well studied. According to Friedrichsen and Dana (2005), teaching orientations are not single homologous entities and should better be presented as complex entities with central and peripheral components (p. 237). It is therefore important when investigating teaching orientations to carefully consider multiple components that are part of these orientations and factors that influence these orientations. The aim of our study was to investigate orientations toward teaching science (science teaching orientations) in the context of a professional development program. We wanted to determine what the orientations of science and mathematics teachers would be after they participated in a professional development program to improve their own teaching. To study teachers' teaching orientations, we used teachers' plans including their purposes, goals, and beliefs about teaching.

2.2. Theoretical framework

2.1.1. Science teaching orientations

The construct of PCK has been an issue of debate over the last two decades. After Magnusson et al. (1999) proposed a model of the PCK construct, many scholars have used and discussed this model in their own research. One component called the orientation of science teaching has been heavily debated due to the lack of consensus about its definition (Friedrichsen et al., 2011). Abell (2008) noted that orientations towards science teaching also have been called: conceptions of teaching (Hewson & Hewson, 1987, 1989; Meyer et al., 1999) or preconceptions of teaching (Weinstein, 1990). The pivotal role of this PCK component lies in the decision-making behind the planning and conducting of classroom teaching and reflection upon it.

Following Grossman (1990), Magnusson et al. (1999) defined orientations as teachers' knowledge and beliefs based on the purposes and goals of science teaching. Teaching orientations are also considered ‘general views about teaching’ (Anderson & Smith, 1987; Magnusson et al., 1999). Magnusson et al. (1999) presented nine different orientations distilled from the research literature on science teaching: (1) activity-driven; (2) didactic; (3) discovery; (4) conceptual change; (5) academic rigor; (6) process; (7) project-based; (8) inquiry; and (9) guided inquiry (see Table 2.1).

Table 2.1.
The nine orientations toward science teaching proposed by Magnusson et al. (1999)

Orientations toward science teaching	Description
Process	Help students develop the ‘science process skills’
Academic rigor	Represent a particular body of knowledge
Didactic	Transmit the facts of science
Conceptual change	Facilitate the development of scientific knowledge by confronting students with contexts to explain that challenge their naïve concepts
Activity-driven	Have students be active with materials, ‘hands-on’ experiences
Discovery	Provide opportunities for students to discover targeted science concepts on their own
Project-based science	Involve students in investigating solutions to authentic problems
Inquiry	Represent science as inquiry
Guided inquiry	Constitute a community of learners whose members share responsibility for understanding the physical world, particularly with respect to using tools for science

The proposed orientations are identified based on two elements: ‘the goals of teaching science that a teacher with a particular orientation would have, and the typical characteristics of the instruction that would be conducted by a teacher with a particular orientation’(p. 97). Magnusson et al. (1999) argued that a teacher’s orientation should not be distinguished by the use of a particular strategy, but by the *purpose* of using this strategy. In this study, we therefore investigated both the teachers' goals of teaching science, or mathematics, and their intended use of instructional strategies to understand their orientations to teaching.

Friedrichsen and Dana (2003, 2005), who studied experienced biology teachers, reported that science teaching orientations play a critical role in understanding the development of PCK. In their study, the teachers held multiple orientations, influenced by multiple factors, including their beliefs about learners and learning, their prior work experiences, professional development, the classroom context, and time constraints. The use of both peripheral and central goals represented the complex nature of science teaching orientations. Central goals such as 'develop environmentally based decision-making ethics' or 'develop skills and techniques to explore scientific questions' dominated the teacher's thinking and drove the instructional decision-making process. The peripheral goals such as 'develop science process skills' and 'develop laboratory skills' can be seen as supportive to the central goals. Furthermore, Friedrichsen and Dana (2003) found that their biology teachers held different teaching orientations for each course they taught. In a later study, Friedrichsen et al. (2011) mentioned the importance of considering the Hodson (1992) goals for science education when studying teaching orientations. Hodson (1992) distinguished three different types of goals of science education: (1) *learning science*, having students acquire conceptual knowledge; (2) *learning about science*, having students develop an understanding of the nature of science; and (3) *doing science*, having students engage in scientific inquiry and problem-solving.

Koballa, Glynn, Upson and Coleman (2005) presented five 'conceptions about science teaching,' held by science teachers: (1) presenting science content to students; (2) providing students with a sequence of science learning experiences; (3) engaging students in hands-on science activities; (4) facilitating the development of students' understanding about science;

and (5) changing students' science-related conceptions. Koballa et al. (2005) found that teachers' conceptions about science teaching guided their instructional decision-making and were consistent with their teaching practice. While the teachers held one main conception of science teaching, it was possible to hold various conceptions simultaneously. When the teachers attempted to implement 'new' instruction, it created tensions with their existing conceptions about science teaching. The teachers' conceptions about science teaching were formed by their prior experiences and acted as barriers to considering 'new' conceptions about science teaching.

Talanquer et al. (2010) studied teacher candidates' preferences for instructional activities and found that the orientations of these candidates were driven by three central goals: (1) motivating students; (2) developing science process skills; and (3) engaging students in structured science activities. Talanquer et al. (2010) therefore described three orientations towards teaching: 'motivating students', 'process', and 'activity-driven'. Of these three, the last two had also been identified by Magnusson et al. (1999). Motivating students, however, seems like a new orientation towards teaching.

2.1.2. Mathematics teaching orientations

In mathematics education literature, Thompson, Philipp, Thompson, and Boyd (1994) stated that an orientation towards mathematics teaching includes the teachers' knowledge, beliefs, and values about mathematics and mathematics teaching. Thompson et al. (1994) distinguished two major orientations: a conceptual orientation and a calculational orientation. The conceptual orientation is mainly driven by a teacher's way of thinking on how students should develop into productive ways, taking into consideration materials, activities and student engagement . On the other hand, the calculational orientation entails teacher's actions driven by the application of calculations and procedures for obtaining numerical results. This does not mean, however, that the teacher is only focused on computational procedures, but rather that he or she has a rather inclusive view of mathematics as being about 'getting an answer' (p. 7).

Andrews and Hatch (1999) identified five conceptions or perspectives of mathematics teaching: (1) process-oriented; (2) skills-oriented; (3) focus on the individual child; (4) collaborative and cooperative; and (5) the importance of a mathematically enriched classroom. The process-oriented conception can be seen as a social construction where students are encouraged to develop their own ideas. The skills-oriented conception has an emphasis on routine practice of skills and whole class teaching where 'pupils can gain autonomy through their regular practice of routine techniques and the acquisition of mental skills' (p. 217). The conception of the individual child rejects the idea of children working on the same task. In this conception children work individually to develop relational understanding. In the cooperative and collaborative conception, the emphasis lies on the interpersonal classroom that scaffolds children's learning. Lastly, the creation of a mathematically enriched classroom is manifested by posting mathematical material such as posters in and around the classroom to encourage individuality of expression. In several studies we found reports of mathematics teachers who focused on inquiry-oriented teaching (Towers, 2010). Towers (2010) found that many beginning mathematics teachers do not have a lot of inquiry experience in their own 'educational histories' (p. 259). Mathematics teachers who used inquiry-based materials enhanced student achievement and mathematical understanding, as well as attitude and motivation (Boaler, 1998; Hickey, Moore & Pellegrino, 2001).

In the present study we investigated the orientations toward teaching of in-service mathematics and science teachers. Following the findings of orientations toward teaching in both the science and mathematics education literature, we created a program where teachers had to think about teaching a lesson they thought needed improvement. Within this context we studied the teaching orientations of these teachers. Using a quantitative approach we aimed to increase our understanding of teaching orientations of in-service teachers.

2.2. The context of the study

This study was conveyed in a professional development program called the mathematics and science partnership program. One of the goals of this program was to have teachers rethink the teaching of specific subject matter in their classroom to increase the performance of their students. The MSP program started with a two-week summer session. In the first week of the summer course, the teachers selected a topic that they wanted to teach the following year and wrote down their concerns about teaching this topic. They also wrote down their goals and purposes for their lessons. In the second week they attended presentations from university staff, had peer discussions about their teaching, and did literature research on the teaching of their topic. At the end of the second week they created a plan including the instructions they intended to use and justified how these instructions would help their teaching. The teachers were given time at the Summer Institute to reflect on their progress each day and to write down their reflections in a journal.

To study the orientations towards teaching of mathematics and science teachers, we investigated how the goals and purposes of teaching were related to the instructions the teachers intended to use in their plans. We used both the teachers' plans and their reflection report to study orientations towards teaching. By creating a more holistic view (Friedrichsen & Dana, 2005), we hoped to understand why science and mathematics teachers hold certain orientations and how these orientations drive their decisions on curricula, instructional strategies, and student assessment.

2.3. Method

2.3.1. Research question

The central question in this study was: *What are the orientations of science and mathematics teachers to teaching science or math in the context of a professional development program?* We used the mixed-methods sequential explanatory design (Creswell, Plano Clark, Gutmann, & Hanson, 2003) to study the orientations to teaching of both mathematics and science teachers. This design is characterized by the collection and analysis of quantitative data followed by the collection and analysis of qualitative data within a single study. The rationale for using this design is the idea that neither quantitative nor qualitative methods are sufficient, by themselves, to capture the understanding of orientations towards teaching. However, in combination, quantitative and qualitative methods complement each other and allow for a more robust analysis, taking advantage of both their strengths. In our study we used this design in two phases. In the first phase, we collected and analyzed the quantitative (numeric) data. Then we collected and analyzed the qualitative (text) data to further understand the quantitative results obtained in the first phase (Steckler, McLeroy, Goodman, Bird, & McCormick,1992). The results of this study are a product of both methods.

2.3.2. Participants

All of the 107 in-service math and science teachers who participated in the three cohorts of the MSP were included in this study. Fifty-four science teachers and fifty-three math teachers were included. The average years of teaching experience was 12.9 (SD = 9.1). The teachers were all located in schools in the Mid West of Illinois. All schools participating in this program had to comply with the learning and teaching standards of the Illinois State Board of Education. All teachers participated in the two-week Summer Institute described above. Teachers who relocated to another school out of the area after the Summer Institute were not included in the study, because they were not able to complete their classroom project.

2.3.3. Data collection

During a two-week Summer Institute the teachers completed an action research plan to improve the teaching of a selected science or mathematics topic. Each teacher could choose his or her own topic for an action research classroom project. In their plans, the teachers wrote down their teaching goals and their purposes for teaching this topic and explained why they focused on these goals and purposes. They also included the instructional strategies they intended to use to reach their teaching goals. We used the teachers' plans and their reflective journals as our data to study the teaching orientations of the participants.

2.3.4. Data analysis

Following a sequential explanatory design , we first collected the teachers' statements from their teaching plans concerning their beliefs and knowledge of the goals and purposes of their teaching as well as the instructions they intended to use in their teaching. We used an open coding approach (Corbin & Strauss, 2003) to code the different statements. We first coded the goals and purposes of their teaching and then coded the nature of the instructions they intended to use to serve those purposes.

Two independent researchers coded the statements of the teachers. To develop a category system to code all data, both authors independently labelled the statements of twelve randomly selected teachers. In an open coding process, data saturation, where no additional codes emerge, is usually reached after twelve participants (Guest, Bunce, & Johnson 2006). Next, the two researchers discussed the codes found and decided which codes to use in the study. Codes with similar content were merged into one code. Then the researchers coded the remaining data of the 95 teachers. An inter-rater reliability (Cohen's kappa) was calculated for the codes on both purposes and goals, and intended strategies (see table 2.2.).

For the purposes and goals, the following codes were used:

Table 2.2.
Codes for purposes, goals and intended strategies

Variables	**Explanation**
Purposes and goals[a]	
P1: content	focus on content with the purpose of increasing students' content knowledge of math or science
P2: skills	focus on skills with the purpose of developing students' process skills in math or science
P3: inquiry	focus on inquiry with the purpose of developing inquiry skills in math or science
P4: motivation	focus on student's motivation with the purpose of increasing students' interest in learning math and science
Intended strategies[b]	
S1: lecture	use of didactic approaches such as direct teaching, lectures and classroom demonstrations
S2: hands-on	use of hands-on activities, such as drawing, cut and paste, computer assignments, internet, game boards etc
S3: experiments	use of classroom or lab experiments
S4: projects	use of inquiry-based projects such as projects and project investigations etc

Note. a: Cohen's kappa = .87; b: Cohen's kappa = .91

After we coded all the data, we determined the frequencies of the codes for the goals and the intended (or preferred) instructional strategies for each teacher. These frequencies were used as quantitative data for statistical analyses. To study possible relationships between the teachers' goals and their preferred instructional strategies, we used two types of statistical analyses for this study. First, we used hierarchical cluster analysis (HCA) on the whole group of teachers to explore whether they could be divided into homogenous subgroups (so-called clusters). HCA divides teachers into various groups based on distinctive characteristics or patterns, which in this case refer to the teachers' goals and their intended instructional strategies. Teachers' membership of a cluster was determined by using HCA to label the participating teachers (Van Driel, Verloop, Van Werven, & Dekkers, 1997) and to determine the clusters consisting of homogenous subgroups with similar patterns. Second, we used an exploratory technique, PRINCALS, to explore the possible relationship between the teaching goals and the instructional strategies. PRINCALS is essentially the same as Principal Component Analyses, with the difference that PRINCALS allows categorical data to be explored (De Heus, Van der Leeden, & Ganzendam, 1995). PRINCALS allows data to be plotted in an n-dimensional manifold, where the underlying structure of both objects (teachers) and variables (goals and intended strategies) in relation to each other is revealed in a biplot (Van Driel et al., 1997). A biplot is a two- or three-dimensional image where objects (teachers) are represented by points, and variables (goals and intended instructional strategies) as vectors (Gifi, 1990, p. 191). When the points are closely situated to each other, this indicates that the teachers may have similar orientations. Vectors pointing in the same direction indicate a stronger relationships between the variables they represent. The position of a point with respect to a certain vector indicates how a teacher's orientation is related to a certain goal or instructional strategy. Using HCA in combination with the PRINCALS manifold resulted in cluster areas of teachers with similar orientations. A 'cluster area' can be defined as a place in the biplot where the points (teachers) belonging to a particular cluster are displayed (Van der Rijst, 2009).

2.4. Results

Using PRINCALS we found two dimensions that accounted for 66 % of the variation of the data. PRINCALS, also generated a table with the component loadings of all the variables (the goals and the instructional strategies) on these two dimensions (see Table 2.3). From this table, PRINCALS used the coordinates of each variable to generate a two-dimensional plot showing the goals and instructional strategies in graphic form (see Figure 2.1).

Table 2.3.
The loadings of the purposes of teaching (P) and the intended instructional strategies (S), on two dimensions

Variables	Dimension	
	1	2
P1: content	.392	.796
P2: skills	-.45	-.730
P3: inquiry	-.491	.595
P4: motivation	-.424	-.346
S1: lecture	.856	.023
S2: hands-on	.762	-.203
S3: experiments	-.859	-.056
S4: projects	-.734	.510

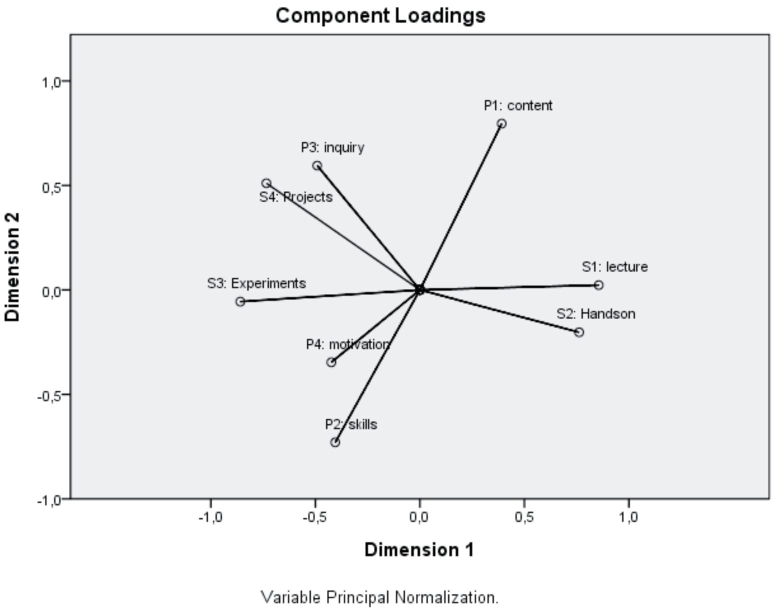
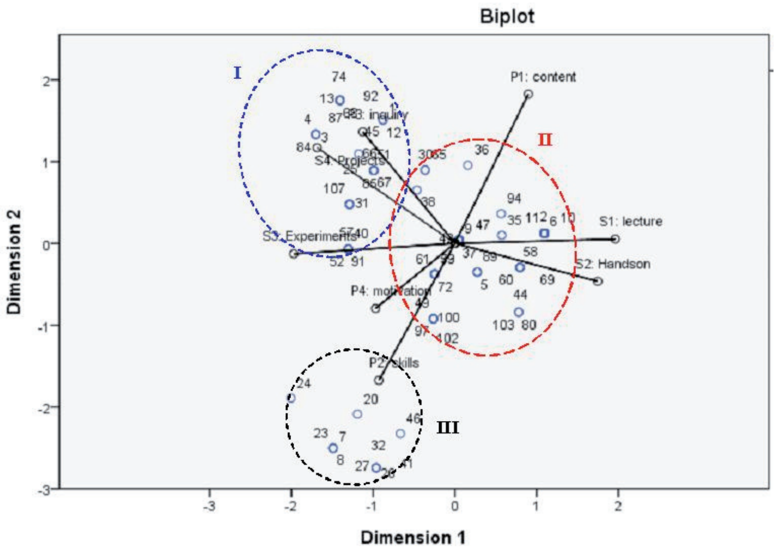


Figure 2.1. Graph of the purposes of teaching (P) and the intended instructional strategies (S), explained in two dimensions.

The vectors of the eight variables that represent the teachers' orientations are also plotted on both dimensions in Figure 2.1. The teachers' intended instructional strategies are best explained by dimension 1. The teachers' intended instructional strategies 'experiments' and 'project work' are found on the left part of this dimension, whereas 'lecture' and 'hands-on' are positioned on the right part. From this dimension we interpreted that the left part predominantly explained student-regulated strategies, whereas the right part explained the use of teacher-regulated strategies. Although hands-on can be seen as a student-centered strategy, we interpreted it to be regulated by the teachers in the classroom, which is why it is found on the right part of the plot (see Figure 2.1). This means that although students were actively involved in the hands-on activities, these activities were selected and regulated by their teachers. We believe that dimension 2 explains the position of the teachers' goals: 'teach content knowledge' and 'teach inquiry' are positioned in the upper part, whereas 'teach skills' and 'motivate students' are found on the lower part of dimension 2.



Note. I, II, III are clusters with different main orientations.

1, 2, 3, etc. are the teachers in the study.

Figure 2.2. Dispersal of teachers belonging to a main orientation achieved by using PRINCALS and HCA.

Using both HCA and PRINCALS, to locate subgroups of teachers in the two-dimensional space, we found three main clusters representing three main orientations. Figure 2.2 shows that cluster I is low in dimension 1 and high in dimension 2, which indicates that teachers in this cluster focused on learning science or math using student-regulated activities. Cluster II is high in dimension 1, which indicates that these teachers were mostly using teacher-regulated activities. No real preference was found in their goals, indicating that they were both interested in teaching math or science content, and also how to do math or science. Cluster III is low in both dimensions indicating that their focus was on doing science or math using student- regulated activities. HCA provided three homogenous groups (see dotted circles in Figure 2.2) of teachers with similar scores on both variables, which we identified as three main orientations:

I. Content-driven with student-oriented activities.
II. Content-driven with teacher-oriented activities.
III. Skills-driven with student-oriented activities.

Within each cluster, we also found subgroups of teachers with particular emphases in their orientation. We elaborate on these orientations using teachers' data to explain each group.

Orientation I: Content-driven with student-oriented activities.

Seventeen science teachers and three math teachers were included in this group. These teachers had the same orientation: to teach content knowledge using experiments or classroom project designs. Their main focus was on teaching content knowledge. Within this cluster we saw, however, that teachers had different emphases in their orientation. Some teachers intended to teach inquiry for the students to learn the content, whereas others intended to focus more on experiments. These emphases appeared to emerge from different concerns resulting in multiple goals. The following is an example of a teacher who wanted to teach her students science content and to teach inquiry: *'I want to see improvements in my students' knowledge about Shawnee National Forest Issues and some possible solutions* *to these issues. The problem is that my students are not problem-solvers nor self-thinkers. My plan is to use inquiry-based learning. Inquiry-based learning will keep my students excited about learning while retaining the information.' (reflective journal of teacher 4)*. Teacher 4 was concerned that since her students were not problem-solvers, they therefore lacked content knowledge. This was different, however, for the next teacher we found in the same cluster: *'I have noticed that students may do well on chapter tests, but when I refer back to the material later in the year, there is no retention of the material. My guess is there was never any real depth of understanding. To increase that depth, I think hands-on, minds-on materials will help in addition to not teaching as many topics and slowing down. Another problem I have is I think my lack of enthusiasm for science transfers to my students. By having them do experiments and observations, their enthusiasm and motivation to retain the knowledge will grow together.' (reflective journal of teacher 91).* Teacher 91 was concerned about her students' lack of content knowledge because they could not apply their previous knowledge as they proceeded in the curriculum. We found teachers who had the same main orientations but their additional goals 'learn inquiry to retain knowledge' (teacher 4) or 'motivate students to engage in experiments to retain knowledge' (teacher 91) resulted in different emphases in their orientations. Figure 2.2 shows teacher 4 in the upper part of cluster I, while teacher 91 is positioned at the lower part of this cluster.

Orientation II: Content-driven using teacher-regulated activities.

Twenty-eight science teachers and forty-six math teachers were found in this group. These teachers intended to teach math or science content using classroom lectures and supplementing these lectures with hands-on activities. From their plans we found that these hands-on activities were all teacher-regulated. In their plans, the teachers also stated that they were concerned about students' poor knowledge of the math or science topic and students having difficulties understanding the concepts related to this topic. These teachers stated that (teacher-regulated) hands-on activities should increase students' knowledge. The teachers intended to use classroom material that would support their lectures. We also found teachers with different emphases in this orientation. Some teachers intended to have students learn science or math by introducing classroom discussions, which were led by the teachers. They believed that when students are more involved, they are more willing to learn science or math. Example: *'In my enhanced lessons the focus shifts from that of the conventional classroom through use of discussion, questioning, and requests for pupils to explain their ideas, conjectures, and reasoning.' (reflective journal of teacher 30).* Other teachers with a different emphasis were those who focused solely on teaching math or science concepts using lectures and hands-on activities. Example of a math teacher: *'I think geometry works best when it is hands-on. With the use of technology, students will be able to better visualize the concepts.(reflective journal of teacher 2).* Another teacher stated that students had a hard time understanding the concepts because they lacked visualization capabilities. This teacher believed that if the students could visualize concepts or processes they would be able to understand these concepts and processes. Example*: 'I plan to use the digital projector to introduce each of the sections of geometry. The students will be able to visualize and experience concepts that have been very difficult to get across using a chalkboard. Geometry has been a low point of understanding for 7th grade students for a long time. I think the use of the digital projector would be a definite help.' (reflective journal of teacher 10).* Another variation was the emphasis on teaching math or science skills together with content using hands-on activities: *'I want my students to work with more 'hands-on' type materials and technology to improve their retention of geometry skills. I feel this would help them retain more geometry if they can physically manipulate the media being used.' (reflective journal of teacher 49).* Some other teachers had a different emphasis based on an additional goal: to motivate students to learn science or math. They believed that when students are motivated, they are more willing to learn science or mathematics content knowledge. Example: *'I am wanting to get the students involved and excited about Earth*

Science. By introducing new things to the students, they will increase their enthusiasm for learning science in the classroom.' (reflective journal of teacher 65).

Orientation III: Skills-driven using experiments.

Four math teachers and nine science teachers formed cluster III. This third group of teachers differed from the first two groups because their orientation was mainly focused on teaching mathematical or science skills. They believed that experiments are good strategies to increase those skills. Their concern was not so much on what students need *to know about math or science*, but more on *doing math or science* (cf. Hodson, 1992). Their concerns were primarily focused on the fact that their students had poor skills in math or science. They believed that students can achieve more and better when they have the necessary process skills: *'I wanted my students to have more skills to apply scientific concepts to the real world to make science relevant to them. I wanted the students to be able to collect data and organize it to be relevant to conduct research… I was able to teach the necessary skills for using microscopes that will hopefully carry over into other areas of science education. Also, I was able to teach them how to conduct experiments through an investigation of a 'crime scene'. (reflective journal of teacher 32).* Another teacher intended to use experiments to teach students about using graphs: *'I need to provide students with a greater diversity of experiences with using graphs in Biology I.'(reflective journal of teacher 7).* In this group of teachers we found no meaningful variation in their orientation, that is, they all had the same emphasis in their orientation: to teach skills.

2.5. Conclusions and discussion

From the literature we found that there is ambiguity about teaching orientations. Teaching orientations are not only described as 'knowledge and beliefs about the purposes and goals' (Grossman, 1990; Magnusson et al., 1999) but also as 'general views about teaching' (Anderson & Smith, 1987; Magnusson et al., 1999). It is because teachers' beliefs are hard to define, that orientations are still messy constructs (Friedrichsen & Dana, 2005; Friedrichsen et al., 2011). In our study, we found that to gain a better understanding of teachers' orientations, it was not sufficient to only determine their knowledge and beliefs about goals and purposes, but it was also imperative to study the intended strategies that served their goals (Magnusson et al., 1999). We found that each teacher had different goals and specific intentions of using instructional activities that lead to specific orientations. However, when analyzing these different goals and intended instructional strategies, we were able to cluster these orientations into three distinct teaching orientations: content-driven with student-oriented activities, content-driven with teacher-oriented activities, and skills-driven with student-oriented activities. Within each of these main orientations we found that the teachers' individual orientations differed. These differences relied on the emphasis found within the orientation based on additional goals or beliefs of the teacher. Earlier studies on teachers' orientations have mentioned that in-service biology teachers' orientations differ because they hold multiple goals referred to as main goals and peripheral goals (Friedrichsen & Dana 2003, 2005). Friedrichsen & Dana (2005) noted that both the main goals and peripheral goals must be taken into consideration when investigating teaching orientations. These studies were conducted on a small number of teachers and they did not mention any similarities or differences between the orientations. We do however support their statement that teachers' orientations contain multiple goals.

We found the Hodson goals (1992) to be important when studying teaching orientations. In our study we found similar goals in different perspectives. The first goal we encountered was *learning science or mathematics content*, which was one of the Hodson's science goals. Hodson's second science goal, *doing science,* was divided into two separate goals in our study: *doing science or mathematics*, which involved learning basic skills, such as 'microscopy' in science; and 'balancing equations' in mathematics and *inquiry*, which involved students following the steps of doing scientific or mathematical inquiry. We did not encounter the Hodson's third goal : *learning about science*. However, we did find a fourth goal: *motivating students to become interested in science or mathematics*. This goal was mentioned by 27 teachers as an important goal and was therefore included as a separate goal in this study. We found teachers with this goal in all three clusters. We believe that when investigating teaching goals, the science goals mentioned by Hodson (1992) as well as 'motivating students to become interested in science or mathematics' should be considered as important goals in future research.

2.5.1. Motivation

Figure 2.1 shows that learning science or math *content* is mostly explained in the upper part, where as *doing* science or math is explained in the lower part. Inquiry as a goal is seen here as part of learning science or math content. Motivation, however, is found between the clusters (see Figure 2.2), meaning that all the clusters had teachers who had motivation as an additional goal. Talanquer et al. (2010) identified 'motivating students' as a separate orientation. In our study, we found that 'motivating students' was not a separate orientation but more a teaching goal. This goal was usually found in combination with another goal leading to different emphases of the orientation. For example, where one teacher responded that she intended to motivate her students to learn specific science concepts (cluster I), another responded that she needed to motivate the students to practice skills to be used in their daily lives (cluster III). Magnusson et al. (1999) did not mention any orientation or goal that relates to students' motivation, but this goal seemed to be an important goal in teachers' orientations towards teaching science or mathematics in our study.

When comparing the orientations of the mathematics and the science teachers, we found that the content-driven orientation with student-oriented activities was dominated by the science teachers. When investigating goals of teachers, we found that inquiry as a goal was mostly found with the science teachers and less with the mathematics teachers. It seems that although mathematics teachers are becoming more inquiry-minded, it is not as common as an inquiry orientation in science teaching. Although research has shown that mathematics educators and researchers have pleaded for more student-oriented activities such as inquiry, the majority of the mathematics teachers in this sample still firmly believed in traditional teaching (Towers, 2010; Jacobs et al., 2006; Stigler & Hiebert, 2004). Although we found a majority of 46 mathematics teachers who used teacher-centered activities (cluster II), we also found 3 mathematics teachers who engaged in inquiry (cluster I) and 4 math teachers who used student-centered activities to practice skills (cluster III).

2.5.2. The Magnusson et al. (1999) orientations

Magnusson et al. (1999) presented nine different orientations distilled from the science education literature. While some scholars have used these orientations in their studies, other researchers have argued that, in practice, teachers do not hold one single orientation, but have multiple orientations (Friedrichsen & Dana, 2005). Friedrichsen and Dana (2005) mentioned that because teachers hold multiple goals they have different orientations. In our study we found that teachers did indeed have multiple goals and multiple strategies which resulted in a complex orientation. However, Magnusson et al.'s (1999) orientations can be traced in our study. Examining the orientations 'academic rigor' and 'didactics' more closely, Magnusson et al. (1999) referred to these orientations as focused on transferring content knowledge. In our study these orientations would be considered content-driven using a teacher-oriented approach (cluster II), while Magnusson et al.'s (1999). orientation 'discovery' may be considered content-driven with a student-centered approach (cluster I). The Magnusson et al. (1999) orientations have been used in plenty of other studies, but empirical studies such as this one are needed to retest and re-examine them. Revisiting these orientations in empirical studies could provide them with clear and complete descriptions making them fit for future research.

2.5.3. Mathematics orientations

Thompson et al. (1994) presented two main orientations: conceptual orientations and calculational orientations. Both of their orientations reflect the main orientations found in this study: content-driven and skills-driven. Thompson et al. (1994) explain the conceptual orientations as the way a teacher acts to 'develop conceptual understanding' with students. This 'development of conceptual understanding' is found in our study as a content-driven orientation. However, we did make a distinction in that teachers can focus on content with either the intention of teaching this content in a teacher-centered way or in a student-centered way. On the other hand, the calculational orientations of Thompson et al. (1994) involve the skills that produce results, that is being able to do mathematics. In our study, this orientation mostly resembled our skills-driven orientation. Other orientations found in the mathematics literature can also be traced in our study. From the five conceptions of secondary mathematics teachers found in the study of Andrews and Hatch (1999), two conceptions resemble the orientations in our study. Their process orientation contains an understanding of students understanding their own concepts, and thus relates to content knowledge, whereas another of their mathematical conceptions involves a skills orientation, which is similar to our skills-driven orientation. The other three orientations in the Andrews and Hatch (1999) study focus on individual learning, collaborative/cooperative learning, and on classroom orientation. In our study we did not find explicit orientations where teachers were concerned about individual or group learning nor an orientation on the classroom.

2.6. Implications

2.6.1. Implications for professional development

When planning professional development programs aiming to improve science or mathematics teaching, it is important to consider teaching orientations. Determining teaching orientations may be complex, but these orientations play an important role in teachers' pedagogical content knowledge. When investigating teachers' PCK in a professional development program, it is important to understand the teachers' orientations and why they have these orientations. During the PD program, teacher educators can influence the orientations in order to help 'shape' other PCK components. If teacher educators want to influence science teachers' PCK, therefore, it may be helpful to understand the science teaching orientations of the teachers. Teacher educators may want to study the teachers' lesson plans to determine what goals and intended instructional strategies the teachers have to understand their orientations to teaching.

2.6.2. Implications for future research

We recommend more empirical studies on teaching orientations for mathematics and science teachers. It is imperative to investigate teaching orientations using a broader perspective than just the definition used by Magnusson et al. (1999). While Magnusson et al. (1999) took into consideration teachers' 'knowledge and beliefs of goals and purposes of science teaching'(p. 97) to describe their science teaching orientations, they also stated that: 'it is not the use of a particular strategy but the *purpose* of employing it that distinguishes a teacher's orientation to teaching science' (p. 97). In our study we took into consideration the teachers' goals and purposes of teaching math or science as well as their knowledge and beliefs about science and mathematics teaching strategies. Empirical studies are needed to determine whether more factors, other than the goals and instructional strategies, are important to understanding orientations to teaching. In a recent article, Friedrichsen et al. (2011) urged that the nature of science be taken into consideration. They also suggested investigating the relations between teaching orientations and other PCK components. Knowledge about the curriculum and knowledge of assessment are also important features in the PCK development as well as the teachers' knowledge about students' learning.

We also suggest that there is a need for in-depth empirical investigation of teachers' main orientations rather than only focusing on the single orientations found in the Magnusson et al. (1999) study. Main orientations refer to general orientations. These general orientations can be concretized into teachers' individual orientations based on their particular emphases. To understand these particular emphases in science teaching orientations, it is imperative to study the teachers' additional goals and their intended instructional strategies. Furthermore, it is also important to study how these orientations 'shape' the other PCK components.

Chapter 3. Typifying science teachers' pedagogical content knowledge based on their concerns and their purposes in science teaching

Abstract

This chapter reports on an investigation of science teachers' pedagogical content knowledge (PCK). Even though the PCK representations were different for individual teachers, these representations could be typified by what the teachers see as their purposes in science teaching. In this paper we discuss three different types of PCK based on teachers' concerns and their ideas on the purposes of teaching. PCK type I focused on the learning of science process skills, type II on learning science content, and type III on motivating students to learn science. When teachers were seeking ways to improve their teaching, the PCK components interacted strongly with their concerns and purposes and thus typified the teachers' PCK.

Keywords: pedagogical content knowledge, purposes, concerns, science teaching

3.1. Introduction

It is generally agreed that students find science subjects difficult (Tsui & Treagust, 2010). Furthermore, science teachers find that students are bored with science (Ebenezer & Zoller,1993; Delpech, 2002), and question its relevance to their lives (Ramsden, 1998). It is within these contexts that science teachers are constantly challenged to make science comprehensible and interesting for their students. To do this, teachers need to change and develop their pedagogical content knowledge (Shulman, 1986), a distinctive body of knowledge necessary for classroom teaching (Kind, 2009). According to Gess-Newsome (1999a), 'pedagogical content knowledge that helps students understand specific concepts is the only knowledge used in classroom instruction' (p. 12) and therefore an important factor in the design and conduct of teaching situations that can improve student learning (Abell, 2008). Various researchers have studied PCK by introducing different components of PCK (Grossman, 1990; Marks, 1990; Magnusson et al., 1999; Halim & Meerah, 2002; Dawkins & Dickerson, 2003; Viiri, 2003; Van Driel et al., 2002). Hashweh (2005) cautioned that there is actually no consensus among researchers about what components or (sub)categories are included in this concept. He explained that in many PCK studies the various components are described in an isolated or static way, leading to a fragmented approach to this concept. Hasweh (2005) pleaded for a more a dynamic concept of PCK, with research focusing more on the interrelations between the PCK components. In one of the few studies in which PCK was investigated as a dynamic concept (Lee & Luft, 2008), PCK representations were constructed by describing how different PCK components were related to each other. Lee and Luft (2008) found that although each teacher holds a unique PCK, there are common elements among the various PCK representations. They concluded that teachers have different types of PCK at different points in their career and that further research on these types should be pursued (p. 1360). Henze et al. (2008) studied the development of PCK in a group of senior science teachers when they started teaching a new syllabus. They found two types of PCK related to the purposes of teaching science. Their purposes of teaching science were adapted from Hodson (1992) and Justi and Gilbert (2002).

Johnson and Ahtee (2006) stated that PCK conceptualizations are often based on teachers' intentions and ideas, as well as their concerns about physics teaching and about certain teaching activities. These concerns included explaining abstract scientific phenomena to students and interesting them in physics activities. Teachers' concerns were used in another study where teachers had to plan lessons based on their concerns related to their professional knowledge (Berry, Loughran, Smith, & Lindsay, 2008). To elicit understandings of professional knowledge, Berry et al. (2008) analysed cases developed by science teachers about concerns related to their practice (p. 579). Other researchers believe that science teaching orientations play an important role in shaping teachers' PCK. (Friedrichsen & Dana, 2005; Magnusson et al., 1999). These orientations include goals and purposes in teaching science (Grossman, 1990). In a series of studies in which Friedrichsen and Dana (2003, 2005) investigated science teachers' orientations towards teaching, it became apparent that in-service teachers referred to their prior work experiences as a major influence in directing their goals and purposes for teaching science.

When examining in-service science teachers' PCK, we need to consider their classroom experiences. In-service teachers take these experiences into account when they plan new lessons for teaching. The teaching concerns, teachers' goals, and purposes in teaching science are therefore important features in the conceptualization of teachers' PCK. In this study we investigated the pedagogical content knowledge of experienced science teachers who were trying to improve their classroom teaching. By focusing on similarities and differences between these teachers' PCK, we tried to identify specific types of PCK. In particular, we investigated how factors such as teachers' intended goals, their purposes in teaching and their teaching concerns influenced the construction of these types.

Reconstructing PCK as an interrelated concept linked to teachers' concerns and teaching purposes could increase our understanding of why teachers use certain PCK to make classroom decisions (Lee & Luft, 2008) and could inform teacher educators how to facilitate pre-service science teachers to construct their own PCK. Understanding how this PCK is actually being used could inform professional development programs aimed at enabling science teachers to make learning science easier and more interesting for their students.

3.2. Theoretical framework

3.2.1. The PCK model of Magnusson et al. (1999)

To understand the interrelations between various PCK components, we used the PCK model of Magnusson et al. (1999). Magnusson et al. (1999), based their model on the findings of Grossman (1990) and described five different components in their PCK model: (1) orientations toward science teaching; (2) knowledge and beliefs about the science curriculum; (3) knowledge and beliefs about the students' understanding of specific science topics; (4) knowledge and beliefs about assessment in science; and (5) knowledge and beliefs about instructional strategies for teaching science (see Figure 1.1). Magnusson et al. (1999) argue that the PCK components interact in highly complex ways, and that in order to examine PCK it is of crucial importance to understand how these interactions occur and how they influence classroom teaching. In the conceptualization of PCK in this study we used Magnusson et al.'s (2009) model as a basis from which to understand how these components are linked when a teacher uses a certain type of PCK to teach a specific science subject. Since we were interested in the relations between PCK components, this particular PCK model was most appropriate for the purpose of our study.

3.2.2. Goals and purposes for teaching science

Magnusson et al. (1999) stated that the component 'orientations toward science teaching' serves as a 'conceptual map' that 'shapes' the other PCK components and is, in turn, influenced by those components. We believe it is important to focus on teachers' goals and purposes if we are to construct PCK representations that science teachers actually use in their classroom to improve the teaching of a specific subject.

In an earlier study Hodson (1992) emphasized three major goals in science teaching based on the nature of science: (1) *learning science*; (2) *learn to do science*; and (3) *learning about science*. In *learning science* the focus is on developing conceptual and theoretical knowledge, taking into account students' understanding of science. *Doing science* means *'engaging in and developing expertise in scientific inquiry and problem-solving'* rather than merely *'following a set of rules that requires particular behaviours at particular stages' (p. 550)*. Hodson describes *learning about science* as students developing an understanding of nature and being aware of the complex interactions between science and society.

When studying pedagogical content knowledge it is important to take teachers' purposes for teaching science into consideration because they guide teachers' decisions and actions in the science classroom. Friedrichsen and Dana (2005) found that such purposes were both content-specific and more general. They concluded that teachers have complex orientations that encompass both science-related and general teaching goals and purposes. We investigated how science teachers' concerns and their purposes for teaching science are related to other PCK components from the Magnusson et al. (1999) PCK model. Our particular aim was to investigate whether teachers with different concerns and purposes had different types of PCK. In this study, we adapted the Magnusson et al. (1999) model to include the explicit use of teachers' general and specific purposes (Friedrichsen & Dana, 2005)

3.3. Context of the study

3.3.1. The Mathematics and Science Partnership Program (MSP)

This study was carried out in collaboration with the Mathematics and Science Partnership program, aimed at improving teachers' classroom performance. The focus of this program was to have teachers improve their presentation of mathematics and science by reflecting on their own practices. To achieve this goal, the science teachers in the MSP program conducted an action research project to reflect on their teaching of a specific subject. Action research can be used by educators to examine classroom learning in relation to their own teaching. Action research has proven to be a powerful strategy for teachers to improve their own professional practice in the classroom. It is often organized on a collaborative basis and teachers collect and analyze data from their own practice to systematically improve their teaching (Feldman, 1996; Lederman & Niess, 1997; Ponte et al., 2004). The MSP program started with a two-week summer session in which the teachers were introduced to action research. In the first week the teachers created an action research plan in which they identified a topic in their field that needed to be transformed into teaching content and attended presentations from the university staff on various science and mathematics topics and best practices in education. In the second week the teachers continued working on their plan, doing literature research in order to deepen their understanding of the subject and to find successful instructional strategies on the topic in question. The teachers were required to reflect upon their earlier teaching of this topic, and to provide reasons why they now intended to use different instruction methods. They developed research questions and identified methods by which to assess their projects. After creating lesson plans they conducted their action research program in the following school year. During that year they had four meetings with the university staff and their colleagues. The academic staff acted as facilitators and colleagues as critical friends in this professional development program (cf. Ponte et al., 2004). At the end of the program the participants submitted their action research progress report. During the action research the teachers also kept an electronic journal to reflect on their learning progress. At the end of the year, twelve participants volunteered to have an interview with the author.

3.3.2. Aim of the study

We investigated how in-service science teachers used and connected various PCK components when improving their science teaching. We also examined similarities and differences in the PCK of teachers who had different concerns, goals, and purposes in teaching science. The aim of this research was to investigate if and how teachers' pedagogical content knowledge can be typified using Magnusson et al.'s (1999) model. Our research question was: How can in-service science teachers' pedagogical content knowledge be typified at the end of a professional development program to improve their teaching?

3.4. Methods

3.4.1. Participants

Twelve American in-service science teachers working in either a middle or high school, who had participated in the MSP program, voluntarily participated in our research. To be included in the study the teachers had to complete their action research project, had to be willing to share the action research report for review, and had to agree to be interviewed as a follow-up on their action research project. All volunteers had teaching experience, but only one teacher had prior experienceof action research. All teachers included in this study were teaching science in the year they did their action research project. Classes ranged from 4^{th} to 8^{th} grade in middle and high schools (See table 3.1.). The schools were located in small rural communities in the Mid-West region of the United States. All participants took part in the two-week summer program and the four follow-up sessions during the school year 2005-2006. The teachers submitted their action research reports with their lesson plans and were interviewed by the author.

Table 3.1.
Demographics of the teachers participating in the study

Teacher	Name (fictitious)	Years of experience	Subject taught	Grade level
1	Betsy	12	Deserts	8th
2	Josh	7	Atomic theory	5th
3	Carlene	8	Rocks and minerals	8th
4	Dana	17	The human body	4th
5	Diane	22	Cell structure/heredity	7th/8th
6	Donna	21	Volcanoes	7th
7	Matt	28	Photosynthesis and respiration	7th
8	Norma	3	Cell structure	7th
9	Rhonda	26	Bats	7th
10	Shania	21	Cell structure	6th
11	Stephanie	10	The human body systems	7th
12	Trisha	2	Earthquakes	4th

3.4.2. Data collection

For our investigation into the teachers' PCK we used two data sources: action research reports and interviews.

a. The action research report

At the start of the program, the teachers prepared an action research plan based on the teaching of a science subject. They established a framework for conducting and assessing this action research. During the year the teachers used an electronic format to record their progress, results, and analyses of their findings. At the end of the school year they submitted the final action research report. This report was used as our first data source in which teachers reported their actions and explained what knowledge underlay their actions in the classrooms. In studying PCK as the knowledge underlying teachers' actions, we used this report as a valuable source in our study. The action research report was therefore invaluable for the understanding of the teachers' PCK.

b. The interview

At the end of the year we conducted a semi-structured interview to investigate the teachers' knowledge underlying their actions and the reflections they recorded in the action research report. The purpose of this interview was to have teachers reflect on the knowledge we distilled from their action research report. In this case we made use of Schön's (1983) *reflection on action* concept, developing a set of interview questions for teachers to think and reflect upon their actions during the action research classroom project. The interview questions were based on the various components of teachers' PCK (see Appendix A). When answers were vague or unclear or showed potential for further investigation to determine the knowledge underlying the teachers' actions, we asked more probing questions. Interviews lasted no more than 30 minutes and were conducted in a place that suited the teacher (a classroom, office, library, or empty playground). The interview questions had been tried out with two teachers who had participated in the same program in a previous year. Their feedback was used to adapt the questions to the different situations of the teachers. All interview data were transcribed verbatim and analyzed.

3.4.3. Data analysis

Identifying codes

To capture the various aspects of PCK we used an open-coding approach when analyzing the data (Corbin & Strauss, 2008). Line-by-line open coding was used to verify and saturate coding (Bryant & Charmaz, 2007). 'The result is a rich, dense theory with the feeling that nothing has been left out' (Glaser & Holton, 2004, p. 50). In open coding processes data saturation is usually reached after twelve participants (Guest et al., 2006, Corbin & Strauss, 2008). The grounded theory enabled us to expand on existing codes found in previous studies (e.g. 'learning science and learning to do science' in the category 'purposes of teaching science'), as well as to include additional codes extracted from the data (e.g. 'learn to like science' in the same category). Table 3.2 provides an overview of all categories (concerns and PCK components) and codes used in this study.

Table 3.2.
Overview of the PCK categories and codes

PCK Components	Codes
Concerns	Students show poor inquiry skills Students have low test scores Students are not interested in science
Purpose of teaching science	Learning science content Learning how to do science Learning about science Learning to like science
Knowledge of science curricula	Knowledge of science goals and objectives based on *science content* (national, state, or classroom level) Knowledge of goals and objectives based on *science process skills development* (national, state, or classroom level) Knowledge of goals and objectives of *developing reasoning* (national, state, or classroom level)
Knowledge of instructional strategies	Knowledge of instructions addressing learning *content* (i.e. knowledge of lecturing the content, knowledge of hands-on strategies to address content) Knowledge of instructions addressing *development of process skills* (i.e. knowledge of experimental activities; knowledge of creating hypotheses, collecting data, creating graphs) Knowledge of instructions addressing *reasoning* (i.e. knowledge of posing problems to find solutions, or knowledge of having students connect with real world issues)

Knowledge of students' understanding	Knowledge of students' *understanding of the content* (e.g. knowledge of students' difficulties understanding the concept, awareness of students' specific misconceptions) Knowledge of students' understanding for *retrieving knowledge* Knowledge of students' *performance of a certain skill* (follow lab instructions, group work) Knowledge of students' *motivation to learn content* Knowledge of students' *motivation to perform a skill* Knowledge of students' *understanding for retaining knowledge* Knowledge of students' ability to *master a skill*
Knowledge of students' assessment	Knowledge of content-based tests Knowledge of checklists for performing a lab exercise or experiment Knowledge of assessing presentations Knowledge of assessing rubrics Knowledge of assessing observation sheets Knowledge of assessing students' portfolios

Data analysis procedure

We used the following procedure to analyze the data:

1. First, we read the action research reports several times in order to become familiar with the content.
2. We identified statements in these reports that conveyed information related to a specific knowledge aspect.
3. We labeled and categorized these statements on the basis of consensus between both authors. Each statement was labeled according to a knowledge component. For example, a teacher found that students had problems classifying fossils because of the names: *'When [the students] start doing the project, some said the fossil part was real hard, because they classified the fossils and they were really hard to classify because a lot of them have such big names on them.'* This statement fell into the category 'knowledge of student understanding', and was labeled as 'knowledge of students' *performance of a certain skill*'.

4. Next, we turned to the interview data. We labeled and categorized the statements from the interviews, in the same way as described above, on the basis of consensus between both authors.
5. To get a better perspective on the content of the teachers' PCK, we captured their coded statements in a representation. To construct this representation we used the coded data from both sources. For example, in a teacher´s (Diane) report we found that she was concerned about her students' low scores on the subject of genetics and wanted to increase her students' knowledge of genetics. We coded this goal as 'learn science content'. In the interview Diane explained how hard this concept was for her students to grasp, and how she used PowerPoint presentations in her lectures to address the topic, in combination with the use of hands-on activities. In both her report and the interview she explained that this new approach resulted in her students' acquiring a better comprehension of the genetic concepts. In her report she mentioned the use of tests to assess her students' content knowledge on genetics, and

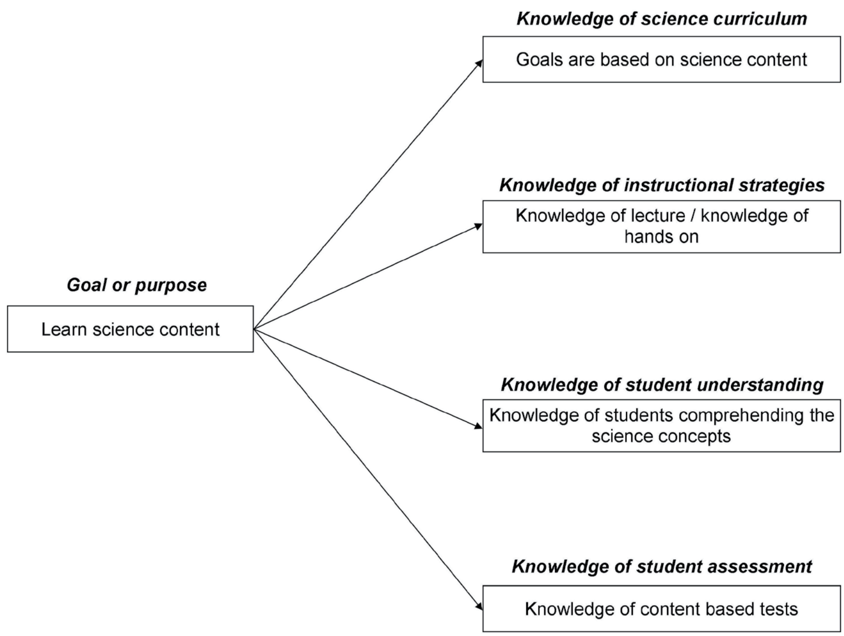


Figure 3.2. An example of a PCK representation level (teacher Diane)

in the interview she explained how easy her tests on genetics were and how she needed to adjust them in order to obtain more objective results. From her coded statements for each PCK component we constructed a PCK representation for Diane (see Figure 3.2) at the end of her action research.

6. In this manner we constructed PCK representations for all twelve teachers, consistently based on consensus of two independent researchers.
7. After we constructed PCK representations for all teachers, we used the constant comparative method (Strauss & Corbin, 1990) to compare the twelve PCK representations with each other. The comparisons were conducted on both PCK representation level and PCK component level. This allowed us to identify different types of PCK emerging from the representations. Here is an example of two PCK representations that represent one type: when we compared Matt's and Carlene's PCK representations, we found that these both focused on teaching science skills. On the component level we found that all their PCK components were related to developing science skills. Even though the teachers used different instructional strategies, all strategies involved students practicing their science skills. In the assessment component both teachers used methods to assess science process skills (Matt used observations and checklists, while Carlene assessed the activity sheets). The second example shows how we divided PCK representations into two different types of PCK: both Josh's and Dana's PCK representations focused on students' learning science content. However, when we compared them at the component level, we discovered that the components of Josh's PCK were strictly focused on learning content, while those of Dana's PCK were primarily focused on increasing students' motivation. When investigating the other PCK components we found that Dana's PCK components were focused on increasing students' motivation to learn science, whereas Matt's PCK components were focused on teaching science content. These PCK representations were therefore considered to indicate two different types of PCK. If the knowledge components of

two representations showed more similarities than differences based on the teaching concerns and the purposes of teaching science, these types were considered one type of PCK.

In the following section we describe the types of PCK we found from the teachers' individual PCK representations.

3.5. Results

On the basis of the data from the science teachers' action research reports and the interviews, we agreed on three different types of PCK representations. Type I representations were aimed at teaching the *process skills* of scientific inquiry. Lesson plans, classroom activities, and assessment procedures were inquiry-based in order to have students develop *science skills* of a specific science content. In Type II the PCK representations were aimed at teaching *science content*. Lesson plans, knowledge about classroom instruction, and knowledge of assessment methods were all focused on teaching the *science subject*. Type III reflected PCK representations in which teachers focused their lessons on *motivating* students to learn about science, using (field) projects to increase students' interest. In their PCK representations, knowledge about instructional strategies and assessment methods were related, aimed at getting students motivated to learn science (see Table 3.3).

Although each individual teacher embodied a unique representation of PCK, it was possible to map each representation to one of the three types. Teachers 3, 7, and 10 fitted Type I; PCK representations of teacher 2, 6, 8, and 12 were representative of Type II, while the PCK representations of the remaining five teachers (T1, T4, T5, T9, and T11) corresponded best to Type III. This does not mean however, that each PCK type excludes the other PCK types. Although PCK type I teachers showed a preference for teaching science skills, it does not mean that they were not interested in teaching science content at all. It merely explains that for this science topic and for these type of students at this grade level, their focus was more on the teaching of science

Table 3.3.
PCK types including teachers' concerns and purposes in teaching science

PCK TYPE	I. Knowledge of teaching science process skills	II. Knowledge of teaching science content using various strategies	III. Knowledge of teaching science through enhancing students' motivation
Teachers	T3, T7, and T10	T2, T6, T8, and T12	T1, T4, T5, T9, and T11
Concerns	Students show poor lab skills and need to develop science skills	Students have low test scores and need to increase their content knowledge	Students are not interested in science and therefore need to increase their motivation to learn science
Purpose of science teaching (Hodson, 1992)	Doing science	Learning science (content)	Learning science content Learning to do science Liking science
Knowledge of science curricula	Understand the process of scientific inquiry	Model and describe and explain the content	Explore science using scientific inquiry and collaboration
Knowledge of instructional strategies	Teacher-guided: instructions to perform lab experiments and internet search to guide scientific inquiry	Teacher-directed: lecture and presentation to explain concepts Lab instructions and internet search to visualize the concepts	Student-centered: investigations experiments internet search
Knowledge of students' understanding	Students understand science better when skills are developed	Students understand science better when they focus on the content	Students understand science better when they are engaged to build on their own knowledge through individual or collaborative investigation
Knowledge of student assessment	Skills test, journals, rubrics	Pre- and post-content tests	Knowledge test, rubrics, surveys.

skills and therefore they used their knowledge primarily on teaching science skills (see Table 3.3). Each type is described in more detail below, using data from the teacher statements.

3.5.1. Pedagogical content knowledge Type I: Knowledge of teaching science process skills

This type of knowledge focused on what teachers know about how to develop students' science skills. Conceptualization of this type of pedagogical content knowledge was established by the teachers' ***concerns about their students' science skills***. Three science teachers reflected on their concerns about students' science process skills:

> *'These students have shown poor skills when doing lab work. A change in tactics while doing lab work needs to be addressed.' (*Interview with Matt)
>
> *'When looking at our ISAT [Illinois Standard Achievement Test] scores, this [inquiry] skill seemed to be our lowest ...'* (Interview with Shania)
>
> *'There is a scientific process you do to investigate something. And that's what I want them to learn.'* (Interview with Carlene)

In their lessons on photosynthesis (Matt), rocks and minerals (Carlene), and the cell (Shania), the teachers aimed at developing students' science skills. During the interviews all teachers said that they intended to have their students develop science skills, but each gave a different reason: Matt wanted to improve students' skills because they performed poorly in the labs; Shania wanted to teach science skills because it was compulsory in the learning standard; and Carlene focused on teaching these skills in her science class because she wanted her students to be able to investigate, and therefore they needed science process skills. All these reasons seemed to link up with the teachers' science purpose 'learn how to do science'. When examining their knowledge of the science curricula, these teachers explained that one typical learning standard was important in their goals and objectives: *'Understand the processes of scientific inquiry and technological design to investigate questions, conduct experiments and solve problems'*(Illinois learning standard 11, from www.isbe.state.il.us/ils/). This standard also shows a focus on the purpose of increasing students' science process skills. When looking more closely at their instructional strategies we found that the teachers showed knowledge of a variety of methods, including inquiry lessons, experiments, and investigations. Teacher Matt, for example, used a computer-based approach to have students design and interpret graphs: *'We studied photosynthesis and respiration from my computer base. It is a much quicker way to measure photosynthetic rates and the data is generally very good. It also gives a graphical display of the data as it is collected, which is easy to understand and this allows me to teach my students about graphs interpretation. I mean the basic concepts of respiration and photosynthesis are the same but you are now looking at it from a graphical point of view, so they had to learn how to interpret the graphs better.'* (Interview with Matt) In the statement above, Matt selected these instructional strategies to facilitate the achievement of the goal of developing students' process skills. Although it may seem from this statement that the teacher would also increase the students' content knowledge, his primary goal was for the students to understand how to do science. In the rest of the interview concerning his knowledge about students' understanding, the teacher stated that he had become aware of his students' performance. In particular, he had become more aware of his students' collaborative skills and noted that they were able to do more sophisticated work than before during the experiments and investigations. *'I was looking more at the group interaction and it did make me see kids doing certain things that I probably was not aware of before. I really think especially if you go to probes and graphing skills that they really improved a lot of times in science.' (*Interview with Matt) Regarding methods of student assessment the teachers showed that they were knowledgeable about skills tests, activity sheets, lab scores, and lab logbooks as tools to assess their students' abilities when they were conducting an investigation or experiment. *'We had a checklist, and then we had many rubrics. They [the students] were able to tell me the processes they needed to do the project. So I believe it.'* (Interview with Carlene)

Type I Summary

This type of PCK seemed to be found among teachers who were concerned about the students' science skills. Although the individual goals, such as graphing the photosynthesis process or classifying rocks and minerals, were different with every teacher, they all show common features in the other PCK components. The teachers explored specific purposes of science teaching, using specific instructional strategies and assessment methods to enable their students to develop the science skills necessary for a specific science subject. Although one teacher used photosynthesis experiments and the other classification activities, they all challenged their students to develop science skills. During their lessons they facilitated lab exercises and used methods to assess experiments and investigations. These teachers learned about students' abilities and inabilities to perform certain experiments and investigations. Their action research project was primarily based on the development of student process skills, with each component strongly connected to skills development. We can therefore conclude that these three PCK representations can be classified as one type of PCK of science teachers in their lessons, related to concern about their students' science skills.

3.5.2. Pedagogical content knowledge Type II: Knowledge of teaching science content using various strategies

PCK representations included in this type of PCK were found among teachers who were concerned about students' low academic scores on a particular science subject in previous years or discovered that students had difficulties understanding the science concepts. The general purpose of their action research was to alter their classroom teaching in order to improve their students' results. Four of the teachers (Josh, Donna, Norma, and Trisha) planned their lessons to teach a specific science content.

> *'I focused on basic atomic theory and chemical processes: just basic understanding of the parts of the atom. It was an area that students had difficulty understanding. So if I could find a way to make [my teaching] more effective, that would be the best area to achieve'*(Interview with Josh).

It was mostly because of this concern that these teachers focused their lessons on ***learning science content.*** Josh responded in the interview: '*Students were studying basic atomic theory and needed to be engaged with the content in a direct way. Due to the content it is difficult for students to explore the nature of atomic structure directly. Then after a basic understanding was gained they were then allowed to deepen their understanding through discovery to uncover patterns and how atoms interact'.* Exploring their knowledge of science curricula the teachers emphasized goals and objectives strongly aimed at learning content knowledge. An example of Trisha's goal: '*Describe and explain short-term and long-term interactions of the Earth's components (e.g, earthquakes, types of erosion).'* (Action Research Report of Trisha) Their teaching focused on increasing students' content knowledge. To this end instructional strategies such as classroom lectures, video, or PowerPoint presentations were used to introduce the content, in combination with hands-on activities. The teachers used hands-on activities to enable the students to visualize the concepts being taught. Norma explained that her students actually understood the content when it was presented hands-on: '*Every day I had ten to fifteen minutes drawing cells. They are really hands-on and you can teach any lesson about cells or bacteria. With this method they can actually visualize and see the cells. So it is not just something that they have to imagine in their minds. When you take a leaf or a piece of grass and you put it underneath the microscope, they can see the cells and then you get that 'aha moment'*.(Interview with Norma) In the example above we found that although Norma was very much hands-on, her focus was primarily based on teaching science content. This is a different type of PCK from PCK type I. In the interviews the teachers stated that these activities helped their students not only to visualize, but also to understand the science concepts and retain the information. Furthermore, the use of hands-on activities motivated students, kept them on task, and helped them understand science much better. Josh: *'The most important discovery that I made was that as long as students were actively engaged with the content they made academic gains, no matter if it was teacher-directed or through student choice of projects.'* (Interview with

Josh) Trisha was pleased to find out that her students succeeded in learning about earthquakes when they taught each other: *'They [the students] knew exactly how to put their knowledge into practice and they transformed the information themselves. I did not have to give them any new information. I think they learned more about earthquakes when they were teaching each other. So they took ownership of their project, and that is what turned it into a success.'* (Interview with Trisha) As to knowledge of assessment, the teachers were knowledgeable on knowledge-based pre-tests and post-tests focused on the science content. Some used pre and post methods of assessment to measure knowledge growth. In peer group discussions some teachers debated how to use students' journals to find out if the students knew more about the subject than before the lessons. In their action research reports the teachers showed awareness of their students' test results.

Type II summary

PCK type II is content-oriented. This type was found among teachers who were concerned about students' low scores on a particular topic. In each component of their PCK, the ***learning of content*** was the central aim. The lesson plans, their knowledge of instructional strategies, and knowledge of assessment methods were related to teaching and assessing specific content knowledge. Although teachers focused on the content, their lessons were not taught solely in a traditional way. Instead, these teachers were knowledgeable about a variety of instructional strategies by which to engage their students in learning science content.

3.5.3. Pedagogical content knowledge Type III: Knowledge of teaching science through enhancing students' motivation

The main idea behind conceptualizing this type of PCK was students' lack of ***motivation to learn science***. In the action research reports and interviews, the teachers reflected on the problem that their students were bored with science and needed more innovative ways to learn science. All teachers of this type showed a firm belief that their students would perform better if they were more motivated to learn science. During the professional development program they seized the opportunity to learn how to change their presentation of the science content so as to increase students' motivation and interest. In the interviews they responded that they had learned that students needed to be engaged in meaningful science if motivation and, therefore, student learning was to improve. Their main purpose therefore was to have students 'learn to like science'. These PCK representations differed from the previous types because these teachers used projects, not only to teach a certain science subject, but also to increase their students' motivation and interest. The teachers' instructional knowledge on project work was geared towards motivation, to which end the learning of science content was embedded in real-life issues. The teachers were knowledgeable on connecting the students' interest with lessons based on the natural, everyday environment, so that the students could develop an understanding of the content. Goals and objectives were aimed at the content, but also focused on real-life situations to increase interest and teach specific science concepts. The following tells of a teacher's goal to teach about the human body: '*We focused on the human body system. The different systems within the human body, how they work together. That was basically it. We had an actual human skeleton brought into the classroom from a local hospital, and the kids got to go up and touch and feel. That was an awesome; I mean they were really awestruck by that and the guy was over a hundred years old.*' (Interview with Dana) Teachers dug into the literature to learn how to challenge their students to work on project assignments in science, and then prepared lab or internet assignments. Their knowledge of instructional strategies included preparing and guiding laboratory experiments and creating websites for online investigations. The laboratory experiments and online investigations were related to real-life situations; students had to read up on the material first (textbook or online) in order to be able to do the assignment. The teachers believed that their students' investigations deepened their understanding of the content. When they had the students do group work they discovered how well they worked together and how much more effectively they acquired information. Diane explained how she needed to facilitate her students to get them excited to learn science: *'What I did different[ly] was to look at their [the students'] ability levels and look at them individually. Allow some to excel and guide others in their project. I did not have to teach them all the same [things]. We mainstreamed the kids from special education with the regular ones and the special education kids got really excited to get the work done and so the other kids did too.'* (interview with Diane) The teachers learned that when students are active in class, motivation and performance improve. Rhonda, teacher 9, reflected on her lessons on bats: *'My kids pay more attention with interactive lessons. They are excited when they come to class. And when I don't use it, they moan and groan and they don't participate half as well. After the pre- and post-tests I saw an increase. And when we finished my little kids were pretty much bat experts.'(*Interview with Rhonda*)* The teachers showed knowledge of a variety of assessment methods, including knowledge-based tests, observations and checklists, lab sheets, rubrics, and surveys. The teachers created their own assessment methods. Diane explained in the interview: '*I liked that it [the assignment] focused them more to write about their experiments. They can focus their learning and write it down versus just talking about it..... they liked the idea of assessing each other....'* (Interview with Diane) Teachers used rubrics and surveys to gain feedback from their work. Stephanie, teacher 11, explained: *'We did surveys, and we did a pre- and a post-test on the probes. We did a pre- and post- test on the human body. We did a technology survey. I kept a journal on the different activities with the probes to find out if they got interested in using them. I have never pre- and post-tested students, and I thought that was neat because you can really see the growth of the students that way. And the surveys were good because I could give the students feedback on the their knowledge on the human body. They liked that.'* (Interview with Stephanie).

Type III Summary

This pedagogical content knowledge type focused on students' motivation to learn science. The teachers showed knowledge about having the students explore science in a natural setting, which increased interest and motivation and therefore facilitated learning. The teachers used project work instead of teaching from the textbook, and were knowledgeable on connecting lessons to real-life issues. They had students conduct experiments and participate in projects that motivated them and enabled them to gain a better understanding of the science content. During the interview they explained that their students did better and improved in content knowledge when they were motivated and eager to learn science that they thought was meaningful and connected with their world.

3.6. Discussion and conclusions

In this study we typified PCK representations mostly on the basis of the teachers' purposes in teaching science. Although the PCK types were not mutually exclusive, the teachers' purposes in teaching science greatly influenced their PCK. This does not mean that teachers who focused on the teaching of science skills were not interested in teaching content knowledge or vice versa. It does show, however, that when the purpose of the teacher was to increase science skills they favoured the use of PCK that served that purpose. We also found that these purposes were closely related with the teachers' concerns. These concerns included the students' abilities or inabilities to learn content or to perform skills, and the students' interest in science. We found that the teachers' concerns and their purposes of science teaching could direct their PCK representations. We found that teachers were consistent within their knowledge components and that these components highly influenced each other. For example: when teachers discovered that their students had insufficient science skills to perform a certain task, they focused on these skills and based their next lesson on the development of these skills using suitable goals, classroom instructions, and assessment methods. However, we found variations within a PCK type which gave clear insights into individual PCKs. In the following section we summarize our conclusions for each PCK type.

Pedagogical content knowledge types

The three pedagogical content knowledge types identified in this study were quite different from each other. In PCK Type I the teachers' purpose was not merely to develop students'skills, but to develop specific process skills connected to the science subject. Carlene (teacher 3), for example, wanted her students to learn about classifying because it was an important skill in identifying rocks and minerals in Earth science. Matt (teacher 7) knew that graphing was one major skill that students needed in order to understand photosynthesis and respiration processes in plant biology. When Hodson (1992) referred to this typical purpose as learning to do science, he did not refer to it as 'just following a set of rules', but as understanding what constitutes this specific science skill and the capacity to successfully master it. The teachers refined this type of PCK by investigating and using certain instructional strategies and assessment methods to foster the learning of these particular science skills. This type of pedagogical content knowledge was different from the other two types.

In Type II PCK the teachers were mainly focused on their students learning science content. They were concerned about their students' low academic scores in science and aimed their lessons at increasing students' content knowledge in the particular subject in which they had shown poor results in previous years. What is remarkable about this PCK type is that the teachers did not restrict their instructions to only traditional teaching methods, but were also knowledgeable about hands-on activities. For example, the teachers organized hands-on activities in which students built models to improve their understanding of science concepts. Although these teachers talked about lecturing and direct teaching as important instructional strategies, they acknowledged that various hands-on activities were also important strategies for teaching science content. They did not merely use teacher-directed strategies to address the issues, but also used more student-oriented approaches to reach their content-related goals. This distinguished PCK Type II from Types I and III.

In PCK type III, we found a different purpose of science teaching, namely motivating students to learn science. Teachers with this type of PCK did not use their knowledge of hands-on activities to have students develop skills, but to get students *motivated to learn science*. It is, therefore, crucial to understand that although several teachers may use similar classroom activities these may be rooted in different types of PCK, thus serving a specific purpose. In a recent study, Talanquer et al. (2010) found that pre-service teachers also hold motivating students as a major orientation towards science teaching. Motivating students to become interested in learning science seems to be an important goal that needs to be explored in detail. In this study we found that when a teacher is focused on motivating the students, this teacher's PCK is different from the other types.

In an earlier study Henze et al. (2008) studied experienced science teachers who were just starting to teach a new syllabus (general science) with unfamiliar content and teaching methodologies. Within this context they identified two types of pedagogical content knowledge (PCK) based on the purposes of science teaching. Type A focused on learning of science content (model content), and type B on multiple purposes, i.e. model content, model production, and the nature of models. Although the 2008 study did not investigate previous concerns or previous experiences, since the participating teachers focused on the curriculum for a new science subject, our findings are consistent with the earlier study in that Hodson's (1992) purposes were found to help shape the pedagogical content knowledge of science teachers. In general, we conclude that these PCK types reflected the concerns of the science teachers in relation to Hodson's purposes. Additionally, we found that teachers may have other purposes than those explicitly identified by

Hodson (1992) such as 'motivating students to learn science'. This purpose is connected to a more general concern of teachers, that is students being bored with science. In that situation we found that teachers used their science goals and instructional strategies in a more meaningful way by connecting them to real life issues.

The types of PCK that we found in this study were very context-bound. From the data it became evident that teachers revealed a PCK that was strongly related to the science topic they taught and to their students at a certain grade level. One may advocate that because PCK is context bound, teachers should not be limited to one type of PCK for each science topic, but should be able to switch to different types of PCK, depending on their concerns and contexts, for example, teaching students in different grade levels. We concluded that good science teachers should be able to use all three types of PCK in their classroom teaching depending on their concerns and their teaching purposes. For each type in this study, we found that the main goal seemed to be to increase students' understanding of science. However, teachers displayed specific concerns when it came to realizing this aim. It is evident, therefore, that different types of pedagogical content knowledge will be found, which need to be taken into careful consideration when designing programs for ongoing professional development.

We conclude that it is both general (e.g. motivation to learn science) and specific science concerns (e.g. lacking specific science skills) together with the purposes of science teaching that determined the teacher's pedagogical content knowledge. These concerns are important and need further research. In a recent study Berry et al. (2008) referred to specific science teaching concerns when they investigated science teachers' professional knowledge. These authors imply 'that change in practice occurs most effectively when it is self-initiated and focused on individual needs and concerns' (p. 577). In our research these concerns mostly related to student learning but more research on teachers' concerns is needed to explore how this important factor shapes a teacher's pedagogical content knowledge. It is important that in professional development programs for in-service teachers both the teachers' prior experience and their concerns in teaching subject matter are taken into consideration. Other scholars have emphasized that it is not only the teachers' goals and beliefs, but also other related issues such as the school context, the types of students and the curriculum that determines the preferences of science teachers regarding their instructional activities (Friedrichsen & Dana, 2005; Talanquer et al., 2010). In this regard we should also take into account the teachers' previous experiences and their concerns resulting from their teaching experience in previous years.

3.7. Limitation and implications of the study

This study was limited to data collected from twelve science teachers. Additional research is needed on more science teachers, in order to distinguish other possible types of pedagogical content knowledge. Additional data sources such as classroom observation and students' interviews could enrich the results and contribute to more in-depth research on the teachers' pedagogical content knowledge. For example, having teachers draw concept maps may help to give a more holistic view of their pedagogical content knowledge (see e.g. Meijer, 1999, who used concept mapping and stimulated recall to investigate teachers' practical knowledge).

It is important to note that teachers should have the opportunity to explore their own purposes and concerns, since their pedagogical content knowledge is related to these concerns. More research is needed to investigate how a teacher's pedagogical content knowledge develops or becomes more refined over the years. A model such as the Interconnected Model for Teacher Professional Growth (Clarke & Hollingsworth, 2002) could be used to investigate how the categories of pedagogical content knowledge develop when teachers participate in a professional development program. The use of action research in the context of such a program is an advantage, since this strategy can focus on changing and testing subject matter teaching. Action research is a cyclic process allowing multiple cycles to be studied. Our study focused on just one cycle of action research. To gain a deeper understanding of pedagogical content knowledge and its development, multiple cycles should be investigated.

For teacher educators it is important to understand that teachers teach subject matter on the basis of a certain type of pedagogical content knowledge. As this study demonstrates, when teacher educators help teachers to develop their pedagogical content knowledge, it is not only important to have them focus on their purposes regarding subject matter teaching, but also to make explicit their concerns in this area. Designing PD programs for teachers to develop their types of pedagogical content knowledge is a complex task. The approach used in this study was not aimed to investigate PCK development, but rather to make the content and structure of PCK explicit and to understand how components of PCK typify this knowledge base. If the aim of a professional development program is to promote the development of other types of pedagogical content knowledge, further research would be needed to identify which criteria are needed to foster such development in ongoing professional development settings. A model for professional growth would be needed to investigate PCK development. In the next chapter we use a model called the interconnected model for teachers' professional growth (IMTPG) to study PCK development in a professional development setting.

Chapter 4. Using the interconnected model of teachers' professional growth to study science teachers' pedagogical content knowledge in the context of a professional development program

Abstract

In this study we investigated the development of the pedagogical content knowledge of twelve secondary education science teachers in the context of an action research project. We used the interconnected model of teachers' professional growth to study changes in the participants' pedagogical content knowledge. We found two distinct types of pathways that teachers follow with regard to pedagogical content knowledge development: one type in which teachers reflect on their students' learning, and another type in which those reflections are lacking. The teachers who reflected on their students' learning were able to alter their classroom practice on the basis of these reflections. In addition, the empirical data revealed that within the action research design the university staff was a main factor in facilitating participants to develop new understandings of student learning, and that teachers learned about new instructional strategies and assessment methods mostly through literature reviews and in discussions with peers.

Keywords: action research, pedagogical content knowledge, professional development

4.1. Introduction

'My 6th grade students have a difficult time understanding science concepts on an abstract level. Heredity for example is a hard concept for most students and no matter what I do, it does not get the results...'

The example above is a quote from the journal of a teacher who participated in an ongoing professional development program, searching for innovative ways to teach genetics. This teacher wanted to learn how she could teach heredity to her 6th-grade students in such a way that they could understand this concept, and this is why she took part in the professional development program. She did not seek to increase her subject matter knowledge per se, but wanted to develop proper instructional strategies so that her students could understand this topic -- in other words, she needed to develop her pedagogical content knowledge. Pedagogical content knowledge is the knowledge teachers use in the process of teaching (Kind, 2009). According to Gess-Newsome (1999a), PCK 'is the *only* knowledge used in classroom instruction that helps students understand specific concepts' (p. 12) and it is therefore an important factor in the design and handling of teaching situations aimed at improving students' learning (Abell, 2008). In this study we developed, implemented, and investigated a professional development program aimed at PCK development.

Educational researchers stress that teachers' professional development impacts on teacher knowledge and practice, and consequently affects students' learning outcomes (Borko, 2004; Fishman, Marx, Best, & Tal 2003; Guskey, 2000). Although it is very hard to actually 'prove' the impact of specific professional development programs (Desimone, 2009), there is a consensus on the fruitful effect of continually facilitating and stimulating teachers' professional growth (Abell, 2008).

Many professional development programs, however, have been found lacking with respect to stimulating teacher learning (Ball & Cohen, 1999; Little, 2001), since teacher educators often assume that teachers are simply filling a gap in their knowledge (Putnam & Borko, 1997), neglecting the beliefs and attitudes these teachers bring into the program (Van Driel et al., 2001; Verloop et al., 2001). Furthermore, professional development programs also fail because they neglect to take into account existing knowledge about how teachers learn (Ball & Cohen, 1999; Borko, 2004).

Only recently have we come to understand that what and how teachers learn from professional development programs has an impact on whether and how they change (in for example knowledge or practice) (Desimone, Porter, Garet, Yoon, & Birman, 2002; Fishman et al., 2003). Studies on teachers' professional development have shown that high-quality professional development programs must entail a form of inquiry (Arons, 1989; Bybee, 1993; Little, 2001; Lotter, Harwood, & Bonner, 2006) that enables teachers to actively construct knowledge through practice and reflection (Guskey, 1986, 2002b; Schön, 1983). Action research might be a possible form for teachers to improve their teaching and acquire new knowledge from their own classrooms (Ponte, 2002; Ponte et al., 2004).

Although numerous studies have focused on the development of teachers' knowledge (Beijaard, Verloop, Wubbels, & Feiman-Nemser, 2000; Meijer, 1999), teachers' individual professional development processes have not been studied extensively (Zwart, 2007; Hashweh, 2003;Wilson & Berne, 1999). Regarding PCK, Kind (2009) argues that studies on professional development programs are needed in order to gain a deeper understanding of how such programs affect individual PCK development.

In this study our aim was to understand what and how teachers learn from taking part in a professional development action research program, specifically with respect to their PCK development. Teacher change is open to multiple interpretations (Clarke & Hollingworth, 2002). Teacher learning is defined as teacher change (see also Guskey, 2002b). In this study we use *teacher change* and *teacher learning* interchangeably to indicate *teacher growth* (Guskey, 1986, 2002a; Clarke & Hollingsworth, 2002; Zwart, 2007). In order to study this change we used Clarke & Hollingsworth's (2002) model: the interconnected model of teachers' professional growth (IMTPG), which takes into account that teachers take an active role in developing their own knowledge (Clarke & Hollingsworth, 2002). Our research focused on identifying possible pathways of change that could lead to the development of science teachers' pedagogical content knowledge when they conducted an action research program in their classrooms. We also investigated how specific elements of a professional development program could foster this development. In the next section we describe the theories underlying the IMTPG model that served as a basis for our study of pedagogical content knowledge development.

4.2. Theoretical Framework

4.2.1. Teachers' Professional Growth

A major question in teacher change literature relates to the issue of whether and how changes in knowledge, beliefs, and attitudes relate to changes in teacher practice (Wubbels, 1992; Richardson & Placier, 2001; Bolhuis, 2006). For a long time it has been widely assumed that when teachers change their knowledge, beliefs, and attitudes on, for example, new instructional methods, their teaching practice will improve and accordingly result in better student outcomes . Since the middle of the 1980s, ideas about teacher change have been more focused on learning through reflection on one's own practice (Guskey,1986, 2002b; Korthagen, Kessels, Koster, Lagerwerf, & Wubbels, 2001). Guskey (1986), for example, proposed a linear model of teacher change, assuming that a professional development program causes changes in a teachers' practice which in turn lead to changes in students' learning, and therefore results in changes in teachers' knowledge, beliefs, and attitudes. The facilitating process here is reflection. Other researchers, however, cautioned that teacher learning is not a linear process, but covers a complex system of processes in which teachers are engaged in active and meaningful learning (Borko, 2004, Clarke & Hollingsworth, 2002, Desimone et al, 2002). In a review study Borko (2004) proposed a non-linear model in which the PD program, the teachers, the facilitators, and the context in which the professional development occurs are key elements in a professional development system.

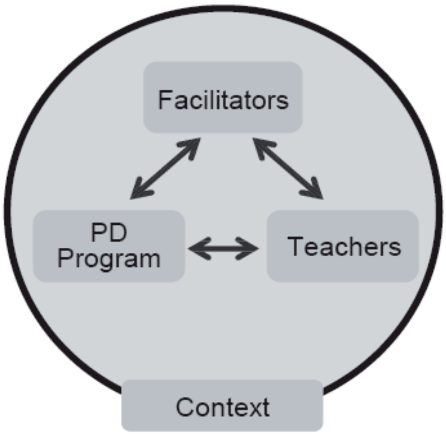


Figure 4.1. Elements of a professional development system (Borko, 2004).

Borko mentions that the relations between these elements have been investigated in various studies. These studies focused on explaining factors found in each element, but were not explicit about what the precise relations are between these elements and how exactly the elements are related, thus leaving the nature of actual teacher growth processes vague. The model proposed by Clarke and Hollingsworth (2002) distinguishes certain domains of teachers' professional activities, and suggests that teacher growth results from processes of reflection and enactment. We used this interconnected Model of Teacher Professional Growth (IMTPG) in our research because it offers the opportunity to study different patterns of change leading to teachers' growth (Clarke & Hollingsworth, 2002).

4.2.2. The Interconnected Model of Teachers' Professional Growth (IMTPG)

In 2002 Clarke & Hollingsworth proposed the IMTPG as a tool for studying teachers' professional growth. Using empirical data on which to base their findings, the authors established four different domains, which encompass the teachers' world and thus play an important role in teacher learning: (1) the Personal Domain, which contains teachers' knowledge, beliefs, and attitudes; (2) the External Domain, which contains external sources of information or stimuli; (3) the Domain of Practice which involves professional experimentation; and (4) the Domain of Consequence, which contains salient outcomes related to classroom practice (see Figure. 4.2).

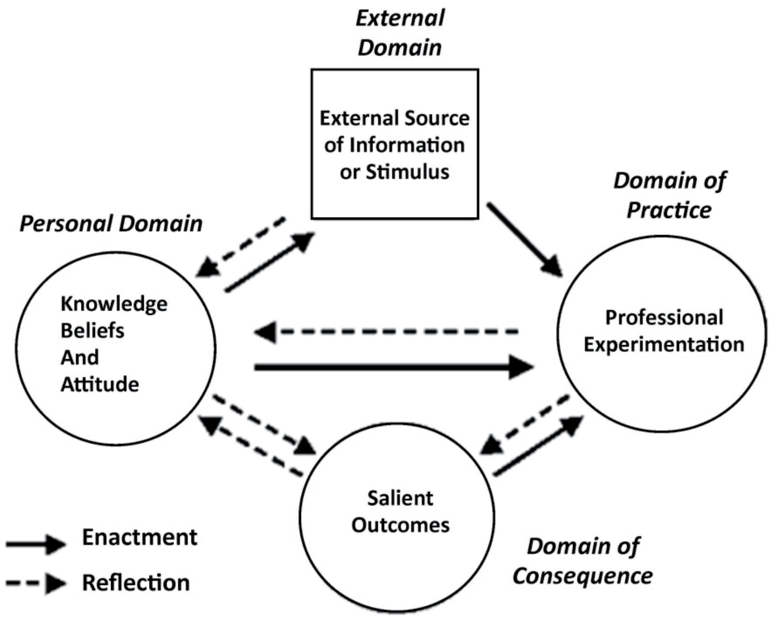


Figure 4.2. Clarke & Hollingsworth's (2002) IMTPG model

Using this model Clarke and Hollingsworth (2002) show that a change in one of the domains is 'translated' into a change in another domain through mediating processes of enactment or reflection. An 'enactment' is defined as something the teacher does as a result of what 'the teacher knows, believes or has experienced' (Clarke & Hollingsworth, 2002). For example, when a science teacher uses certain analogy to explain the atom model, because s/he believes that it is a hard concept for students to understand. The term 'reflection' refers to 'a set of mental activities to construct or reconstruct experiences, problems, knowledge or insights' (Zwart et al., 2007, p. 169). For example, when a science teacher realized that the analogy to explain the atom model enabled the students to visualize the model so that they understood the differences between the protons and the electrons. Clarke and Hollingsworth (2002) suggest that pathways for change appear through mediating processes of enactment and reflection. These pathways can result in either a 'change sequence' or a 'growth network'. Change sequences occur when a change in one domain leads to a change in another, supported by enactive or reflective links; a growth network is a more complex and ongoing change in more than one domain. In the context of a professional development program, Clarke and Hollingsworth (2002) use the IMTPG to study changes in teachers' knowledge as a result of active and meaningful learning. 'Teacher growth becomes a process of construction of a variety of knowledge types (content knowledge, pedagogical knowledge, and pedagogical content knowledge) by individual teachers in response to their participation in the experiences provided by the professional development program and through their participation in the classroom' (Clarke & Hollingsworth, 2002, p. 955).

4.2.3. Pedagogical Content Knowledge

In the context of 'what teachers need to know to teach others', Shulman (1986) and other researchers (Grossman, Wilson, & Shulman, 1989; Shulman & Grossman, 1988) describe pedagogical content knowledge as the basis for subject matter teaching, derived from what teachers know about the subject and about teaching. Shulman (1986) argues that teachers need this type of knowledge to structure the content of their lessons, to choose or develop specific representations or analogies, to understand and anticipate particular preconceptions or learning difficulties on the part of their students, and so on. In a recent study on PCK development, Kind

(2009) concluded that 'PCK is a useful concept and tool for describing and contributing to our understanding of teachers' professional practices' (p. 198). In her review she describes how the PCK models of Grossman (1990) and Magnusson et al. (1999) were derived from Shulman's (1986) original proposal which has 'explanatory power', and 'can provide a clearer statement about how PCK develops' (p. 198). In order to understand teacher growth in terms of PCK development, we used the model of Magnusson et al. (1999), whose PCK model consists of five components: (1) orientations towards teaching science; (2) knowledge of the science curriculum; (3) knowledge of science-instructional strategies; (4) knowledge of students' understanding; and (5) knowledge of student assessment. According to Magnusson et al. (1999) the four latter components are ' shaped' by teachers' overarching orientations towards teaching science, that is their knowledge and beliefs about the purposes and goals of teaching science. 'Knowledge of the science curriculum' refers to teachers' knowledge about the goals and objectives of science curricula (state and national) and specific curricula. 'Knowledge of instructional strategies' covers knowledge of both subject-specific and topic-specific teaching strategies. 'Knowledge of students' understanding' refers to teachers' knowledge about the requirements for student learning and areas of student difficulty. 'Knowledge of student assessment' refers to teachers' knowledge of methods for assessing student performance.

For the study of PCK development we focused on the changes that occurred in teachers' knowledge during their action research projects. In these projects the science teachers started by stating a specific purpose for teaching science to a certain target group. We focused our research on changes in the four PCK components (2) to (5), mentioned above.

4.2.4. Action research

To facilitate their PCK development, the science teachers conducted an action research project in their classrooms. Using action research in the classroom the science teachers could examine their own teaching in relation to their students' learning, for example, by collecting data from their students. Action research has proven to be a powerful professional development tool in situations where teachers have to improve their classroom practice (Feldman, 1996, 2007; Lederman & Niess, 1997; Ponte, 2002; Ponte et al, 2004). By means of action research teachers acknowledge their classroom problems, seek answers to these problems, and act responsibly to solve them. Ponte et al. (2004) studied the professional knowledge development through action research of in-service teachers over a period of two years. They found that when left to themselves teachers developed knowledge related to the domain of educational methods, techniques and strategies, but rarely developed knowledge regarding other domains such as educational norms, values, objectives, or the relations between the phenomena in educational reality. However, when the teachers in Ponte et al.'s study received help from their facilitators in their action research processes, they developed knowledge in all domains. In this study academic staff acted as facilitators to the teachers as they engaged in their own action research project.

4.3. Context of the Study

4.3.1. The MSP Program

Our study was conducted in the context of a one-year professional development program called the Mathematics and Science Partnership program, which aimed at increasing teachers' knowledge. In this program teachers were encouraged to use action research as part of a professional development tool by which to improve their classroom performance. The MSP program started with a two-week summer session in which teachers were introduced to action research. In the first week the teachers created an action research plan in which they selected a topic from their curriculum that needed to be transformed into teaching content, and attended presentations from the university staff on various science and mathematics topics and best practices in education. In the second week the teachers continued working on their plan, doing literature research in order to deepen their understanding of the subject and to find successful instructional strategies on the topic in question. The teachers were asked to reflect upon their earlier teaching of this topic, and to provide reasons why they now intended to use different instruction methods. They developed research questions and identified methods by which to assess their projects. After creating lesson plans they conducted their action research program in the following school year. During that year they had four meetings with the university staff. The academic staff acted as facilitators and the colleagues as critical friends in this professional development program (Ponte et al., 2004). At the end of the program the participants submitted their action research progress reports. During the action research the teachers also kept an electronic journal to reflect on their learning progress.

4.3.2. Adaptations to the IMTPG model

We adapted the IMPG model to the specific needs of our study. In the Personal Domain of the IMTPG we included the four PCK components described in Magnusson et al. (1999). Furthermore, we created three sub-domains in the External Domain. Zwart (2007) proposed two sub-domains (the context of the specific professional development program and the more general external sources of information) to examine whether or not teachers' knowledge changes as a result of taking part in a professional development program (in this case, reciprocal peer coaching). In this study we subdivided the External Domain into three sub-domains: university staff, peers within the action research program, and other external sources of information. In accordance with the study by Zwart (2007), we also divided the Domain of Practice into two sub-domains: preparing and teaching. In the professional development program the teachers prepared an action research plan for their classrooms. This preparation was different from the general meaning of 'preparation' in the Domain of Practice, which means the preparation of lessons for classroom teaching. Furthermore, in order to study how a change in one domain triggers a change in another domain we used, as customary in this model, the mediating processes of 'enactment' and 'reflection'. Criteria

Table 4.1.
Criteria used in this study to establish relations in the IMTPG (adapted from Justi & Van Driel (2006)

Relation	Mediating process	Criterion
From PD to ED	Enactment	When a specific aspect of the teacher's initial cognition or belief influenced what s/he did or said during the learning activities in which s/he took part
From ED to PD	Reflection	When something that happened during the learning activities modified the teacher's initial cognitions or beliefs
From ED to DP	Enactment	When something that happened during the learning activities influenced something that occurred in teaching practice.
From PD to DP	Enactment	When a specific aspect of the teacher's cognitions or beliefs influenced something that occurred in teaching practice
From DP to PD	Reflection	When something that the teacher did in his/her teaching practice modified his/her cognitions or beliefs (without reflection on classroom outcomes first)
From DP to DC	Reflection	When the teacher noticed and reflected on something that s/he or his/her students did in teaching practice that caused specific outcomes (such as student learning, teacher control, student motivation, and student development)
From DC to DP	Enactment	When a specific outcome made the teacher state how s/he would modify the associated teaching practice in the future When a specific outcome made the teacher change his/her practice at that moment (reflection-in-action)
From DC to PD	Reflection	When the teacher reflected on a specific outcome, thus changing a specific aspect of his/her previous cognitions or beliefs When a teacher's evaluative reflection on the salient outcomes led to a change in cognition
From PD to DC	Reflection	When a specific aspect of the teacher's cognition helped him/her in reflecting on/analyzing a specific outcome of his/her teaching practice

Note. PD – Personal Domain, ED – External Domain, DP – Domain of Practice, DC – Domain of Consequence for each of these mediating processes have been determined by Justi and Van Driel (2006), who stated that the use of these criteria was crucial in the IMTPG in order to understand the development of teachers' practical knowledge. Their research revealed the usefulness of this model in enabling understanding of reciprocal relationships between domains. For our study we used the criteria as adapted by Justi & Van Driel (2006) (see Table 4.1).

Another important adaptation we made was the use of several arrows simultaneously to indicate the mediating processes. Clarke and Hollingsworth (2002) showed one pathway for each change. In our study, however, we found more (and sometimes even simultaneous) pathways between domains. For example, when a teacher changes an idea about the science curriculum and enacts upon this with respect to not only changed behavior in the professional development context (see arrow 1 from PD to ED in Figure 4.3), e.g. an adjustment of her action plan, but also as regards changed behavior in the Domain of Practice, e.g. by changing her lesson plan (see arrow 1 from PD to DP in Figure 4.3). In that case two processes occur simultaneously and these were given the same number (see Figure 4.3).

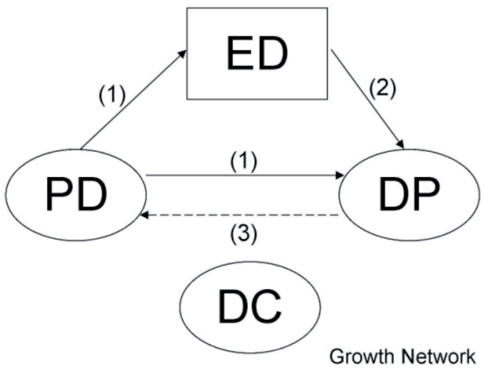


Figure 4.3. Simultaneous process in a growth network

4.4. Method

4.4.1. Research question

The following research question was central to the present study: *What are the possible pathways that lead to changes in science teachers' pedagogical content knowledge in a professional development program?* To answer the research question we formulated the following specific sub-questions:

1. What pathways of change can be identified among the participants of a professional development program using the IMTPG model?
2. Which of the identified pathways are related to the development of science teachers' pedagogical content knowledge?
3. What specific elements of the professional development program contribute to development in the teachers' pedagogical content knowledge?

4.4.2. Participants

Twelve in-service science teachers from middle and high schools in the Mid-West region of the United States volunteered to participate in this study (see table 4.2). The criteria for participation were completion of their action research project, willingness to submit an action research report, and willingness to be interviewed as a follow-up on their action research project.

The participants' schools were located in small rural communities. All participating teachers were present at the two-week summer program and the four follow-up sessions during the school year 2005-2006. The teachers submitted an action research report which included lesson plans and did an interview with the author.

4.4.3. Data collection

In order to understand the complex pathways between the domains for each PCK component, we used three data sources: the teachers' action research

Table 4.2.
Demographics of the teachers participating in the study

Teacher	Name (fictitious)	Years of experience	Subject taught	Grade level
1	Betsy	12	Deserts	8th
2	Josh	7	Atomic theory	5th
3	Carlene	8	Rocks and minerals	8th
4	Dana	17	The human body	4th
5	Diane	22	Cell structure/heredity	7th/8th
6	Donna	21	Volcanoes	7th
7	Matt	28	Photosynthesis and respiration	7th
8	Norma	3	Cell structure	7th
9	Rhonda	26	Bats	7th
10	Shania	21	Cell structure	6th
11	Stephanie	10	The human body systems	7th
12	Trisha	2	Earthquakes	4th

reports, a semi-structured interview, and the teachers' reflective journals about the professional development process.

4.4.3.1. The action research report

At the start of the summer program the science teachers received an electronic outline of an action research report. During the MSP program the teachers worked on their action research reports while they documented their findings in this format (see timeline in Figure 4.4). As the program continued the teachers were able to build upon this document and make revisions. At the end of the year it was this document that they submitted as the action research report; it also included an overview of their lesson plans and of products made by students that were collected during the year.

4.4.3.2. The electronic journal

All teachers kept a personal electronic journal in which they reflected on their personal progress. At some points during the MSP program, time was allotted for the teachers to write their experiences in this journal. They were asked to reflect on the presentations by the university staff and the workshop activities during the summer course, as well as on their findings in the classroom, their action research progress, and how they felt about the action research project. At the end of the year the teachers submitted this journal as part of the evaluation process.

4.4.3.3. The interview

After the teachers submitted their action research report and journal, the first author conducted interviews with the volunteering participants. During the interview the teachers were asked about their action research project. Whenever more detailed information was needed on certain topics

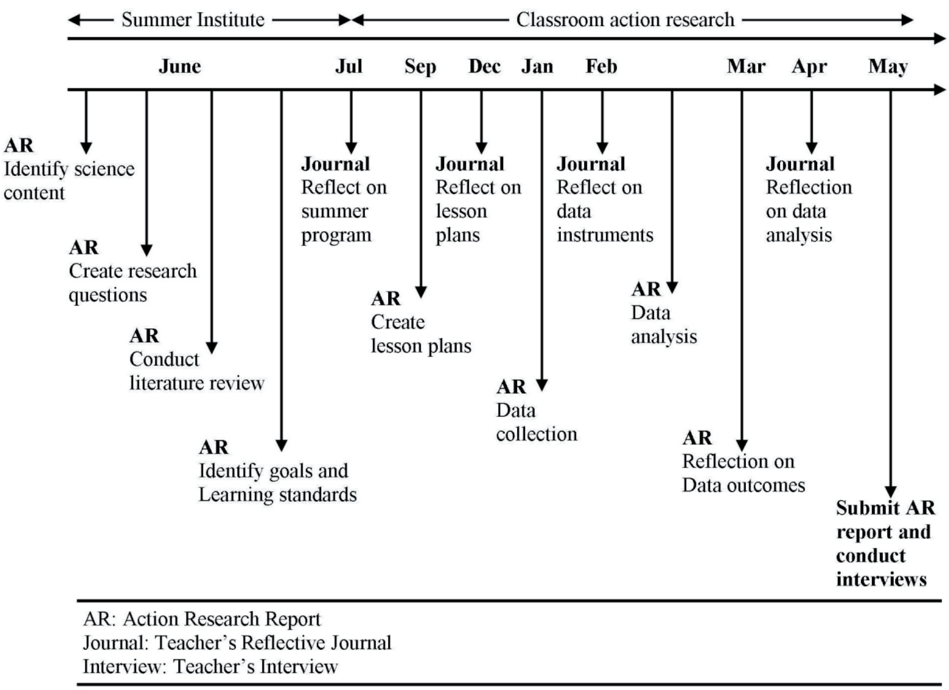


Figure 4.4. Overview of data collection in this study.

concerning the development of PCK, more probing questions were asked. For example, when a teacher wrote in her action research project about *'the use of models to study the atom theory'*, specific questions were asked about how the teacher learned about this method, how the method was used, and what her personal experience was of using that method to teach a specific science subject. The timeline shows how and when these data sources were developed (see Figure 4.4)

4.4.4. Data analysis

Data analysis was conducted in the following steps:

1. All interviews were transcribed verbatim.
2. All data were examined and selected for indications of teacher change. To record the changes we used the following statements:
   a. Changes in cognition included statements such as *I have learned that, I know how to, I understood why, etc.*
   b. Changes in attitude or beliefs included statements such as *I feel that now I can, I believe now that, I am confident in, I think now I can, etc.*
   c. Changes in perceived or intentional behavior included statements such as *Now I am doing, I used to do… but now I am doing…, I tend to do more…, I am doing things differently now, etc.*
3. We categorized the selected statements indicating change to one of the PCK components suggested by Magnuson et al. (1999).

   Example 1: *I found that I could use portfolios to assess experiments in photosynthesis* indicates teacher change in the use of an alternative student assessment tool. This statement was categorized as the PCK component *knowledge of students' assessment*.

   Example 2: the statement: *Instead of explaining, I could use models to explain the atom theory* indicates change in using a different type of instruction. This was linked to the PCK component *knowledge of instructional strategies.*

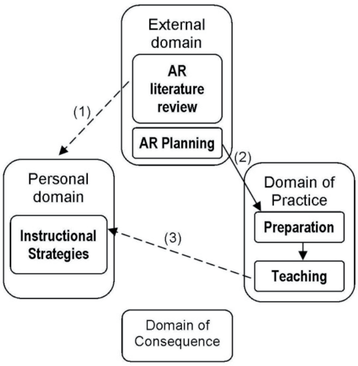
   All the statements from the three different sources were triangulated to ensure reliability and were then linked to each PCK component.

4. Next, using the adapted criteria from Justi and Van Driel (2006) (Table 4.1), we examined these changes to determine if there were any relations between domains of the IMTPG. Then we determined in which domain the entry point occurred, and how this affected the other domains, especially in the Personal Domain, which includes the teachers' PCK (see Table 4.3).
5. We then constructed a pictorial representation (pictogram) for the development of each PCK component, showing relationships between the domains of the IMTPG (see an example of a pictogram in Table 4.3). We created one pictogram for each PCK component per teacher, which resulted in 48 pictograms.
6. In accordance with the work of Zwart et al. (2007), we studied the 48 pictograms in order to identify particular pathways on the basis of the common entry points (start), the sequences of changes, and the end points. We investigated particularities of the pathways and discussed how one pathway differed from the others before agreeing on each pathway. After identifying the pathways we categorized each pictogram by its particular pathway.

To strengthen the internal validity of the analysis, the selection and categorization of the patterns of change were conducted independently by the author and an independent researcher (Cohen, Manion, & Morrison, 2000), and the results obtained were compared. In only a few cases was there a difference; in those cases the discrepancy was discussed until agreement was reached.

Table 4.3.
Example of a pathway that indicates a change in a teacher's PCK component based on the teacher's data (based on instructional strategies of teacher Josh)

Sequence of processes	Relation between domains	Criteria (from Justi & Van Driel, 2006)
Josh reflects on the use of differentiated instructions in his lessons about atoms: '*Differentiated instruction has been promoted through discussions with the university faculty as part of our professional development school partnership. I had been tentative about implementing differentiated instruction because of the commitment of the variety and quantity of materials, the difficulty of accurately assessing student performance, as well as being able to have reliable objective data to reflect on to determine if differentiated instruction would fit my current teaching style' (from AR)*	External Domain to Personal Domain (arrow 1)	When something that happened during the learning activities modified the teacher's initial cognitions, behavior or beliefs
Josh decides to use differentiated instructions in the classroom: '*Students working on differentiated projects were allowed to choose from differentiated laboratory activities and completed these activities within the same timeline as the standard. The goal was that all students would be able to explain the modern theory of the atom, read a periodic table and identify the symbol's name and determine the number of protons, neutrons, and electrons the element has, and identify the 4 basic chemical reactions'(from AR)*	From External Domain to Domain of Practice (arrow 2)	When something that happened during the learning activities influenced something that occurred in the teacher's practice.
Josh responds to this classroom strategy: *'I find myself uncovering new features and gaining confidence in the use of differentiated instruction. I see increasing opportunities for classroom use. I still am not sure whether the commitment of managing 70 or more students would make this easier or just different from current methods. The idea of working in this setup is intriguing, but I will have to keep an open mind and wait and see what develops' (from journal).*	From Domain of Practice to the Personal Domain (arrow 3)	When something that the teacher did in his/her teaching practice modified his/her cognitions or beliefs (without the teacher reflecting on classroom outcomes first)



4.5. Results

We found three different pathways of change. In this section we discuss each pathway by explaining how they were constructed and how they differed from each other. Where necessary, we will use statements from the teachers' journals to explain the typical enactments and reflections associated with each of the pathways.

4.5.1. Knowledge of science curricula

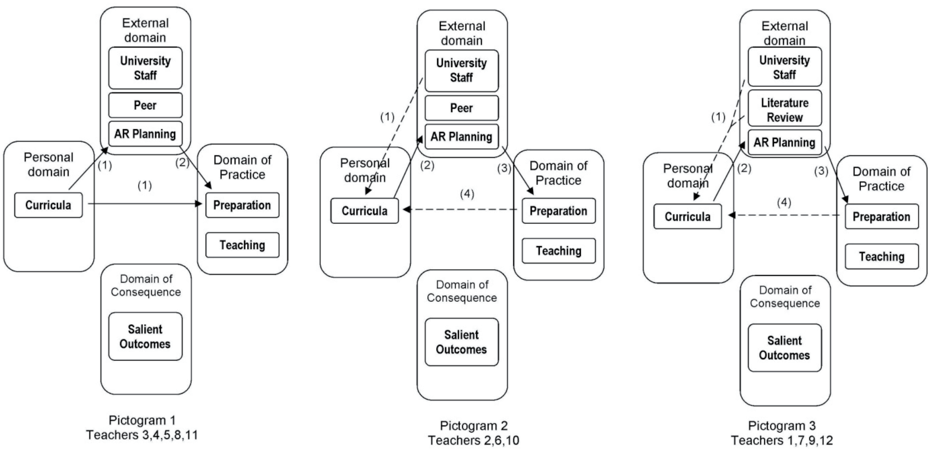


Figure 4.5. Pictorial representations of development of knowledge of science curricula

When investigating pathways that related to the PCK component knowledge of science curricula, we identified three pathways (see Figure 4.5). In this study changes in the PCK component *knowledge of science curricula* are represented by two different types of pictograms (pictograms 2 and 3), whereas pictogram 1 does not indicate a change in the teachers' knowledge of the science curricula. In pictogram 1, the changes originate from the teachers' Personal Domains (entry point). These teachers used previous knowledge of goals and objectives in their action research planning (AR planning) and their lesson plans (see arrows 1), but did not show any reflection on their science curricula, thus showing no changes in their knowledge of science curricula.

In pictogram 2, the entry point is in the External Domain, where teachers consulted the university staff. An example of pictogram 2 from teacher 6: Donna, a seventh-grade science teacher, contacted the university staff. *'[The university staff] helped me a lot. She [university professor] did one presentation on molecular structure and bacteria and it was so good. I gained a lot of knowledge from presentations and mentoring. She [mentor] was very informative and anytime I needed [to know]something... She was my source of information* (arrow 1. source: teacher interview). When conducting her action research, Donna reflected: *' I do need to address the problem of heredity. I used the sites in my [classroom] project to integrate some ideas that address this issue'* (arrows 2 and 3. source: teacher interview). After she had planned her lessons, Donna said*: ' I wanted them to learn and understand the structures of cells. And it was basically the beginning of microbiology, so I wanted them to get the basic framework to understand cellular structure'* (arrow 4. source: teacher interview).

In the third pictogram the teachers not only consulted the university staff, but also reviewed the literature to learn about their science curricula. For example, Matt (teacher 7), a 7th -grade high school teacher, used the presentations from the university staff and did a literature review on photosynthesis to improve his lessons: '*I was forced to reflect on what I taught and began making changes [in the curriculum] based on the presentations from [the university staff]*' (see arrow 1 in pictogram 3. source: reflective journal). After his literature review, Matt learned that '*... the microcomputer can now be used as a tool in the laboratory by students of all ages. The ability to connect a device (a probe) to the computer that can measure things in the real world (such as temperature, position, sound intensity, pH, light intensity and force) now allows students and teachers to acquire information about the world in a way that is new and exciting and can make a major contribution to the science conceptual development of the user. The ability of the microcomputer to transform these data into a real-time graph as the experiment progresses is a second critical contribution to conceptual development.*' (arrow 1. source: action research report). Matt incorporated these findings in his action research plan (arrow 2) and prepared his lesson plan accordingly (arrow 3). At the end of the project Matt reflected on his lesson plans: '*This is a new area that I want to move into that offers great possibilities for student learning in regard to cellular respiration and photosynthesis*' (arrow 4. source: teacher interview).

4.5.2. Knowledge of instructional strategies

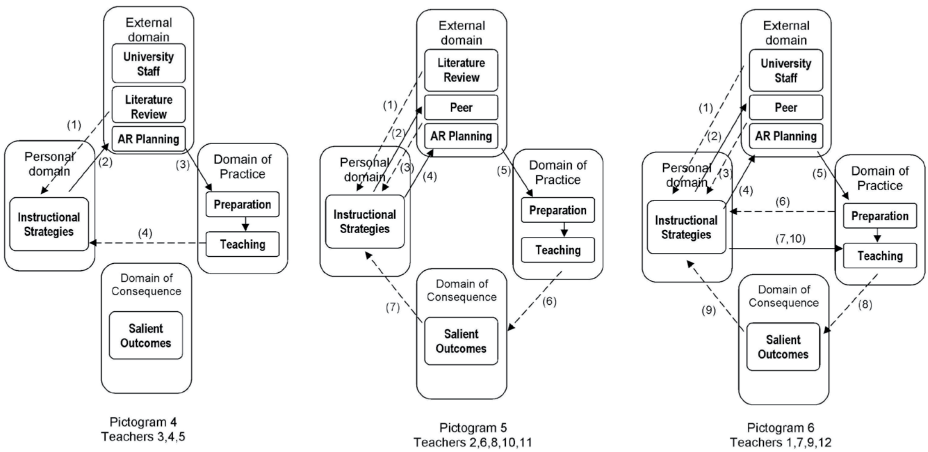


Figure 4.6. Pictorial representations of development of knowledge of instructional strategies

Data analyses for the PCK component *'knowledge of instructional strategies'* shows pictograms with similar entry points but with three different pathways leading to three distinctly different learning outcomes (see Figure 4.6). All entry points are in the External Domain, where teachers reviewed the literature. The participants used the literature extensively to search for appropriate instructional strategies for their lessons. Some teachers discussed their instructional strategies with their peers (pictograms 5 and 6), others did not (pictogram 4). After planning (arrow 2), preparing (arrow 3), and conducting their lessons, pictogram 4 teachers reflected on their lessons (arrow 4). An example from Dana (teacher 4): '*I used experiments while studying the human body because I wanted my students to have as many experiences as possible. I think that they do learn better by providing different evidence themselves, not just out of a book* (pictogram 4, arrow 4. source: teacher interview).

Pictogram 5 teachers reflected on their classroom practice (arrow 6) and their classroom outcomes (arrow 7). An example of arrows 6 and 7: After Donna (teacher 6) taught her 6^{th}-grade class on volcanoes, she told us that her students did not learn that much when they were taught in the traditional way. Now, she was convinced that her students did learn something: '*Now they remembered something.. .. throughout their school life, an thing that has to do with cells will come back to them, and I think that alone makes a lot of difference'* (pictogram 5, arrows 6 and 7. source: teacher interview).

Pictogram 6 teachers continuously reflected on their instructional strategies: on past experiences (arrow 1), after reviewing literature (arrow 2), after consulting peers (arrow 4), after preparing lesson plans (arrow 7), and after teaching (arrow 9). Furthermore, after these teachers reflected on their classroom outcomes (arrow 10), they acted on it in order to change their classroom teaching (arrow 11). Matt's (teacher 7) example of arrows 10 and 11: *Through using them [micro-based computer labs], I was forced to reflect on how these types of labs work with seventh graders. I saw how they* *impacted the learning in my room as we reviewed video tapes of students doing microcomputer-based labs* (arrow 10. source: action research report)... *We also did a study last year on our pond. And it had all kinds of little spin offs, where we wanted to go with it... So the second time I did [the micro-based computer labs] it was actually better than the first* (arrow 11. source: teacher interview).

4.5.3. Knowledge of student understanding of science

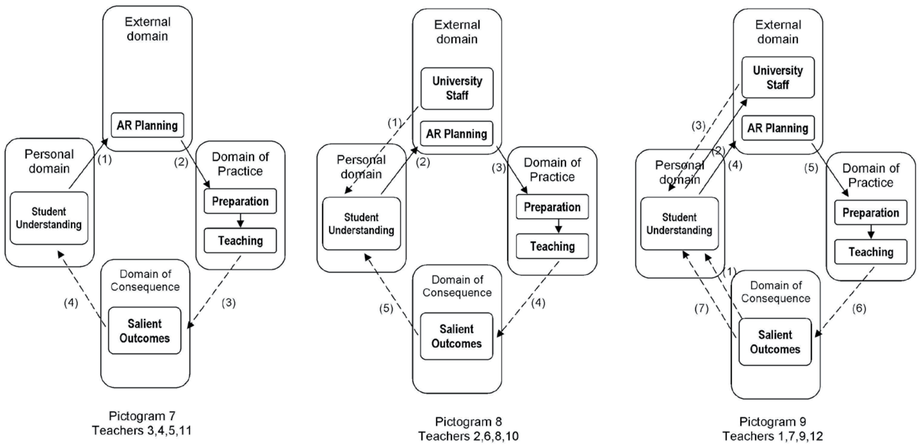


Figure 4.7. Pictorial representations of development of knowledge of student understanding of science.

For *knowledge of student understanding of science* we found that science teachers used three different entry points from three different domains (see Figure 4.7): pictogram 7 shows that the science teachers started from the Personal Domain with some knowledge of how their students learned science best (pictogram 7, arrow 1). In pictogram 8 we see that the teachers were inspired by the university staff on how students learn science (pictogram 8, arrow 1). In pictogram 9 the entry point is in the Domain of Consequence, where teachers reflected on gaps in their students' knowledge left after previous classroom experiences (pictogram 9, arrow 1). Pictograms 8 and 9 show similarities, since they both show that teachers consulted university staff in their process of developing knowledge of student understanding.

Here are two examples of university staff contributions: Josh (teacher 2) reflects on the presentations given by the university staff: *'I saw another way to teach the science content to students. This activity [integrated presentations] can be used at any grade level. It helped me to grow in my ways of teaching by showing me the ways the students learn and giving me their perspective*' (pictogram 8, arrow 1. source: reflective journal*)*. Matt (teacher 7) said that '*a lot of new things were presented in either math or science. I found out a lot of things about how children learn: they learn better by doing and we picked up on the research that was done that we could use in our classroom'* (pictogram 9, arrow 3. source: reflective journal). In all situations related to knowledge of student understanding we found that teachers used classroom outcomes to reflect on student learning. Example from Trisha (teacher 12): '*The part where the students taught themselves was a strong feature. I think they learned more about earthquakes when they were doing the teaching themselves. So they took ownership of their project and that is what turned it into a success*' (pictogram 9, arrow 6. source: teacher interview).

4.5.4. Knowledge of student assessment of scientific literacy

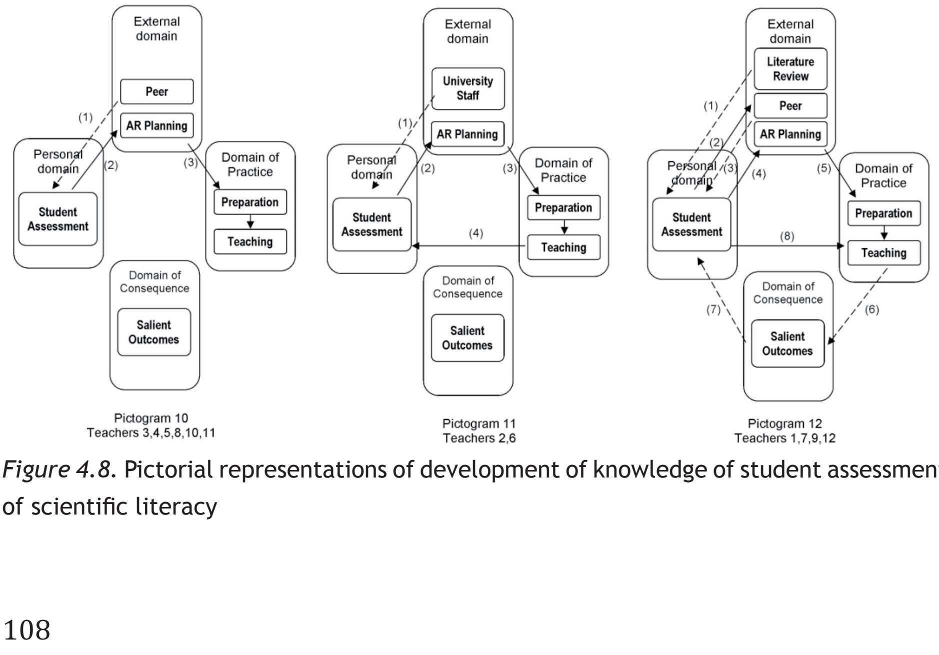


Figure 4.8. Pictorial representations of development of knowledge of student assessment of scientific literacy

In *knowledge of student assessment of scientific literacy* the entry points are all in the External Domain, but in different sub-domains (see Figure 4.8). Pictogram 10 shows that the teachers started with peer discussions about what assessment methods were appropriate for their lessons. Pictogram 11 teachers received guidance on assessment methods from the university staff. They reflected on assessment methods but did not use classroom outcomes as part of these reflections. Donna (teacher 6) reflected: *'after I do a lesson I often, as just a part of the evaluation, go through and reflect upon what worked'* (pictogram 11, arrow 4, source: interview*).* Pictogram 12 teachers first consulted the literature and then used a colleague to discuss ideas with. Pictogram 10 teachers did not reflect on their classroom practice. Pictogram 12 teachers used classroom outcomes to reflect on assessment methods. A final example from Matt (teacher 7): *'During the actual project at the time, when we were looking at respiration and photosynthesis, I was looking at the group interaction and what was happening to them (pictogram 12, arrow 6. source: teacher interview). It did make me see the kids doing certain things [performing certain skills] that I probably was not aware of before… I have also found that my students are much more capable of doing sophisticated work than I thought* (pictogram 12, arrow 7. source: teacher interview*).*

4.6. Conclusions and discussion

Our study focused on three major questions: (1) What pathways of change can be identified among the participants of a professional development program using the IMTPG model? (2) Which of the identified pathways are related to the development of science teachers' pedagogical content knowledge? (3) And what specific elements of the professional development program contribute to development in the teachers' pedagogical content knowledge? Our research aim was to analyze different pathways that lead to changes in the various components of PCK. We discuss the different pathways in detail in this section.

4.6.1. Different pathways related to PCK development

Although we found that each pathway was different for each teacher, we were able to categorize these pathways, based on similar entry points, similar domains, and similar ending points. For each PCK component we thus found three distinct pathways that teachers could follow when participating in the MSP. One pathway did not lead to changes in the teachers' PCK (see pictogram 1). This pictogram includes the teachers' knowledge of science curricula and indicates that 5 teachers did not show whether they had learned anything about the science curricula. Clarke and Hollingsworth (2002, p. 958) use the term 'change sequence' when there is a relationship between two different domains. We consider the pathways in pictogram 1 as change sequences. These change sequences may have occurred, because these teachers already knew the science topic or were not interested in learning new content knowledge on this topic.

When investigating pathways that lead to PCK development, we found two distinct pathways that lead to changes in PCK: pathways that include the Domain of Consequence (see pictograms 5, 6, 7, 8, 9, and 12) and pathways without the Domain of Consequence (pathways in pictograms 2, 3, 4, 9 and 10). Clarke and Hollingsworth (2002, p. 958) use the term 'growth networks' when more than two relationships exist between different domains. They state that 'growth networks' demonstrate professional growth and reflect ongoing and lasting changes. In our study, pathways *without* the DC reflect 'simple growth networks', whereas pathways *including* the DC can be seen as more 'complex growth networks'. When closely examining those pathways showing a 'simple growth network' we did find changes in the different domains; however, the teachers did not demonstrate whether they learned from their classroom actions. For example, Dana (teacher 4) reflected on her knowledge of instructional strategies after preparing lesson plans, but failed to reflect on how her students perceived this new way of teaching (see pictogram 4). In the pathways with a 'complex growth network' the teachers reflected on their students' learning (a change in the Domain of Consequence) and were able to specify what they learned from their students. For example: Matt (teacher 7) reflected on the teaching strategy used in his classroom, based on student feedback, and was able to argue whether the instructional strategy was effective or not (see pictogram 6). In our study we found that teachers with a more 'complex growth network' indicated obvious changes in their pedagogical content knowledge. Teachers with a 'simple growth network' did show change, for example in cognition, but it is doubtful whether this change affected their teaching. These findings show that reflections on classroom outcomes were important for the PCK development of these in-service teachers.

We also concluded that there were two distinctly different groups of teachers in this study when we investigated the pathways that led to PCK development. One group (teachers 3, 4, and 5) showed similar pathways in pictograms 1, 4, 7, and 10, while the other group (teachers 1, 7, 9, and 12) showed the same pathways in pictograms 3, 6, 9, and 12. When comparing these two groups, we concluded that the second group of teachers was constantly reflecting on their changes, while the first group showed few reflections in their pathways. In particular, the second group (i.e., teachers 1, 7, 9, and 12) had pathways including reflections from the Domain of Consequence, except in the PCK component *knowledge of the science curricula*. It could be, however, that the teachers did reflect on their curricular knowledge when they planned their lessons (see pictograms 2 and 3), but never reflected on how this curricular knowledge was actually used in the classroom. Pathways found for the first group of teachers (i.e., teachers 3, 4, and 5) did not include this Domain of Consequence except in the pictograms on *knowledge of student understanding*. The pictograms of teachers 2, 6, 8, 10, and 11 had pathways that did not belong to either of these two groups. We were therefore unable to categorize teachers 2, 6, 8, 10, and 11 in one of the two groups.

Looking at the details we also found that on the basis of the reflections in the Domain of Consequence, some teachers (i.e., teachers 1, 7, 9, and 12) were able to enact from their Personal Domain in order to revise their classroom teaching (see pictograms 6 and 12). From the Clarke and Hollingsworth (2002) model, it was evident that teachers who reflected on past experiences and their own understanding (from the Domain of Consequence) searched for new and improved methods (in the External Domain), tried new experiences (in the Domain of Practice), reflected on student outcomes (once again Domain of Consequence), and were able to build new understandings, thus developing their PCK (see pictogram 12). Although we did not focus in this study on classroom teaching, we found that teachers who reflected on their teaching through the Domain of Consequence, developed their PCK in such ways that seemed to enable them to alter their classroom teaching.

Working with the IMTPG as an analytical tool proved to be helpful, giving us more insight into the processes leading to PCK development. It enabled us to make the, often tacit and implicit, change pathways explicit and, furthermore, it enabled us to indicate powerful elements of the action research program.

4.6.2. Powerful elements in the professional development program

Investigation of the different entry points led us to conclude that changes in the External Domain often induced major changes in the PCK found in the Personal Domain. Forty-one of the 48 entry points were located in the External Domain. Fourteen entry points were linked to the university staff, seventeen entry points were found when teachers used their literature review, and ten were prompted by teachers participating in peer discussions. Furthermore, we noted that the university staff contributed most in helping participants define science curricula, and in constructing knowledge of student understanding. The literature review and peer discussions were used extensively in the search for instructional strategies and assessment methods. It should also be noted that teachers valued the use of the educational and science literature reviews to improve their teaching. When teachers studied the literature they were able to adapt their instructions more to current recommendations from this literature (pictograms 3, 4, 6, and 10). This tallies with the findings of other scholars (Fennema, Carpenter, Franke, Levi, Jacobs, & Empson, 1996; Rhine, 1998). Rhine (1998) believes that resources on educational research can be crucial for in-service teachers as a 'lifelong resource' for lesson planning. Although reading research publications is still seen as an informal experience in professional development (Ganser, 2000), we concluded that teachers may benefit from it. Teachers in this study used the literature to find information on science subjects and to learn about effective ways to teach these subjects. Then when they discussed their findings from the literature with peers, this helped them reflect on this newfound knowledge, providing a deeper understanding of their PCK (pictograms 6 and 12). Furthermore, many teachers conducted their literature reviews with an eye to problems or concerns that had arisen from previous classroom experiences. In general we found that teachers who conducted a literature review and participated in peer discussions acquired a better understanding of the use of instructional strategies and assessment methods, such as the use of micro-based computer labs to increase students' science skills, and the use of students' journals to assess their students' knowledge. In the planning of professional development programs, therefore, teachers' reading of educational research literature should not be underestimated, since it creates opportunities to construct new knowledge.

4.6.3. Implications for professional development programs

In this study we used the IMTPG model to study teacher change processes and reported the results back to the teachers. In future practice, however, teachers participating in a PD program that includes action research, may benefit from using the model and gathering evidence to analyse their change processes themselves. In that sense, teachers themselves should become aware of their own mediating processes (e.g. enactment of ideas and/or reflection on student learning) – or lack thereof - which could provide them with the opportunity to improve their learning.

For researchers conducting professional development activities it is important to examine the content of the teachers' experiences, the processes that occur, and the contexts in which they occur (Fielding & Schalock, 1985; Ganser, 2000). It is also important to be able to monitor changes in teachers' long-term processes. The interconnected model of teachers' professional growth is a model that serves to capture such changes, making it possible to describe the changes and uncover the processes for research purposes. In this study we were able to show changes in teachers' PCK by way of their processes of enactment and reflection. Furthermore, this model has shown the differences between teachers' PCK development processes, acknowledging that pedagogical content knowledge is indeed personal and context-bound. The model also illustrated that professional development is not a linear process, but rather a complex network of processes sometimes occurring simultaneously. We found evidence that the Domain of Consequence plays a crucial role in a teacher's PCK development. More attention should be paid to how this domain interacts with the other domains. Furthermore, when we adapted this model by refining the different domains, it became evident that specific factors in one domain triggered changes in other domains. For example, we found that the university staff in the external domain triggered teachers' knowledge in instructional tools. This makes the model very useful as an analytical tool by which to investigate teachers' knowledge development. The model shows how changes in teachers' knowledge occur, why they occur, and sometimes under what circumstances they can occur. Clarke and Hollingsworth (2002) have argued that professional development programs should offer participants the opportunities to enact change in a variety of forms. We support this idea and conclude that external sources are essential to professional development programs.

In this study action research was used as an effective tool to help teachers reflect on their classroom experiences, find improved strategies for their teaching, and reflect on their classroom findings. Cohen et al. (2000) mention that action research is suitable when specific knowledge is needed in certain classroom situations. It is therefore important for professional development programs to have teachers reflect on their classroom findings (Van Driel et al., 2001). Professional development trainers should consider having participants reflect on their own classroom outcomes. Although we acknowledge that in this study only a few teachers reflected on their classroom outcomes, reflecting on classroom learning seems to be important in the development of PCK. Reflections via the Domain of Consequence seem to be important in order for teachers to be able to learn from their actions and their classroom outcomes, and to alter their ways of teaching in such a way as to increase student learning.

With a limited number of participants we were only able to draw conclusions based on a one-cycle action research process of teachers in this particular program. More research is needed to investigate long-term processes in teachers' professional development, such as teachers' reflective processes that contribute to their PCK development.

Chapter 5. The relation between teachers' orientations towards science teaching, teaching concerns, levels of inquiry-based instructions, and their classroom activities

Abstract

A group of 24 science teachers were studied to investigate the relationships between teachers' orientations towards science teaching, teaching concerns, and their levels of inquiry-based instructions. We used a qualitative approach to study these relationships. We found that when science teachers planned to use inquiry-based instructions at lower levels such as 'confirmation' and 'structured inquiry', they were mostly concerned about their students' low grades, their lack of science knowledge, and their lack of inquiry skills. When science teachers planned to use inquiry-based instructions at higher levels such as 'guided inquiry' and 'open inquiry', we found that they were still concerned about the weak relation between students' inquiry skills and their inquiry experiences of the real world. When studying the teachers' orientations, we concluded that teachers who engaged in lower levels of inquiry mostly had teacher-centered orientations, while teacher who engaged in higher levels of inquiry mostly expressed student centered orientations.

Keywords: inquiry, science teaching orientations, concerns.

5.1. Introduction

The use of inquiry-based instructional methods in the science classroom has been widely advocated in the past decade from a variety of sources, including the American Association for the Advancement of Science (AAAS, 1993) and the National Research Council (NRC, 1996). Inquiry-based learning tends not only to help students to develop content knowledge, but also to teach them what science is and how it is done (Sanger, 2007). From a teacher's standpoint, it is important to know how science can be taught through inquiry, and how students learn science when it is taught that way (NSTA, 2000). With inquiry-based learning, students engage in scientific investigations and problem-solving. In addition to general problems such as time constraints, limited classroom facilities, and complex class schedules, the implementation of inquiry lessons is also influenced by various important factors (Roehrig & Luft, 2004). These include the teachers' understanding of science concepts (Hashweh, 1987), the complex processes of teaching and learning and the nature of science (Duschl, 1988), and teachers' beliefs about science teaching and learning (Pajares, 1992). Magnusson et al. (1999) argued that teachers' orientations towards science teaching filter teachers' decisions about implementing inquiry in their classrooms (Magnusson et al., 1999). Some studies have linked teachers' beliefs to their inquiry lessons (Crawford, 2007), but so far none have focused on teachers' orientations towards science teaching and their inquiry lessons. To understand how, and why, science teachers construct inquiry lessons in their practice, we investigated experienced science teachers' orientations towards science teaching in relation to their ways of implementing inquiry teaching. Since in-service teachers take into account their experience from previous years of teaching, we also investigated their concerns, and the potential obstacles they perceived when implementing inquiry teaching.

The aim of this research was to gain a deeper understanding of science teachers' inquiry lessons and how their orientations towards science teaching interacted with their classroom decisions. For this purpose, we focused on a group of science teachers who planned and conducted inquiry-based lessons in their classrooms in the context of a professional development program.

5.2. Theoretical framework

5.2.1. Science inquiry

In several studies, Crawford and others have explored the complex nature of teaching science inquiry in schools (Crawford, 1999; 2000; 2007; Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005). Crawford (1999) found that novice teachers are too inexperienced to create inquiry-based instructions due to their lack of content knowledge, pedagogical knowledge, and pedagogical content knowledge. She noted that 'there is a paucity of research on how to design instructional environments to promote students' understanding of science inquiry' (Crawford, 2000, p. 917). She concluded that teachers should be knowledgeable in not only engaging students in hands-on activities, but also in engaging 'students in cognitive processes used by scientists, when asking questions, making hypotheses, designing investigations, grappling with data, drawing inferences, redesigning investigations, and building and revisiting theories' (p. 934). In a more recent study, Crawford (2007) acknowledged that despite a professional development school setting aiming to teach science as inquiry, prospective teachers practiced teaching strategies that ranged from traditional teaching to full-inquiry projects.

Even if teachers engage in inquiry-based teaching, not all inquiry activities are equivalent (Bell et al., 2005). Inquiry-based activities can range from highly teacher-directed to highly student-oriented. Bell et al. (2005) proposed a four-level model of inquiry (see Figure 5.1). Level 1 is called 'confirmation inquiry' where the teacher provides a research question to which the students know the answer in advance. Students are thus confirming what is already known. In level 2, structured inquiry, the research question is also provided, but the students do not know the answer in advance. However, the students are provided with a set of prescribed procedures. In level 3, guided inquiry, it is the teacher, again, who poses a research question, but the students devise their own methods to answer this research question. Level 4 is called open inquiry, where the students are responsible for creating their own research question and their research design for answering this question.

		How much information is given to the student?			
	Level of inquiry	Question?	Methods?	Solution?	Inquiry based activities
1	Confirmation	x	x	x	Highly teacher directed
2	Structured	x	x		↕
3	Guided	x			
4	Open				Highly student directed

Figure 5.1. Four-Level Model of Inquiry (adapted from Bell, Smetana, & Binns, 2005)

5.2.2 Orientations towards teaching science

Various scholars have argued that orientations towards teaching science should be seen as knowledge and beliefs that guide instructional decisions in the classroom (Borko &Putnam, 1996; Magnusson et al., 1999). In particular, science teachers' beliefs influence the inquiry activities they use in their science lessons (Crawford, 2000, 2007). No research, however, has shown evidence how these orientations actually guide the planning and conducting of classroom instructions. Magnusson et al. (1999) stated that 'the orientations are generally organized according to the emphasis of the instruction, from purely process or content to those that emphasize both and fit the national standard of being inquiry-based.' (p. 97). These scholars proposed nine different orientations ranging from a process orientation (process) to content (academic rigor, didactic, conceptual change), to both (activity-driven, discovery, project-based science, inquiry, guided inquiry) (see Table 2.1). Magnuson et al. (1999) elucidated that these teaching orientations are based on teachers' purposes and goals for teaching science (p. 97).

Friedrichsen and Dana (2005) studied these orientations empirically and concluded that science teachers hold science-specific orientations as well as general orientations. In their study they evidenced that biology teachers have both central and peripheral teaching goals. They concluded that orientations consist of three major goals: (1) affective domain goals; (2) general schooling goals; and (3) subject matter goals. They noted that in addition to the teachers' orientations, prior work experience appeared to be an important factor influencing preparation for teaching. Tsur and Crawford (2001) also noted that teachers held more than one orientation with one or two primary orientations. Examining these orientations closely, we found that they include the purposes of science teaching (Magnusson et al., 1999). Friedrichsen et al. (2011) re-examined the science teaching orientations and concluded that this concept is problematic because (a) orientations are used in different or unclear ways; (b) there is an absent or unclear relationship between the teaching orientations and the other PCK components; (c) teachers cannot simply be assigned to one of the nine categories of Magnusson et al. (1999) orientations; and (d) the overarching function of this component is ignored in the literature. They propose defining science teaching orientations as a set of beliefs using the following dimensions: goals and purposes of science teaching, views of science, and beliefs about science teaching and learning.

5.2.3. Science teaching concerns

Teachers' knowledge plays an important role in the preparation, implementation and evaluation of lessons. Awareness of obstacles in learning is also part of the teachers' knowledge which they take into consideration when planning and conducting science lessons. De Jong and Van Driel (1999) found that as teachers teach, they learn more about the obstacles of teaching. Earlier studies on teachers' concerns have shown that prospective teachers have other concerns than in-service experienced teachers (Melnick & Meister, 2008). In-service experienced teachers have concerns and orientations that are closely related to their prior work experiences (Friedrichsen & Dana, 2005). De Jong and Van Driel (1999) reported that prospective teachers have three different pedagogical content concerns (PCC): self PCC, task PCC, and student PCC (cf. Fuller & Brown, 1975), where one PCC may be dominant over the others (De Jong, 2000). Berry et al. (2008) asked in-service science teachers to start from their own science teaching concerns when they investigated teachers' pedagogical content knowledge (PCK). They found that teachers were concerned about students' learning when they planned their lessons. In this study we also focused on the teachers' concerns when they planned their inquiry-based lessons.

5.3. Context of the study

The present study was conducted in the context of a professional development program called the mathematics and science partnership program in the year 2006-2007. One of the goals of the MSP was to increase teachers' performance when teaching mathematics or science. A specific aim of the MSP program was to increase teachers' knowledge of teaching science and mathematics through inquiry. In this study we only investigated the science teachers who participated in the MSP program of 2006-2007 in the South West region of Illinois. The teachers were asked to conduct inquiry lessons in their class. As part of the MSP, teachers were asked to use an action research approach to develop and conduct their inquiry-based lessons. In this way they could systematically monitor their own progress. Applying this approach, the teachers were required to plan their lessons, conduct their lessons, collect data for their action research, write a progress report, and keep a journal of their reflections. To start the program, a two-week Summer Institute was organized during which the science teachers were exposed to scientific inquiry. In the first week of the Summer Institute, university staff taught them about scientific inquiry, explaining the different steps of scientific inquiry. The university staff posed a problem on ecology and the science teachers had to create their own questions. Discussions were used to help the teachers to focus on these questions on ecological relationships. Next, the university staff facilitated the teachers in an outdoor activity where the teachers could design how to collect data on different plants and invertebrates in the neighbourhood. They then had to analyze their data and explain the ecological relations based on analyses of the data collected. Each group had to present their findings to other groups, including how they answered their questions. In the second week, the teachers were required to conduct a literature review on inquiry-based teaching. They could discuss and share their findings with other teachers, and the university staff acted as mentors for in-depth questions on inquiry-based learning. After the Summer Institute the teachers created lesson plans using scientific inquiry as the basis for lessons on science topics of their own choice. Throughout the entire year, each teacher worked on a progress report, which was part of their action research. All the teachers kept an electronic journal to reflect on their lessons.

5.4. Method

5.4.1. Aim and research questions

Our aim was to gain a better understanding of how and why teachers conduct inquiry-based lessons. In particular, we were interested in how teachers' orientations, their concerns and other variables, such as years of teaching experience and grade level, were linked to their inquiry-based teaching in the context of a PD program (i.e., the MSP). We investigated teachers' orientations towards science teaching and their teaching concerns in relation to how they planned and conducted their inquiry-based lessons. The main question which guided this study was: *What is the relation between teachers' concerns, their orientations towards science teaching, and the instructional levels of inquiry when they design and conduct lessons?* This main question consisted of the following specific sub-questions:

1. What level of inquiry do science teachers use when planning inquiry-based lessons?
2. How are the teachers' concerns and their orientations towards science teaching related to their levels of inquiry?

5.4.2. Data collection

Twenty four in-service science teachers participated in the MSP program of 2006-2007 and were included in this study. Throughout the entire year these teachers documented the progress of their action research. A pre-formatted document was used to make sure that the teachers documented all the different steps of their action research in the progress report, in which they had to provide a rich description about why the teaching of this topic had been a problem in previous years. The teachers included their purposes and goals for teaching this topic as an inquiry lesson in the report. All the reports were collected at the end of the year. To study the teachers' planned activities, we also collected their lesson plans, in which they described the activities that they planned for their inquiry lessons. As a third data source we collected the teachers' reflective journals. We asked the teachers to write down their reflections in an electronic journal during the year. Three different data sources were therefore used for this study: the teachers progress reports, their reflective journals, and their lesson plans.

5.4.3. Data Analyses

To safeguard the objectivity of the data analyses, coding was carried out independently by two researchers and a research assistant over the whole analysis process. We read the data several times to become familiar with the various data sources and their content. We then decided what data to use from each of the data sources.

1. From the teachers' *progress reports* we selected general information such as years of teaching experience, students' grade level, number of students in the class and science topic taught. From these reports we also

selected statements teachers had made regarding their concerns and their orientations towards teaching. Statements regarding the teachers concerns usually started with: 'My students had difficulties with...', or 'My students don't have any experience in…' or 'Last year I had a hard time to...'. To code the teachers' concerns, data analysis aimed at identifying codes emerging from the data using a grounded theory approach (Glaser & Strauss, 1967). To determine the teachers' orientations, we used statements from the progress report starting with: 'My goal for this project is to…'or 'I want my students to …'. To study the science teachers' orientations we coded the statements using the nine orientations of Magnusson et al. (1999). From the data we found some statements that did not reflect the orientations of Magnusson et al. In that case we used additional codes for the teaching orientations that emerged from our data.

2. From the teachers' *lesson plans* we determined what level of inquiry was used following the model of Bell et al. (2005). When a teacher planned to use inquiry to confirm what was lectured or demonstrated in the classroom, this was labeled as level 1:confirmation. A teacher's inquiry level was labeled structured inquiry (level 2) when the teacher provided a research question and gave students the procedures to conduct inquiry. We labeled a statement as level 3 (guided inquiry) when a teacher posed the research question but had their students come up with their own method of inquiry. The teacher had to make sure that the students' inquiry plan would lead them to researching and answering their research questions. Level 4 (open inquiry) was coded when we found that the teacher only presented the science subject, and the students had to come up with their own research questions and plan and conduct their own inquiry.

After categorizing the statements with the different codes, we grouped the teachers according to the different levels of inquiry, that were assigned to them (see above). We then characterized each group by analyzing the relations between the teachers' concerns and their orientations. We used a cross-case comparison to identify similarities and differences between the teachers. Yin (1994) noted that multiple case studies provide the researcher with greater opportunities to explore patterns and themes within the data, so we decided to treat each teacher as an individual case. 'Understanding unique cases can be deepened by comparative analysis' (Patton, 2002, p. 56). The process of comparing teachers' concerns and their orientations with the same level of inquiry across the case profiles allowed us to gain a deeper understanding of the data.

5.5. Results

We first created a spreadsheet with the codes used for statements found in the different data sources (see Appendix B). Based on this spreadsheet we created Table 5.2 with an overview of the results, where the teachers are grouped according to their level of inquiry.

We found eight teachers who engaged in confirmation inquiry, eight science teachers at the level of structured inquiry, six teachers at the level of guided inquiry, and two teachers at the level of open inquiry. Although we found that all teachers were oriented towards teaching content, different patterns occurred at each level of inquiry. All teachers were also oriented towards teaching skills, except those who engaged in confirmation inquiry. To explore the relationships between the teachers' concerns, their teaching orientations and the level of inquiry, we describe each group explaining the level of inquiry, the teachers' orientations, and their concerns. We illustrate each group using examples from the teachers' data.

Level 1: Confirmation inquiry

From analyzing the teachers' lesson plans, we identified a group of 8 teachers who were using inquiry to confirm what was already known. In their lesson plans we found that the teachers typically followed the sequence: explain

Table 5.2.
Overview of the science teachers' levels of inquiry, their concerns and their orientations

Level of inquiry	Confirmation (N = 8)	Structured (N = 8)	Guided inquiry (N = 6)	Open inquiry (N = 2)
CONCERNS				
Low test scores	X	X		
Lack of knowledge	X	X		
Lack of inquiry skills		X	X	
Lack of real world inquiry experience			X	X
TEACHING ORIENTATION				
Content-driven	X	X	X	X
Skill-driven		X	X	X
Activity-driven	X	X		
Didactic	X	X		
Academic rigor	X	X		
Inquiry			X	X
Discovery			X	X
Project-based			X	X

the science concept, then explain the scientific method, then provide a research question. Next, they selected an activity that aimed to assist the students to find answers to the research question. The traditional 'cook-book' method was often used to plan the lessons. In our exploration of the data we found that the teachers in this group were either concerned about the students' low grades or their lack of knowledge of a certain topic. This lack of knowledge was sometimes inferred from low grades in previous years. When exploring their orientations to teaching, we found that these orientations were focused on knowledge; teachers intended to use mainly didactic and hands-on approaches. In their progress reports, the teachers' purposes in engaging students in inquiry focused on the use of hands-on activities. However, when we explored the progress reports and their reflective journals, we found that the teachers often engaged in lecturing and explaining certain science concepts before engaging students in hands-on activities. Here is an example of how we linked a teacher's orientation and his concerns to his inquiry lessons: Ben, a 5th grade science teacher wanted his lesson to be more student-centered: *'I have 19 low ability students in my class this year. I am unsure what lesson plan to use, therefore I don't quite know how I will use the inquiry-based approach. One of the units covered in our science curriculum has to do with ecology. I have never felt confident with the lesson because I never had a good activity to go with the lesson. I am hoping to gain more inquiry-based activities to use in this unit. I feel that if I use more 'hands-on, minds-on' activities and require the students to use science vocabulary words in discussions, the students will remember and explain how living organisms interact with each other and their environment.'(from Ben's reflective journal).* Ben simplified his lessons on inquiry and started to explain to his students about ecological disturbances, before actually exposing his class to an inquiry activity. This activity was very much based on 'cook-book' instructions, where the students had to merely follow the instructions to get to the answers: *'I drew and explained the ecosystem within a control area and disturbance area. I read books about types and compatibility of fish and plants and explained this to my students, I then made an aquatic habitat with various aquatic plants and animals and so my students were able to observe and explain the minor disturbances in that ecosystem....'(from Ben's progress report).* Ben's orientations towards science teaching was focused on the science content and based on didactics and hands-on activities. As we can see from this example, he used the confirmation level to teach his lessons on general ecology. He used the aquatic habitat as an activity, so the students could explain through this activity what disturbances are, and so that he could confirm that the students understood what he had explained in class.

Level 2: Structured inquiry

At this level, the teachers (n=8) started their lessons by explaining the scientific method to their students. Next, they introduced the topic and posed a research question. The students were given clear instructions on how to answer the research questions. In some cases, they handed in their answer sheets and in other cases they were asked to share their findings in a group presentation. Regarding the teachers' concerns, we found that, like the previous group, the teachers were also concerned about students' low grades or lack of content knowledge. However, with this group, we found in addition that the teachers were also concerned about the students' lack of inquiry skills or their lack of knowledge of the scientific method. Concerning their teaching orientations, we found that these were geared towards didactic and hands-on approaches, which were similar to the instructional approaches of level 1. The planned activities were a sequence of lecture, demonstration, explanation of the scientific method, followed by hands-on activities to become familiar with the topic or a specific skill. This sequence was then followed by an inquiry activity geared towards answering a research question. The following is an example from Kathy, an 8th grade science teacher, who reflected on her lesson plans: *'My students need to be able to understand the process of scientific inquiry, in order to investigate questions, conduct experiments, solve problems and understand fundamental concepts, principles and interconnections of life sciences… I have planned to take students out into the field and introduce them to the concept of inquiry-based approach by giving them their freedom to investigate/explore the prairie land behind our school for a preset amount of time and when they return explain the 5E method of inquiry. From that method they will hopefully begin to realize they have some control over what they will learn not just what I will tell them to do.'(from Kathy's reflective journal)*. Kathy wanted her students to find out what the soil of a specific grassland biome would contain for the grassland to grow. From her research report we found that she structured her activities to ensure that her students got engaged in inquiry-based learning: *'I did an introduction to the soils located in a grassland biome… Students were allowed to reflect on the unit of soil and were put in small groups… Then I explained the correct method to collect a soil sample… Tools (hand trowel, bag for soil) were distributed to each group and each group of students was paired with a teacher… I allowed students to* *choose the area to gather soil samples… Students took photographs as they collected their soil samples… They collected soil samples per collection data instruction sheet… They were asked to reflect and predict what their samples would contain… They then engaged in a discussion of soil color, particles, organic matter, soil creatures, and texture. Students then completed their soil texture experiment…' (from Kathy's research report)*. Kathy's orientation was skill-driven, aiming to let the students gain some experience in inquiry. Kathy used the structured inquiry approach in her lessons: She introduced the concept and gave them the assignments. She showed them the procedure for doing an inquiry by teaching the students how to collect and analyze soil samples.

Level 3: Guided inquiry

Teachers at the guided inquiry level (n=6), structured their lesson plans so that they posed the problem and stated the question based on their science topic. They asked their students to find a solution to this problem. We found that these teachers' concerns were focused on students' limited life experiences: lack of real life inquiry experience, lack of interest in science, or failure to connect science to the real world. Examining their orientations, we found them to be focused on the process of inquiry learning. Both discovery learning and project work were two major themes in their orientations towards science teaching. These teachers tended to pose a problem and questions to be answered. The students then began to work on a plan on how to answer these questions. The teachers had the role of supervising or facilitating the students. The activities were inquiry-based aiming to get the students to investigate the problem. We give the following example of Bertha, a fifth grade science teacher. Her purpose in these lessons was to get her students to engage in more inquiry-related learning: *'I would like for students to engage in inquiry-based lessons to help them learn about ecosystems.' (from Bertha's research report).* Bertha started her lessons by posing problems about ecosystems and provided a question*: 'I began my lesson by asking my students why we don't have wildlife habitat in our area…*

then I provided them questions about habitats in the area... I let my students decide how they wanted to answer the questions... One of the groups wanted to go on the internet to research habitats in the area and so I let them go on the internet for 45 minutes each day, making sure that they discussed their findings after each session' (from the reflective journal). Bertha also let other groups decide about their approach. When one group decided to go to the zoo, Bertha suggested a field trip to the zoo to her students: *'my students decided to observe fish in an aquarium to investigate aquatic habitats in the zoo, so they took a trip to the zoo...' (from Bertha's progress report)* . Bertha gave students time to collect and analyze their data about aquatic habitats. To evaluate their projects, Bertha asked her students to share their results: *'Upon return from the field trip, students were allowed time to work in their groups to make small presentations about their habitat findings. They decided to make charts or posters about their findings. Some students used pictures from the internet, while others used photos they had taken at the zoo. The presentations were evaluated by me, based on presentation of habitat materials and overall participation in the group (from Bertha's reflective journal)*. Bertha's orientation toward teaching was content and inquiry-driven using a project-based approach. Her level of inquiry was guided. Although she intended her students to do inquiry, she gave them 'guided' questions to research. She stimulated the use of inquiry activities to have her students gain an authentic inquiry experience in the field.

Level 4: Open inquiry

We found only two teachers who planned to use an open inquiry approach in their lesson plans. These teachers applied similar inquiry activities in their lesson plans as level 3 teachers. However, the difference with the previous groups is that these teachers did not pose research questions to the students. In both cases, the teachers introduced the topic and encouraged the students to come up with questions for research. After the students posed several questions, the teacher held a classroom discussion on what questions were worth investigating and the students were divided into groups to start working on a research plan. Examples: *'Students ask their own 'real' questions, they took ownership in their project and were motivated to learn' (from Lila's progress report). 'Since inquiry-based learning is student initiated, I took my students to the pond behind the school and let them discuss with each other what they wanted to investigate and why.' (from Brenda's progress report)*. Both teachers intended to incorporate inquiry learning into the lives of their students. Brenda wanted the students to explore their own natural surroundings, while Lila wanted them to incorporate inquiry into their lives. Lila reflected on her student's ability to create research questions: *'Some students had difficulty thinking of what questions to ask. I don't know if the task assigned was difficult or that the actual writing of the question was difficult. I think that in the future I need to spend more time on technical writing and focus on the use of language.' (Lila's reflective journal)* Both teachers decided that project-based science would help them to reach their goal. We found that these teachers had similar orientations to the level 3 group. The orientations towards science teaching included project-based science, and inquiry learning: *'I have been missing out on a lot of great things that are happening in the world of inquiry-based learning. I have been using hands-on activities for many years, but I haven't allowed my students to expand on the learning. I am anxious to see how my students respond when given the opportunity to plan some of their own tracks for learning. This year I want to have them design their own projects instead of doing small hands-on activities in class.'* (Brenda's reflective journal) In the sequence of the planned classroom activities, these teachers let students decide how they wanted to answer their research questions. In this regard the teachers facilitated their plans. *'In October I placed the students in groups of four. Each group chose a habitat that was not found in our area. The groups researched their own habitats using the internet and generating questions to be answered. One group decided to seek answers in the zoo. While other groups decided to do field work. All the groups presented their findings and made a visual display for the class.' (Brenda's progress report)* Both teachers used open inquiry to facilitate their students in their projects. We found that both of these teachers were content and inquiry-oriented using project-based learning and inquiry learning to reach their goal.

5.6. Conclusions and discussion

In this section we draw conclusions with respect to each of our two specific research questions.

RQ1: What level of inquiry do science teachers use when planning inquiry-based lessons?
We concluded that the teachers we investigated in this study operated at one of four inquiry levels when they planned their inquiry-based lessons. In particular, we found eight science teachers at the confirmation level of inquiry. They planned to start a lecture about the science concepts and then have students engage in hands-on activities concerning the concept. We also found eight science teachers at the structured inquiry level, where the teachers planned to prescribe all inquiry steps for students to follow. Six teachers planned their lessons at the level of guided inquiry. These teachers posed research questions to the students and intended to facilitate the students' own research. Only two science teachers in this study were found to plan their lessons at the level of open inquiry. They planned to encourage their students to think of research questions and to plan inquiry approaches to answer their research questions. Our study found that more teachers explored inquiry teaching at lower levels than at the higher levels. However, more research is needed with a larger sample of teachers to determine which level is more often used by teachers. Other factors such as the specific context of an inquiry and typical characteristics of the teachers will have to be further explored to determine why these teachers planned to operate at a particular inquiry level.

RQ2: How are the teachers' concerns and their orientations towards science teaching related to their levels of inquiry?

When researching the relations between the science teaching orientations and the teachers' level of inquiry, we found that although the orientations identified by Magnusson et al. (1999) were used to code the teachers' orientations in this study, we had a hard time identifying the orientation of a teacher using a single orientation from the Magnusson et al. (1999) orientations list. We found that the teachers did not hold a single orientation from the Magnusson et al. (1999) list. Rather, the majority of teachers had more than one orientation. Combinations of Magnusson et al.'s orientations (1999) were needed to determine these teachers' orientations. Previous scholars have already made references to teachers holding multiple orientations (Friedrichsen & Dana, 2005; Abell, 2007; Talanquer et al., 2010; Friedrichsen et al., 2011), arguing that orientations towards teaching are more complex than was suggested by Magnusson et al. (1999) due to factors other than the teachers' goals and purposes, such as teachers' prior work experience, professional development, and time constraints, . Magnusson et al. (1999) explained that didactic and academic rigor are teacher-centered orientations, while inquiry and project-based are considered more student-centered orientations. In our study, the teachers operating at the lower levels, that is, inquiry level 1 (confirmation inquiry) and level 2 (structured inquiry), had similar teaching orientations: didactic (or academic rigor) and activity-driven. This combination of didactic and activity-driven is indicative of orientations which are both teacher and student-centered. In earlier research, Simmons et al. (1999) noted that teachers who vacillate between student-centered and teacher-centered beliefs had difficulties planning for even if they were knowledgeable about inquiry. They reported that it takes more than just having inquiry knowledge to change the teachers' decisions to have them use inquiry-oriented teaching approaches. Teachers need to learn, rethink, and adopt different knowledge, thoughts, and practices related to inquiry-based teaching to become inquiry-minded, student-centered educators (Simmons et al., 1999, p. 948). The higher levels, level 3 (guided inquiry) and level 4 (open inquiry), were dominated by three distinct orientations: project-based, discovery, and inquiry learning. We concluded that teachers operating at the higher inquiry levels had more student-centered orientations, focusing their lessons on activities (i.e., project, inquiry, or discovery) which were mostly performed and even directed by the students. Other scholars have also noted that teachers who are inquiry-minded focus on student-centered activities in observed lessons (Rushton, Lotter, & Singer, 2011; Roehrig & Garrow, 2007).

Roehrig and Luft (2004) argued that factors other than teaching orientations may also influence the teachers' inquiry-based instructions (p. 20). These factors include the teachers' concerns about students' low ability and low motivation as well as concerns about classroom management. We therefore investigated the relations between the teachers' level of inquiry and their teaching concerns and concluded that teachers had different concerns when they engaged in different inquiry levels. Level 1 teachers were more concerned about their students' knowledge and poor test scores, whereas teachers who engaged their students in structured inquiry were also concerned about their students' poor inquiry skills. At these two lower inquiry levels, we found that the teachers were concerned about their students learning knowledge and inquiry skills, whereas at the higher two levels we saw that they were mostly concerned about the relevance of inquiry for their students' lives. In this regard we can conclude that orientations towards teaching science as well as the teachers' concerns were linked to their level of inquiry. In previous literature (Bell et al., 2005; Bianchi & Bell, 2008), it has been suggested that teachers gradually move from the lower level to a higher level of inquiry. We found that teaching at different inquiry levels may be related to teachers' concerns about teaching science. Teachers concerned about the students' lack of inquiry skills engaged their students at level 1 or 2, while teachers who wanted their students to apply their inquiry skills in other settings engaged them at level 3 or level 4 of inquiry. Moving to higher or lower inquiry levels may depend on the teachers' level of concern. Using the confirmation level may be useful for teachers who have time constraints or want to double check whether students understood their lessons, whereas guided or open inquiry may be useful for teachers who have more time and want students to gain real life experience.

In general we can conclude that the four levels of inquiry as suggested by Bell et al. (2005) are suitable for studying inquiry-based science education. In our study we encountered all four levels of inquiry. When investigating the teachers' concerns and their orientations, we found that there were few differences between level 1 and level 2 on the one hand, and between level 3 and level 4 on the other hand. However, we found major differences between the lower levels (1 and 2) and the upper levels (3 and 4). Interestingly we found that the teachers' orientations, their classroom activities and their levels of inquiry were also related to their concerns. The concerns in level 1 were mostly at content level (lack of content knowledge), which expanded in level 2 to lack of content knowledge and lack of scientific inquiry. At level 3 and 4 we found teachers' concerns were broader, encompassing concerns about students' lack of inquiry experience in real life and real science. Teachers operating at level 3 and 4 were more concerned about students needing to transfer their learning to real life application than the teachers operating at the lower levels. Based on these findings we can argue that teachers' concerns and their orientations were important factors in determining their actions in the classroom regarding their planned classroom activities.

Based on our study we therefore suggest that the four levels of inquiry are linked to the concerns and orientations as presented in Figure 5.2. Relationships between levels of inquiry and teachers' concerns should be further investigated as should other factors in students' learning. These factors include the science curriculum, time constraints, available classroom material, and the teachers' own intention regarding inquiry teaching.

Level of inquiry	Teachers' concerns about students	Teachers' science teaching orientations
1-Confirmation	Lack of knowledge	Highly teacher oriented (such as didactic and academic rigor)
2- Structured	Lack of knowledge and skills	
3- Guided	Lack of knowledge and skills related to real life experience	
4- Open	Lack of application of knowledge and skills to real life science	Highly student oriented (such as inquiry and guided inquiry)

Figure 5.2. Linking the four level of inquiry model (Bell et al., 2005) with the teachers' concerns and orientations.

Teachers' concerns have been studied with pre-service teachers (de Jong & van Driel, 1999; de Jong, 2000) with a focus on their pedagogical content concerns. Little research if any is found about in-service teachers' science teaching concerns. More research is needed to find out what the concerns of in-service teachers are and how these concerns relate to their teaching. Investigating whether teacher concerns are situation or context-bound could be one focus of further research. This is important to establish whether a teacher's concern is influenced by other factors such as school policy, classroom situations, grade levels, science topics etc. Future research may also focus on the importance of the relations between a teacher's concern and a teacher's orientation towards teaching. From this study we can conclude that the teaching orientations and teachers' concerns were closely related to the inquiry levels of science teachers.

Other factors influencing teachers' levels of inquiry

We did not find clear relationships between the teachers' years of experience, their grade levels, and level of inquiry. One would expect that as teachers gain more teaching experience, they would engage in higher levels of inquiry to engage students in learning opportunities in new and challenging situations.

However, Simmons et al. (1999) found that as beginning teachers gained more experience, their beliefs became more student-centered, while their classroom actions became more teacher-centered. One would also expect that teachers who teach upper grade levels would use the higher levels of inquiry to prepare lessons aimed to engage and challenge their students to learn complex concepts. In our study, neither the teachers' years of experience nor their grade levels showed any direct and overt relationship with the teachers' level of inquiry (see Appendix B). More research with other variables is needed, however, to further explore the relationships between teaching experience and grade levels and science teachers' levels of inquiry. These other variables could include teachers' personal actions, their social interaction in class, and their personal experimentation (Simmons et al., 1999, p. 948). Perhaps future studies on teachers' beliefs and perceptions on inquiry teaching can apply longitudinal designs, where teachers' beliefs and actions are investigated over a longer period of time.

5.7. Implications

Inquiry-based instruction has been a part of science teaching for a long time (Bybee, 2004; De Boer, 2004). The goal of inquiry learning is to enhance students' ability to practice science like scientists do, using inquiry skills to develop science concepts and science process skills (Schwab, 1962). DeBoer (2004) also explained that engaging students in scientific inquiry serves many purposes including: student motivation, preparing future scientists, and developing autonomous and independent thinkers. Understanding why and how teachers construct inquiry-based lessons to engage their students in scientific inquiry could help teacher educators to prepare teachers to teach in ways that enable students to become inquiry learners. In our study we found that teachers' concerns and their orientations played an important role in their actions. PD programs that promote science as inquiry could especially benefit from our research aimed at understanding why teachers with certain concerns and orientations engage in a typical level of inquiry. The results from this study could help teacher educators to construct PD programs where teachers with different concerns could practice using different levels of inquiry instructions and eventually develop lessons at all four levels. The MSP program is a suitable program for teachers to develop their own professional skills by preparing and conducting inquiry lessons for their own classroom that improve their teaching. Our research indicates that there is a close relationship between the teachers' concerns, their orientations and their level of inquiry. These findings may lay the basis for future studies to investigate and understand the content of these relationships.

Chapter 6. General conclusions and discussion

6.1. Introduction

The aim of this research was to examine the pedagogical content knowledge of science teachers who prepared and conducted lessons to improve their teaching. The research was conducted in the context of a professional development program aimed at improving science and mathematics teaching. Examining science teachers' PCK is a complex task (Abell, 2007). Our main question was: *What is the pedagogical content knowledge of science teachers when they prepare and conduct lessons as part of a specific professional development program to improve their science teaching and how does this PCK change when they participate in a PD program?* To answer this question, we used the PCK model of Magnussonet al. (1999). Magnusson et al. (1999) defined five components of PCK: (1) orientations toward science teaching; (2) knowledge and beliefs about science curriculum; (3) knowledge and beliefs about students' understanding of specific science topics; (4) knowledge and beliefs about assessment in science; and (5) knowledge and beliefs about instructional strategies for teaching science (p. 97). This model illustrates how various knowledge components are related to one another in the PCK framework (see Chapter 1). Using this model, we investigated the teachers' orientations towards teaching (Chapter 2), as well as how the PCK components related to one another in different types of PCK (Chapter 3). We also studied how these components changed as teachers participated in a PD program (Chapter 4) and we investigated how the orientations were related to the science teachers' practices when conducting inquiry-based lessons (Chapter 5).

To answer the main question, we conducted four studies with the following research questions:

1. What are the orientations of science and mathematics teachers to teaching science or math in the context of a professional development program?
2. How can in-service science teachers' pedagogical content knowledge be typified at the end of a professional development program to improve their teaching?
3. What are the possible pathways that lead to changes in science teachers' pedagogical content knowledge in a professional development program?
4. What is the relation between the teachers' concerns, their orientations towards science teaching, and the instructional levels of inquiry when they design and conduct lessons?

6.2. General conclusions of the studies

6.2.1. Study I

In the first study we aimed to identify teaching orientations of mathematics and science teachers. We investigated 107 science and math teachers who participated in three cohorts of the mathematics and science partnership program, where they conducted an action research project to improve their teaching of math or science. We used their action research plans to determine the teachers' orientations. We found that although math and science teachers held specific teaching orientations, these orientations could be categorized in three main orientations: content-driven orientations with teacher-oriented activities, content-driven orientations with student-oriented activities, and skills-driven orientations with student-oriented activities. Teachers who were content and teacher-centered, wanted their students to gain a better understanding of math or science. They intended to use traditional approaches such as classroom lecture combined with some hands-on activities. Another group of teachers was also content-driven, but intended to use student-oriented activities. They wanted their students to gain a deep understanding of math or science using other types of activities, such as experiments, projects, and laboratory work. The third group of teachers was skills-oriented. They wanted their students to be able to do science or do mathematics. They intended to use classroom investigations or projects to have the students learn how to do science or mathematics. We found that the Hodson goals (1992) were very useful in describing these orientations. The Hodson goals include the learning of science (or math) content, the learning of skills and learning about science (or math). In this study, we found that some teachers had an additional goal: liking science or mathematics. This goal represented the increase in students' motivation or the development of a positive attitude to learning science or math. We found that motivation was a goal found in all three orientation types (see Table 6.1)

Table 6.1.
Three main orientations with different goals and intended strategies

Orientation to teaching	Main goals	Intended instructional methods
Content-driven with teacher-centered approaches	Increase students' content knowledge	Lecture, hands-on activities
Content-driven with student-centered approaches	Increase students' content knowledge and skills	Experiments, hands-on activities, laboratory work
Skills-driven with student-centered approaches	Increase students' skills	Projects, experiments, classroom investigations

We concluded from this study that the orientations played an important part in teachers' PCK. Although we found that the orientations towards teaching could be categorized in three main orientations, we concluded that these orientations were influenced by multiple goals, which made the orientations rather unique to each individual teacher. The goals were often influenced by the teachers' individual concerns, making it important to have teachers reflect on past experiences as their concerns were to a large extent determined by their past experiences. We also concluded that motivating students to make them interested in science or math was an important goal which was found in all orientations. Teachers were concerned that students were not motivated to learn science and therefore did not succeed in their endeavors. We concluded that the orientations towards science or mathematics teaching were mostly determined by the goals, the teachers' concerns, and their intended instructional strategies .

6.2.2. Study II

To answer the second research question we selected twelve science teachers, investigated their action research reports and conducted interviews with them. From their plans and their responses to the interview, we found three types of PCK, which were primarily driven by the teachers' concerns and purposes for teaching. The first type of PCK was characterized by teaching science skills. Teachers with this type of PCK started their action reports worrying about their students not being able to do science. The second type was focused on teaching content. We found that teachers with PCK type II were concerned about their students' low test scores. The third PCK type was focused on motivating students to learn science and to learn about science. The teachers with this type of PCK found that their students were bored with science and wanted them to get excited about learning and doing science (see Table 6.2).

Table 6.2.
Three types of non-topic-specific PCK.

PCK TYPE	Concerns	Science teaching purpose
I. Knowledge of teaching science process skills	Students have poor lab skills Students need to develop science skills	Doing science
II. Knowledge of teaching science content using various strategies	Students have low test scores Students need to increase content knowledge	Learning science (content)
III. Knowledge of teaching science through enhancing students' motivation	Students are not interested in science Students need to increase their motivation to learn science	Learning science content Learning to do science Liking science

In the second study we concluded that science teachers' unique PCK could be typified by investigating the content of the PCK components. Types of PCK could be determined by the content of the PCK components and the relationships between those components. We also concluded from this study that the teachers' concerns and their orientations influenced the content of the other PCK components. Components of PCK influenced one another and were closely related to each other. When teachers were seeking ways to improve their teaching, the PCK components interacted strongly with their concerns and purposes and thus typified the teachers' PCK. In this study we concluded that the PCK types did not mutually exclude one another. Although teachers may have a PCK that focuses on teaching science skills, this does not mean that they do not intend to have their students learn science content knowledge and vice versa.

This study, however, did show evidence that the teachers' concerns and their purposes of teaching, and thus their orientations toward science teaching, determine their PCK type. Therefore, it was concluded teachers' concerns and purposes of teaching should play a prominent role in future research on types of PCK.

6.2.3. Study III

To answer the third research question, using the Clarke and Hollingsworth (2002) interconnected model of teachers' professional growth (IMTPG), we used different data sources of the twelve science teachers from the second study. According to Clarke and Hollingsworth (2002), pathways that lead to changes in teachers' professional knowledge, can either be a change sequence, or a growth network. In this study, three distinct pathways were found, where only two of those pathways led to changes in the science teachers' PCK (see Figure 6.1). In particular, we found that there were differences in the growth networks. In the simple growth networks, changes in teachers' knowledge seemed to occur without the Domain of Consequence. These teachers simply reflected on the lessons as prepared and taught. In the complex growth networks, however, teachers reflected on the outcomes of their teaching using the Domain of Consequence. These teachers were able to report what they had learned from their lessons, their classroom, and their students, and how this inspired them to revise their teaching. In addition, we found that peer discussion and literature reviews altered the teachers' knowledge of instructions, whereas consulting academic staff altered their knowledge of the curriculum.

The IMTPG model is a suitable model to study teachers' growth. The strength of this model lies with its ability to have teachers reflect upon their thoughts and their actions. These reflections make teachers' growth processes explicit . This model is a useful analytical tool for making PCK changes explicit by outlining the processes of change. The IMTPG model has great potential in PCK research. In an earlier study, Justi and Van Driel (2006) argued that the IMTPG model can also be used as a predictive tool in professional development programs, where the structure of events in the PD program can act as a mechanism to promote teachers' change. In particular, with this

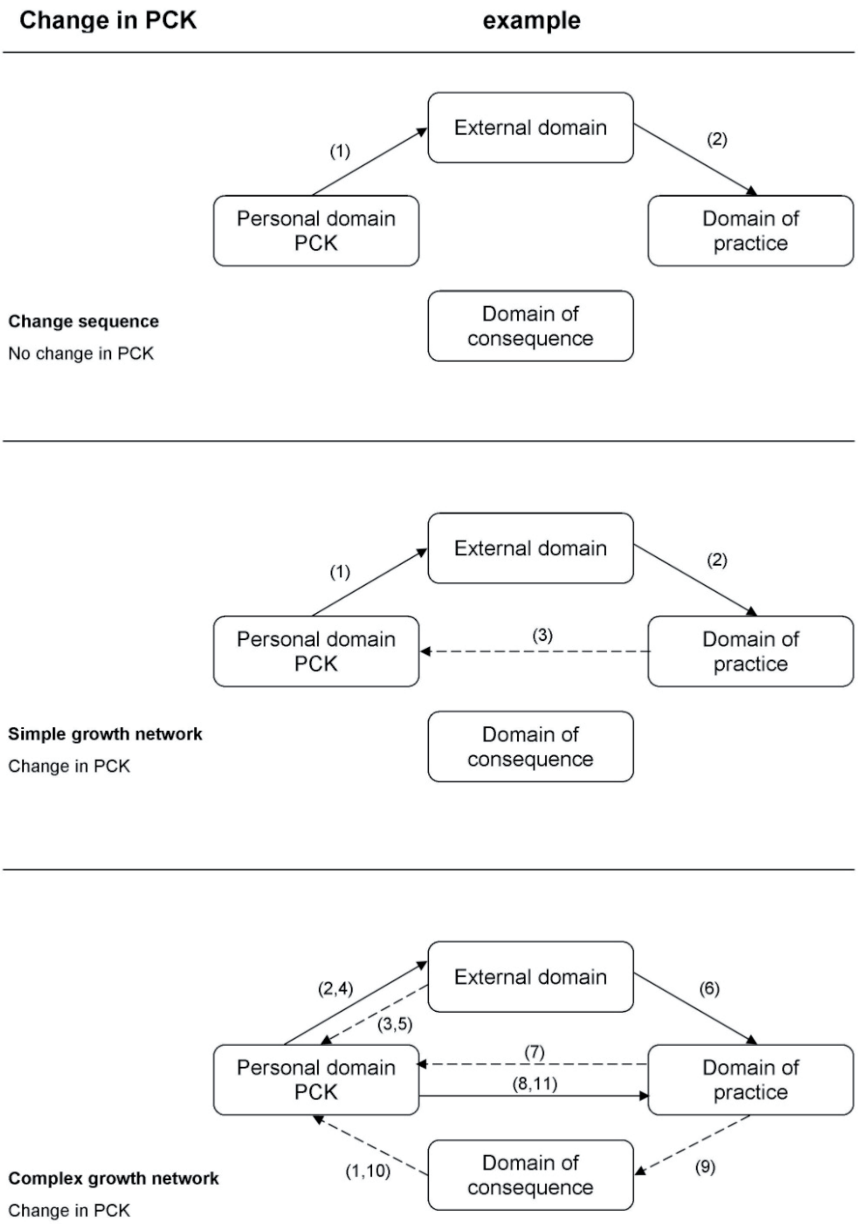


Figure 6.1. Examples of different pathways of change which may or may not lead to PCK development

model, teacher educators can select those aspects in the PD program that promote the development of teachers' knowledge.

From this study we can conclude, with the use of IMTPG as an analytical tool, that the MSP influenced the teachers' PCK, which in some cases enabled teachers to alter their classroom actions. In particular, we concluded that teachers' reflections were important features in PCK development, since they allowed teachers to confirm certain teaching beliefs or construct new knowledge.

6.2.4. Study IV

To answer the fourth research question, we studied 24 science teachers from the last cohort (2006-2007) who engaged in inquiry-based teaching. Using a four level of inquiry model (Bell et al., 2005), we found that teachers who engaged in a *confirmatory* level of inquiry were concerned about the low test scores and the gap in content knowledge of their students. Their classroom activities were all teacher-centered and focused on learning content. Teachers who engaged in the *structured* level of inquiry were still content-driven, but also skill-driven, and used a lot of hands-on activities to teach their inquiry-based lessons. In addition to their concerns about low test scores and lack of content understanding, the teachers were also concerned that the students lacked inquiry skills and were therefore not able to do science. Teachers who engaged in *guided inquiry* were concerned that their students lacked inquiry skills and that they did not get enough real world inquiry experience. They used student-oriented activities such as experiments and classroom projects. The teachers who engaged in *open inquiry* wanted their students to apply inquiry skills to real world situations, so that they gained experience in real science. They had their students design their own projects and come up with their own research questions.

From the fourth study we concluded that teachers' concerns and their orientations were major factors in influencing their classroom actions. In particular, teachers' concerns, together with their orientations, influenced the inquiry level of science teachers' instructions when they prepared inquiry lessons. We concluded that the teachers using the first two levels of inquiry, confirmation and structured inquiry, had almost the same concerns and science teaching orientations. Teachers using the higher two levels, guided and open inquiry, had distinctly different concerns and different teaching orientations. We also concluded that science teachers' concerns played an important role in the level of inquiry. When the concerns were limited to classroom matters such as lack of content and lack of science skills, the teachers' inquiry-based instructions were found to be in the lower levels. However, when teachers expressed broader concerns, such as about connection with real life and application or understanding of the real world, their level of inquiry-based instructions increased to the higher levels.

6.2.5. The MSP program

We concluded from our research that use of the MSP as a professional development program allowed teachers to develop their PCK, using specific elements in this program. Use of action research in the classroom, in particular, enabled them to engage in classroom actions and to reflect on those actions inducing changes in their PCK. The use of specific elements in the MSP were crucial in determining science teachers' PCK. A special feature of the MSP was the Summer Institute, where teachers got to learn about action research and had the opportunity to work with academic staff and discuss their project with peers. The use of action research throughout the whole school year and the use of a reflective journal were also key factors in having teachers gain experience and reflect on those experiences. Abell (2008) noted that teachers' knowledge can change through experience Teacher programs allow teachers to gain as much possible experience in teaching and get opportunities to reflect in order to build up a well-defined PCK over time. We concluded that the structure of the MSP allowed teachers to gain experience (including inquiry experience) by using their PCK and reflecting on this knowledge.

6.3. Discussion

The results and conclusions from the studies revealed that the science teachers' pedagogical content knowledge was an important and complex phenomenon. The PCK model of Magnusson et al. (1999) proved to be a useful framework in the four studies of this dissertation. Magnusson et al. (1999) portrayed relations between the five PCK components of science teachers, giving special attention to their orientations to science teaching. We found that the teachers' PCK guided their classroom decisions. This finding is based on the studies where science teachers used their knowledge to plan their activities. Their teaching orientations and their concerns were especially closely related to their practice (Study 4). In Study 2 (Chapter 3), we also found that it was possible to determine the teachers' PCK type.

6.3.1. Orientations towards science teaching

The Magnusson et al. (1999) PCK model illustrates the teachers''orientation towards science teaching' can be seen as a 'conceptual map' that shapes the other components of science teachers' PCK, making it an important component in the model. Research on orientations to teaching has shown, however, that these orientations are not static, rigid and well-defined concepts (Abell, 2007; Friedrichsen & Dana, 2005; Talanquer et al., 2010). In our studies, we found that teachers did not hold a 'single' orientation from the Magnusson et al. (1999) orientations list, but may have held multiple orientations from that list, making these orientations rather complex to study. For example, some science teachers who were didactically oriented also expressed ideas that are indicative of a hands-on approach to teaching. We found that science teachers' orientations could be integrations of multiple orientations presented by Magnusson et al. (1999). Earlier studies confirm this finding (Friedrichsen & Dana, 2003, 2005; Anderson, 2007).

In our first study, we found evidence that teaching orientations were indeed greatly influenced by the teachers' goals and their intentions to teach following a certain strategy. These teaching goals seemed to reflect two of the Hodson (1992) science goals for learning: learning science (or math) and doing science (or math). Hodson's (1992) third goal, learning about science, was not encountered in this study. Using the first two goals of Hodson (1992) and the teachers' intentions on how to reach those goals, we were also able to capture the teaching orientations in three main categories: content-driven with teacher-centered activities, content-driven with student-centered activities, and skills-driven with student-centered activities (see Chapter 2). In each category we also encountered variations in the teachers' orientations. These variations were mainly based on teachers' additional goals and their classroom concerns. We concluded that, although teachers had common main orientations, their individual orientations were rather unique. Friedrichsen and Dana (2003; 2005) refer to these additional goals as peripheral goals. They explain that teachers have multiple goals that influence the nature of their orientations. In our study we concluded that although main goals were useful to determine main orientations of teaching (Talanquer et al., 2010), additional goals were equally important to gain a deeper understanding of these orientations that drive other PCK components (Friedrichsen & Dana, 2005). For example , we found that when a teacher was interested both in teaching content knowledge and increasing students' motivation, he or she portrayed an orientation 'motivate student to learn content knowledge'. While another teacher whose goals were to increase students' content knowledge and their ability to retain this knowledge, portrayed an orientation 'have students learn science or math skills to retain content knowledge'. Both teachers had a similar main orientation (content-driven using student-centered activities), but had different emphases and thus portrayed specific individual orientations.

We found that the nine Magnusson et al. (1999) orientations reflected the purposes, goals, and instructional strategies from our first study. For example, the Magnusson et al.(1999) orientations: inquiry, project work, hands-on, and didactics were coded in our study as teachers' goals or as intended instructional strategies. Knowing that science teaching orientations are more complex than the ones found in the Magnusson et al. (1999) study, it may be time to re-consider the orientations of Magnusson et al. (1999) and to investigate how the complex nature of these orientations can best be captured and classified. Recently, Friedrichsen et al. (2011) noted that the definition of teaching orientations is still blurred, since multiple explanations have been given to the same concept. While some scholars explain teaching orientations as 'the goals and purposes of science teaching', other scholars have explained the orientations as 'a general way of viewing teaching science' (Friedrichsen et al., 2011, p. 366). More research is needed to (1) give clarity to this concept and (2) reexamine the orientations of the Magnusson et al. (1999) study.

6.3.2. Science teaching concerns

In our study we found that teachers' concerns were closely linked to their teaching orientations. The PCK model of Magnusson et al. (1999) indicates that teaching orientation is the one component that 'shapes' other knowledge components. In our research, however, we found that teachers' concerns also influenced the PCK components (Chapter 3) as well as teachers' practice (Chapter 5). We found that although the teachers had certain teaching orientations, their concerns were evidently present when we investigated their PCK. In Chapter 3, we typified the teachers' PCK and found that their purposes for teaching, their teaching orientations, and their concerns played a major role in 'shaping' the other PCK components. In-service teachers' concerns originated from their teaching experience. When the science teachers in our study reflected on past experiences, they all expressed a certain concern, which was related to their teaching goals and purposes, namely their orientations. Research focused on pre-service teachers' concerns mentions that investigating in-service teachers' concerns can help us understand why and how teachers use their knowledge to conduct their lessons (Melnick & Meister, 2008). In our fourth study (Chapter 5), we found that teachers' concerns were closely linked to their inquiry-based lessons, and we therefore concluded that these concerns influenced teachers' decisions when preparing and conducting lessons. Earlier studies have noted that classroom management is one of the most important concerns of pre-service teachers (Melnick & Meister, 2008). In our fourth study (Chapter 5) we found that understanding and retaining content knowledge, mastering science skills, and motivating students, were the most important concerns of in-service science teachers. Understanding the concerns and how these concerns influence teachers' knowledge and actions could enhance our understanding of how teachers draw upon their PCK to conduct and prepare lessons. From our experience of doing this research, we conclude that teachers' concerns influence their teaching orientations as well as the other PCK components. However, whether the teachers' concerns influenced their orientations, and therefore influenced the other PCK components, or whether these concerns influenced all PCK components directly is open to debate (Figure 6.2).

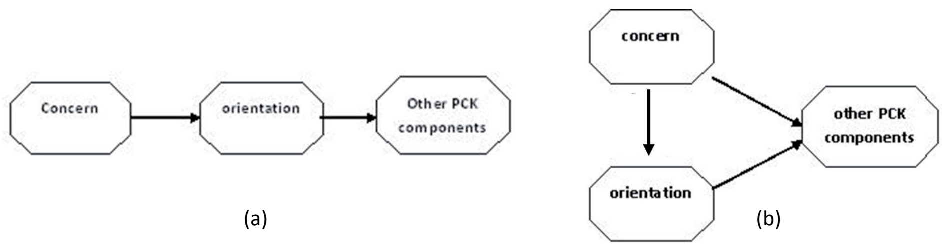


Figure 6.2. Two ways teachers' concerns could influence PCK components

More research is needed on the nature of in-service science teachers' concerns and their influence on their PCK. Knowledge of in-service teachers' concerns can be useful to design programs aimed at pre-service teachers, who start making the transition into the classroom as beginning teachers and then later on as experienced teachers. Shifts in concerns may occur, which may lead to PCK development. We wonder how PCK develops over time and how shifts in teachers' concerns may play a role in this development. Future longitudinal research on concerns is needed to determine how PCK is influenced by these concerns, which in turn influence the teachers' lesson plans and their practice.

6.3.3. Models for PCK development

In our third study (Chapter 4) we used a model to understand PCK development. A lack of understanding of teachers' knowledge development (Beijaard et al., 2000; Eraut, 1994) makes models extremely useful for studying teacher development. Different models have been offered over the years (Bell & Gilbert, 1996; Borko, 2004; Clarke & Hollingsworth, 2002; Fraser, Kennedy, Reid & McKinney, 2007; Guskey, 1986). We used the model of Clarke and Hollingsworth (2002), which was adapted from Guskey's model of teacher change (1986), to study teachers' professional growth. Clarke and Hollingsworth (2002) altered Guskey's (1986) model, explaining that teacher change is not a linear, but rather a cyclic process (see Chapter 1 and Chapter 4 for a discussion of the IMTPG model).

Justi and Van Driel, (2006) noted that when teachers engage in action research, connections between the Domain of Practice and the teachers' Personal Domain can be established. They found that reflective relationships dominate the growth networks of the teachers' knowledge development. The present study supports their finding that when teachers conduct action research in their classroom changes in their knowledge often occur. We found that the action research did indeed allow teachers to reflect on their classroom situation, making relationships between the Domain of Practice and the Personal Domain evident. However, we also found that a personal reflective journal was useful for establishing deeper relationships between the External Domain, the Domain of Practice, the Domain of Consequence and the Personal Domain. In the teachers' reflective journals we found evidence that teachers who could reflect from the Domain of Consequence were also able to translate their changed knowledge into new practices. The teacher interview was, in addition to the teachers' reflective journal, another valuable tool for gaining deeper understanding of the processes underlying these changes. During the interview the teachers could explain why they enacted certain classroom decisions and how they reflected upon these actions.

The IMTPG model is a useful model for analyzing PCK changes in a teacher. The use of participants' action research in combination with the IMTPG model allows robust research in PCK development and provides useful insights into the processes of PCK changes in a teacher. Useful data collection tools include the use of action research reports, teachers' written material, teachers' interviews, and personal reflective journals to capture the underlying thoughts of teachers. Other professional development models should also be explored to give new perspectives on PCK development. Borko (2004) offered a model where four crucial elements are interconnected: the teachers, the PD program, the facilitators, and the context. In our study the context was the action research project. Van Driel et al. (2001) posited that PCK is context-bound, making Borko's (2004) PD model another model to consider when exploring PCK development.

6.4. Strengths and weaknesses

6.4.1. Strengths

Many professional development programs use a top-down approach when having teachers participate in the program (Desimone, 2009). In this study we did not investigate topic-specific PCK research, where all teachers teach the same concept at the same grade level. We wanted the teachers to develop their own thinking, present their own thoughts and develop their own knowledge and skills necessary for teaching. Studying teachers who can choose and investigate their own 'troubled' concepts and develop their own action research provides a deeper understanding of their teaching concerns and the thoughts and beliefs that underlie their knowledge and ultimately their actions. The combination of teachers' action research and the Summer Institute within a professional development program provided a solid framework in this study. Action research not only allows teachers to conduct research in their own classroom, but also creates opportunities for them to be creative in improving their own teaching. Action research, through teachers ‘reports and their reflective journals, gave us insight into how teachers think, act and construct new knowledge.

We used triangulation to collect data from multiple sources to capture a deeper scope on the knowledge of teachers and to maintain the credibility of this study. Patton (2002) notes that ‘one can compare the consistency of findings generated from different data sources within the same method’ (p. 556). Triangulation was used in different forms: the use of multiple data sources and the use of multiple groups of teachers from different cohorts. The use of multiple cohorts enabled us to study a heterogonous group of teachers when investigating PCK elements.

6.4.2. Weaknesses

All the research instruments used in our studies produced data of teachers' expressions in written or verbal forms. We only showcased the knowledge, beliefs, and attitudes that teachers were able to express. We did not capture their practices through observations in the classrooms, but only captured them when the teachers mentioned them in their lesson plans and progress reports or talked about these skills in an interview. Classroom observation would provide data which could make this research more reliable. Classroom observation data would also allow to explore the consistency of the data used in the present study, with the teachers’ practice.

One other weakness in the present study, was the fact that we did not capture the teachers’ context thoroughly. Teachers’ context is an important aspect in understanding the knowledge that teachers use in their practice. Since PCK is context-bound (Van Driel et al., 1998), including teachers’ context in this research would have provided us with useful insights on how teachers’ orientations and concerns are related to their PCK within a certain context. In our study, however, we chose to use the IMTPG model to study the teachers' change processes. The Clarke and Hollingworth's (2002) model proved to be suitable for studying this change, although it does not account for the teachers' context.

We did not focus on student understanding or student outcomes in relation to teachers' PCK. That would have gone beyond the scope of our study. However, investigating student understanding and student outcomes in relation to the teachers' PCK could have helped us to understand how PCK actually influences student learning. It thus remains an important aspect for future research on PCK to conduct frequent investigations in classroom settings, taking the learners into account.

6.5. Implications and suggestions for future research

6.5.1. Practical implications

Understanding PCK use and PCK development is critical for the success of science teaching education (Abell, 2007). Teacher educators, for instance, could have their pre-service teachers observe experienced teachers in the classroom, but teachers' knowledge is often tacit and not easily understood by novice teachers. Furthermore, prospective teachers must consider teacher cognition a valuable aspect and should not only focus on teacher behaviors (Verloop et al., 2001). Teacher educators play an essential role in helping their students understand the knowledge that underlies the behavior of experienced teachers. The results of this study may help teacher educators to understand what PCK in-service science teachers use when they plan and conduct their teaching. Understanding teachers' pedagogical content knowledge and the development of this knowledge is important for innovative teacher training programs. More research is needed to inform teacher educators how PCK is translated into practice. This research should inform the educators about whether and how the translation finds its way into positive student outcomes. In general, PCK research ofhow pre-service teachers' make the transition to beginning teachers and how their PCK changes over time, would be useful for teacher educators. They might benefit from these longitudinal studies to adjust their teaching programs to facilitate the PCK development of their prospective teachers. We agree with scholars such as Shulman, Grossman, and Magnusson that PCK development should be the primary goal of science teacher education. We also recommend that science teacher educators use a PCK model as a framework in their courses. The PCK model of Magnusson et al. (1999) is recommended to be used for this framework.

Our research found that the MSP program was a robust program for understanding and developing the PCK of in-service teachers. The combination of the two-week Summer Institute and the one-year action research project gave the teachers the opportunities to (1) reflect upon their own teachings; (2) develop new knowledge and skills to improve their lessons; and (3) reflect upon their experience and build upon new knowledge suitable for use in their classroom teaching. Van Veen, Zwart, Meirink, & Verloop (2010) described seven characteristics that define an effective professional development program: (1) content knowledge and pedagogical (content) knowledge; (2) active learning and inquiry learning; (3) collective and collaborative participation; (4) length of the PD program; (5) quality of resources; (6) related to (educational) policies; and (7) theory of improvement. The MSP offers the participants the possibility of increasing their content knowledge and their pedagogical content knowledge. The program also offers teachers the opportunity to be engaged in collaborative inquiry learning through the use of action research. Furthermore, this one-year program, which is tied into educational policies through the Illinois State Board of Education, offers participants the opportunity to make use of resources such as consultations with peers and academic staff. Advocating for life-long learning, teachers around the world should have the opportunity to participate in programs to develop their own professional knowledge, taking those PD characteristics into consideration. The MSP program could be an example for other PD programs. The MSP could also be offered to classroom courses other than the mathematics and science courses which are offered in the students' curricula. If we want to have teachers continue to work on their own professional development, then PD programs such as the MSP would be effective to offer to in-service teachers. The results from the MSP as reported in this dissertation provide us with information to improve our conceptualizations and measures of PCK and PCK development. Insightful scopes from the MSP could help to elevate the quality of professional development programs and to elevate our understanding of ways to shape and implement teacher learning opportunities, which could lead to the development of strong PCK that would benefit both teachers and students. The use of action research and the use of a reflective journal during the action research projects were good examples from this MSP that helped us to understand how teachers translate their knowledge into practice.

6.5.2. Research implications

In different sections of this thesis we have already mentioned several implications for research. Many studies have focused on PCK development and PCK structure, but few studies refer to PCK structure and PCK development of experienced science teachers in a professional development setting (Van Driel et al., 1998; Henze et al., 2008). In this study we show what PCK teachers used when they participated in a professional development program to improve their teaching. The study also provided insights into the processes of PCK development in the context of a professional development program. The results of this study could be useful to future researchers attempting to gain a deeper understanding of how and why teachers use PCK in their lessons. In particular, the role of teachers' concerns in the structure of PCK has not been studied well (Chapters 2 and 5), nor has the influence of teachers' orientations on their practice been studied extensively (Chapter 5). One main focus of continuing research should be on understanding how PCK is actually translated into practice. A model that explains how teacher knowledge is actually translated into practice could be used with multiple data sources to help us understand how teachers use their PCK in practice. First hand empirical data such as classroom observations, teacher journals and teacher interviews could be useful data sources in such research.

Another focus of future research could be the investigation of longitudinal processes that underlie PCK development. Robust instruments need to be developed to capture rich empirical data to describe the development of PCK. In the present study, teachers' reflective journal proved to be a useful tool, as well as the teachers' action research reports, their lesson plans, and the interviews (Chapter 4), but they are not extensive enough for longitudinal studies. Additional creative instruments, such as teacher and student diaries, and field texts (Mulholland & Wallace, 2005), could be developed to create longitudinal datasets which are needed to design and test models for continuing PCK development.

Summary

This dissertation reports on four studies in which the pedagogical content knowledge of science teachers was examined during a professional development program. Pedagogical content knowledge (PCK), one of the seven knowledge bases required for teaching, is described as that *unique* knowledge of teaching that aims to make students understand the content of science (Shulman, 1986). In this dissertation we examine the PCK of experienced in-service science teachers in relation to their educational beliefs, to help us understand why and how teachers make their classroom decisions as they teach science. Understanding this particular body of knowledge could help us guide and develop 'good science teaching' in our teacher education programs.

Chapter 1: Introduction

The introduction chapter gives an overview of the background of the research, the theoretical framework for examining PCK, and the structure of this dissertation. In this chapter we discuss the literature on PCK, which was first introduced by Shulman as 'that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding' (1987, p. 8). After Shulman (1987), Grossman (1990) and later Magnusson, Krajick, and Borko (1999) proposed a PCK model consisting of the following components: (1) orientations toward science teaching; (2) knowledge and beliefs about science curriculum; (3) knowledge and beliefs about students' understanding of specific science topics; (4) knowledge and beliefs about assessment in science; and (5) knowledge and beliefs about instructional strategies for teaching science (p. 97). In this model, the orientations toward science teaching are seen as the PCK component that 'shapes' the other components.

We used the Magnusson et al. (1999) model to study the content of PCK when science teachers participated in a professional development program called the mathematics and science partnership program. We also describe the PCK development of science teachers in the context of this professional development (PD) program. The mathematics and science partnership program (MSP) is a professional development program aimed at promoting teachers' abilities to enhance students' learning. For this purpose, the main goals of the MSP include increasing teachers' content knowledge, increasing their pedagogical content knowledge, and use of action research in the classroom The MSP program was designed to have teachers use an action research approach to study and reflect on both their content knowledge and their pedagogical content knowledge with help from academic staff. The MSP started with a two-week Summer Institute where mathematics and science teachers were introduced to action research and where they prepared an action research plan for the following school year. To prepare their plans, teachers selected their own science or math topic, sought advice from academic staff who acted as their mentors, and participated in peer discussions. In the following school year, the teachers met with their mentors on four follow-up days spread out over the year. All the participating teachers worked on their action research throughout the year, wrote their own progress report, and kept a reflective journal. At the end of the school year, the teachers finalized and submitted their progress report as their final action research report together with their lessons plans and students' artifacts. For our research purposes, some teachers were asked to voluntarily participate in an interview. The MSP was conducted in three consecutive years with three different cohorts. The cohorts included math and science teachers (see Table I).

Table I.
Number of math and science teachers per cohort

Cohort	Mathematics teachers	Science teachers
I	16	16
II	18	14
III	19	24

The main questions in this study were: *What is the pedagogical content knowledge of science teachers*[2] *when they prepare and conduct lessons as part of a specific professional development program to improve their science teaching and how does this PCK change when they participate in a professional development program?*
To answer these questions we conducted four studies where we used the teachers' action research plans, their progress reports, their lessons plans, and the interviews as multiple data sources in the different studies.

Chapter 2: Orientations toward teaching of mathematics and science teachers

This study reports on the teaching orientations of 107 math and science teachers who participated in the three cohorts of the MSP program. The main question for this study was: *What are the orientations of science and mathematics teachers to teaching science or math in the context of a professional development program?* We used the teachers' action research plans, their lesson plans, and their reflective journals to investigate their teaching orientations. We investigated the goals and purposes for teaching from the action research plans, as well as the teachers' intentions to use certain instructional strategies in their lesson plans. The analyses of the data from the teachers' action research plans and their lesson plans resulted in the identification of three main orientations: (1) content-driven with the intention

2 This dissertation focuses on science teachers but in study 1 we also studied the orientations toward teaching of mathematics teachers.

of using teacher-centered classroom strategies; (2) content-driven with the intention of using student-centered classroom strategies; and (3) skills-driven with the intention of using student-centered classroom strategies. From the data analyses we found that although teachers had the same main orientation, individual orientations may differ within a main orientation. We found that teachers had multiple goals and different intentions for using a specific instructional strategy. These goals and different instructional strategies resulted in teachers having different emphases within their main orientations. For example, when two teachers had a 'content-driven and student-centered activities' orientation, one teacher may want to increase the students' content knowledge by using *inquiry*, while the other teacher may intend to increase the students' content knowledge by *motivating* the students to learn content.

Chapter 3: PCK types of science teachers

In this chapter we typified science teachers' PCK in a professional development setting. Twelve science teachers were interviewed after they submitted their action research report and their reflective journals. We used these data sources to determine what type of PCK the teachers drew upon when they intended to improve their science teaching. The central question of this study was therefore: *How can in-service science teachers' pedagogical content knowledge be typified at the end of a professional development program aimed to improve their teaching?* To study the teachers' PCK, we made PCK representations of these twelve teachers, using the Magnusson et al. (1999) PCK model. Based on the teachers' PCK representations, we categorized their PCK in three types: (1) knowledge of teaching science process skills; (2) knowledge of teaching science content using various strategies; and (3) knowledge of teaching science through enhancing students' motivation. The types were primarily based on the teachers' goals and purposes for science teaching. Two of the goals, teach science content and teach science skills, showed similarities with Hodson's (1992) science goals for learning: (1) learn science and (2) learn how to do science. In this study, we did not find

Hodson's third goal, learn about science, but we found an additional goal: increase students' motivation to learn (how to do) science. PCK type III focused on this goal. We found that the teachers' goals in their projects were linked to their classroom concerns and portrayed a PCK that was typified by their goals and concerns. Based on the results from this study we found that teachers who were concerned about their students' poor grades in science stated that their goal was to have students increase their content knowledge and therefore they had a PCK representation that was focused on teaching content knowledge (type II). Teachers who had PCK type I, teaching science skills, stated that their students lacked the inquiry skills to learn science. PCK type III teachers stated that their students were bored with science and therefore did not do well in the subject, so their aim was to motivate their students to become interested in science. We found that both factors, teachers' concerns and their purposes for teaching science, influenced science teachers' PCK. When science teachers were seeking ways to improve their teaching in a professional development context, we found that their PCK components interacted strongly with their concerns and purposes and thus helped typify the teachers' PCK.

Chapter 4: PCK development of science teachers

In the third study we investigated the development of the pedagogical content knowledge of the previously selected twelve science teachers when conducting their action research projects. We used the interconnected model of teachers' professional growth (IMTPG) (Clarke & Hollingsworth, 2002) to study changes in the participants' pedagogical content knowledge. The research question for this study was: *What are the possible pathways that lead to changes in science teachers' pedagogical content knowledge in a professional development program?* The IMTPG model consists of four different domains which interact to foster teachers' professional growth: (1) the Personal Domain, which contains teachers' knowledge, beliefs, and attitudes; (2) the External Domain containing external sources of information or stimuli; (3) the Domain of Practice, which involves professional classroom experimentation; and (4) the Domain of Consequence containing salient outcomes related to classroom practice. We collected the teachers' action research reports, their lesson plans, and the interviews to investigate their PCK development. Using the IMTPG model we identified three distinct types of pathways with regard to teachers' pedagogical content knowledge development (see Figure I).

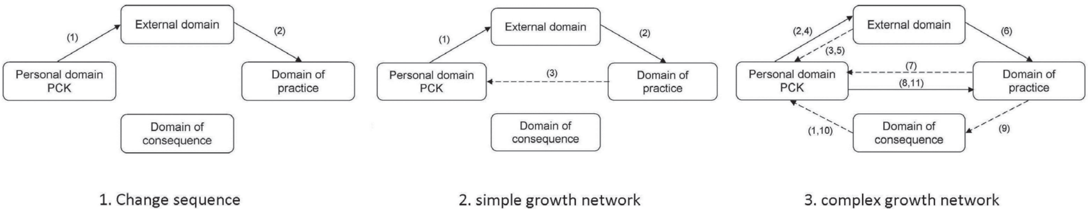


Figure I. The different pathways

The first pathway is considered a change sequence and indicates that although a change in practice was noted, no change occurred in the teacher's PCK. The second and third pathways are considered 'growth networks' and indicate that science teachers' PCK did change. Clarke and Hollingsworth (2002) argue that growth networks indicate lasting changes in teachers' practice and their knowledge (pp. 958-959). In this study we found two types of 'growth networks'. The 'simple growth network' did not include the domain of consequence (seeFigure I.2). This indicates that the teachers only reflected on their lessons when they were preparing and teaching them in class. They did not, however, reflect on the outcomes of their lessons. The 'complex growth network' included the domain of consequence (see Figure I.3). From this growth network we found that, through the domain of consequence, the teachers reflected on their teaching and on their students' learning. These teachers could specify what and how students learned. Through these reflections we inferred that obvious changes occurred in their pedagogical content knowledge. We also found that in some cases teachers who reflected on their students' learning were able to alter their classroom practice on the basis of these reflections (see arrows 9, 10 and 11 in Figure I.3).

In addition, we found that the MSP program offered some interesting features that fostered PCK development. In the IMTPG model, the MSP program was located in the external domain referring to external stimuli that the teachers received from this PD program. From this study it became evident that within the external domain, the role of the university staff was particularly important in the development of teachers' PCK. Having the university staff on site was a critical factor in helping participants develop new understandings of students' learning. This was the case in all three types of pathways found for the development of the PCK component 'knowledge of student understanding'. We also found that teachers learned about new instructional strategies and assessment methods when they were able to review literature and discuss their findings with peers.

Chapter 5: Relations between PCK components and science teachers' inquiry practice

This chapter describes the study conducted in the third cohort of the MSP program, in which we investigated the inquiry-based levels of instructions of science teachers' in relation to their concerns and their teaching orientation when planning and conducting inquiry-based instructions in their lessons. The main question for this study was: *What is the relation between teachers' concerns, their orientations towards science teaching, and inquiry-based instructional levels of inquiry when they design and conduct lessons?* The teachers' action research reports, their lesson plans and their reflective journals were used as data sources for this study. To determine the level of inquiry of 24 science teachers we used the inquiry model of Bell et al. (2005) which distinguishes between four levels of inquiry teaching: (1) the confirmation level; (2) the structured level; (3) the guided level; and (4) the open level of inquiry. In our study 'confirmation' and 'structured inquiry' were considered lower levels, whereas 'guided inquiry' and 'open inquiry' were considered higher levels. We found that the teachers' orientations and their concerns connected to the lower inquiry levels differed from the orientations and concerns of teachers who used inquiry-based instructions at the higher inquiry levels.

Science teachers who used inquiry-based instructions at lower levels were mostly concerned about their students' low grades. They also found that their students lacked science content knowledge, and inquiry skills. When investigating these teachers' orientations, we found that they were 'content-driven', 'skills-driven', and 'activity-driven', as well as focused on 'academic rigor' and 'didactics'. Furthermore, the lower level inquiry teachers engaged their students in classroom activities that were mostly teacher-centered, teacher-structured or teacher-induced. Comparing these teachers with the science teachers who used inquiry-based instructions at higher levels, we found that those teachers had concerns that included 'students lacking inquiry skills' and 'students lacking real world inquiry experience'. We found that these teachers also had 'content-driven' and 'skills-driven' orientations, but that their orientations were combined with other orientations such as, 'inquiry', 'discovery' and 'project-based'. Furthermore, the teachers who engaged in the higher levels of inquiry mostly included student-centered activities in their lessons.

Chapter 6: Conclusions and discussion

Based on the results of the four empirical studies, our conclusions and the main discussion are presented in Chapter 6. From the first study we concluded that the teachers participating in the MSP program had complex orientations. Although the study suggested that the teachers' orientations could be categorized in one of the three main orientations, individual teachers' orientations remained unique. On an individual level, each teacher had multiple goals and a variety of instructional strategies that resulted in a unique orientation. In their study, Magnusson et al. (1999) presented nine different orientations: (1) activity-driven; (2) didactic; (3) discovery; (4) conceptual change; (5) academic rigor; (6) process; (7) project-based; (8) inquiry; and (9) guided inquiry. These orientations were distilled from the research literature on science teaching and Magnusson et al. (1999) ascribed one orientation to each individual teacher. In our study however, we found that the teachers did not have 'single' orientations as presented by Magnusson et al. (1999). We therefore concluded that although teachers have one main orientation, their orientations are complex because of different emphases, due to their multiple goals and strategies.

The main conclusion from the second study was that science teachers' PCK can best be typified when their concerns, goals, and purposes in teaching science are taken into consideration. We furthermore concluded that the science learning goals of Hodson (1992) were important goals for science teachers, and that motivation to learn science was another important goal when typifying science teachers' PCK.

In the third study we found that teachers' PCK development followed different pathways of change. Pathways of change can be categorized into change sequences, simple growth networks, and complex growth networks. In our study we concluded that only the two latter pathways led to changes in the teachers' PCK. Teachers with simple growth networks had pathways without the domain of consequence. They showed changes in PCK but these changes did not result from the teachers reflecting on their classroom outcomes. Usually these changes occurred because the teachers reflected on how they planned their lessons. Teachers with a complex growth network (including the domain of consequence) appeared to reflect on the outcomes of their students' learning. We therefore concluded that the domain of consequence was an important domain for identifying lasting changes in teachers' PCK.

In the fourth study we concluded that teachers' concerns and their teaching orientations were closely related to their planning of inquiry-based instructions. We also concluded that teachers using lower levels of inquiry instructions engaged in teacher-oriented activities, whereas teachers using higher levels of inquiry instructions engaged in student-centered activities.

Our research led us to conclude that the Magnusson et al. (1999) PCK model is useful when investigating the content and development of science teachers' PCK. PCK representations of teachers can be drawn based on the five different components in this model. These PCK representations helped us to understand the relationships between the different components, which in turn offered interesting insights into the nature of PCK types. We found Hodson's (1992) science learning goals useful when determining the teachers' goals for teaching. Additional goals such as 'motivating students to learn science' also appeared to be important when examining teachers' orientations toward teaching science in relation to their other PCK components. It became evident that both teaching orientations and teachers' concerns can influence science teachers' PCK. Science teachers' concerns, in particular, deserve more attention in research on science teachers' pedagogical content knowledge.

We believe that PCK is tacit knowledge and we used multiple data sources, such as teachers' reports, their lesson plans, reflective journals, and interviews, to try to capture that knowledge. We found that these were valuable tools in grasping the content of PCK from the data. However, using classroom observations, would have enabled us to see how the PCK is actually translated in the classroom, and how students respond to this. In addition to using classroom observation in future research, we believe that large-scale and longitudinal research studies are needed. Using a greater number of respondents could give a better understanding of the different types of PCK found within in-service teachers and using instruments to capture the complexity of this particular teacher knowledge over a longer period of time could deepen our understanding of how PCK transforms in the context of teachers' own practices.

Nederlandse samenvatting

Dit proefschrift omvat vier deelstudies waarin de 'pedagogische vakkennis' (pedagogical content knowledge ofwel PCK) van bètadocenten wordt onderzocht. PCK wordt omschreven als de unieke kennis van docenten die gericht is op het begrijpen van vakkennis door leerlingen (Shulman, 1986). Het onderzoek is uitgevoerd in de context van een onderwijsprogramma gericht op het bevorderen van de professionele ontwikkeling van bètadocenten. In dit proefschrift is de PCK onderzocht van ervaren bètadocenten in relatie tot hun eigen onderwijsopvattingen. Het begrijpen van deze relatie kan mogelijkerwijs helpen verklaren waarom docenten juist die keuzes maken die leiden tot bepaalde handelingen en acties in het bètaonderwijs. Hiermee wordt een bijdrage geleverd aan kennis en inzicht van PCK en indirect ook aan de manier waarop PCK kan bijdragen aan de ontwikkeling van bètaonderwijs.

Hoofdstuk 1: Inleiding

Het eerste hoofdstuk geeft een overzicht van de achtergrond van het onderzoek, het theoretisch kader van PCK, en beschrijft de opbouw van deze dissertatie. Na de introductie van PCK door Shulman, aangeduid als 'that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding' (1987, p. 8), hebben Grossman (1990) en daarna Magnusson, Krajcik, en Borko (1999) PCK-modellen ontworpen met verschillende PCK-componenten: (1) oriëntaties op het leren en onderwijzen van bètaonderwijs, (2) kennis en inzichten over het leren en opvattingen van het bètacurriculum, (3) kennis en opvattingen over hoe leerlingen begrippen aanleren in het bètaonderwijs, (4) kennis en opvattingen over assessment procedures in het bètaonderwijs en (5) kennis en opvattingen over didactische principes voor het bètaonderwijs. In het model van Magnusson et al. (1999) wordt benadrukt dat de PCK-component: 'oriëntatie op het leren en onderwijzen in het bètaonderwijs' een overkoepelende component is, die andere componenten beïnvloedt en helpt vormgeven. Oriëntatie wordt hier gezien als het handelen vanuit een bepaald perspectief, bijvoorbeeld gericht op ontdekkend leren of op een conceptuele verandering. Magnusson et al. (1999) hebben in hun studie negen verschillende oriëntaties gepresenteerd: "activity-driven, didactic, discovery, conceptual change, academic rigor, process, project-based, inquiry and guided inquiry" (zie Tabel I, Magnusson et al, 1999, blz. 100). Deze oriëntaties hebben zij gedistilleerd uit de literatuur over het bètaonderwijs.

In dit proefschrift wordt het model van Magnusson et al. (1999) gebruikt om PCK te onderzoeken van docenten die deelnamen aan een professionaliseringsprogramma genaamd het Mathematics and Science Partnership Program (MSP). De PCK-ontwikkeling wordt daarom ook beschreven in de context van dit programma. Het MSP richt zich op het bevorderen van de bekwaamheid van docenten uit het voortgezet onderwijs die hiermee het leren van leerlingen moet verhogen. De MSP-doelen zijn specifiek omschreven als: (1) het bevorderen van de vakkennis van docenten, (2) het bevorderen van de PCK en (3) het bevorderen van het gebruik van actieonderzoek in de klas. Via het actieonderzoek kunnen docenten in het voortgezet onderwijs reflecteren op hun PCK. Het MSP startte met een tweeweekse zomercursus waarin docenten kennis maakten met actieonderzoek. De docenten bereidden een actieonderzoeksplan voor het komende schooljaar voor. Tijdens de tweeweekse zomercursus konden docenten zich in een onderwerp verdiepen waar zij eerder moeite mee hadden in de klas. In het MSP-programma participeerden ook universiteitsdocenten afkomstig van de bètafaculteiten (school of mathematics en school of science) en de lerarenopleiding (school of education) van de Southern Illinios University Carbondale (SIUC). Om het actieonderzoeksplan te ontwerpen werden de VO-docenten bijgestaan door deze universiteitsdocenten. Daarnaast konden zij hun ideeën vrijblijvend voorleggen aan andere collega's. De universiteitsdocenten fungeerden als mentoren in het MSP-programma. Gedurende het schooljaar ontmoetten de docenten hun mentoren voor vakinhoudelijk en educatief advies,voerden zij hun actieonderzoek uit, hielden een logboek (reflective journal) bij en werkten aan een ontwikkelingsrapport (progress report) waarin zij hun vorderingen konden vastleggen. Aan het eind van het schooljaar schreven de docenten hun ontwikkelingsrapport uit tot een eindrapport en leverden dit rapport in met de bijbehorende lesplannen en de leerlingenartefacten. Leerlingenartefacten waren voornamelijk logboeken van leerlingen, leerlingenpresentaties, foto's van leerlingprojecten, alsook voorbeelden van leerlingenevaluaties. Aanvullend werd een aantal docenten vrijwillig geïnterviewd. Het MSP werd uitgevoerd in drie opeenvolgende jaren in steeds drie aparte cohorten (zie Tabel 1.1).

De hoofdvragen in deze studie zijn: (1) Wat is de PCK van docenten wanneer zij lessen voorbereiden en uitvoeren als onderdeel van een professionaliseringsprogramma om hun lesgeven te bevorderen en (2) hoe verandert deze PCK wanneer zij participeren in dit programma? Om antwoord de kunnen geven op deze vragen zijn vier deelstudies uitgevoerd waarvoor verschillende databronnen zijn gebruikt. In de nu volgende hoofdstukken wordt telkens een deelstudie besproken.

Hoofdstuk 2: Oriëntaties over onderwijzen van wiskunde en bètadocenten

In de eerste deelstudie is gerapporteerd over de oriëntaties van 107 bètadocenten in drie verschillende cohorten van het MSP-programma. Hoofdvraag in deze studie was: *Wat zijn de onderwijsoriëntaties van wiskunde- en bètadocenten in de context van een professioneel ontwikkelingsprogramma?*

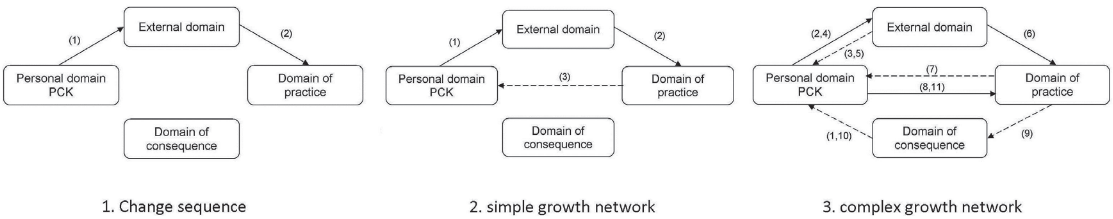
De onderzoeksplannen, de lesplannen, en de reflective journals (logboeken) van de VO-docenten werden gebruikt om hun oriëntaties te onderzoeken. Zowel de doelen in de actieonderzoeksplannen (AR-plannen) als de intenties die docenten hadden om bepaalde didactische principes of strategieën te gebruiken, zijn onderzocht. De analyse van de data van zowel de AR-plannen als de bijbehorende lesplannen hebben geresulteerd in drie verschillende hoofdoriëntaties: (1) oriëntatie op vakkennis met docentgestuurde onderwijsstrategieën, (2) oriëntatie op vakkennis met studentgecentreerde onderwijsstrategieën en (3) oriëntatie op vakvaardigheden met studentgecentreerde onderwijsstrategieën. Uit de data-analyse bleek dat er bij docenten die dezelfde hoofdoriëntaties hebben wel onderlinge verschillen zijn tussen de individuele oriëntaties. De meervoudige doelen en de intentie om verschillende onderwijsstrategieën te gebruiken hebben ertoe geleid dat docenten steeds een andere nadruk leggen binnen hun hoofdoriëntatie. Voorbeeld: Twee docenten kunnen dezelfde hoofdoriëntatie ‘oriëntatie op vakkennis met student gecentreerde onderwijsstrategieën’ hebben, maar docent 1 heeft als doel om vakkennis bij de leerlingen te bevorderen door middel van een gestructureerd onderzoek (‘structured inquiry’), terwijl docent 2 de leerlingen voornamelijk wil motiveren om hen zodoende tot het leren van vakkennis aan te zetten.

Hoofdstuk 3: PCK-typen van docenten

In de tweede deelstudie werd de PCK van de bètadocenten uit de cohorten 1 en 2 in de MSP-setting getypeerd. Twaalf docenten werden geïnterviewd nadat zij hun eindrapport en hun ‘reflective journal’ hadden ingediend. Er werden drie databronnen gebruikt om PCK-typen te identificeren. De centrale vraag in deze deelstudie was: Hoe kan de PCK van bètadocenten worden getypeerd wanneer deze docenten meedoen met een onderwijsprogramma gericht op de eigen professionele ontwikkeling? Op basis van de doelen van het bètaonderwijs, kon de PCK van de docenten in drie typen worden onderverdeeld: (I) kennis van het leren en onderwijzen gericht op bètavaardigheden, (II) kennis van het leren en onderwijzen van vakkennis met gebruik van verschillende didactische werkvormen en (III) kennis van het leren en onderwijzen van vakkennis door leerlingen te motiveren. Twee van deze onderwijsdoelen vertonen overeenkomst met de doelen zoals beschreven door Hodson (1992): (1) Leren van science (vakkennis) en (2) leren hoe science uit te voeren (skills). In deze studie is het derde doel van Hodson (1992), namelijk leren over bètaonderwijs, niet gevonden. In dit onderzoek is wel een ander doel geconstateerd: motiveren en interesseren van leerlingen in het bètaonderwijs. Het is vooral PCK-type III dat zich richt op dit doel. In deze studie is geconstateerd dat de doelen (goals) die door de docenten gesteld zijn een link hebben met een bepaalde 'bezorgdheid' (concern) van de docent, in de literatuur aangeduid als 'teaching goals' en 'teaching concerns'. Uit de resultaten kwam naar voren dat docenten die bezorgd zijn over de slechte resultaten van de leerlingen zich voornamelijk richten op het verhogen van vakkennis bij deze leerlingen (PCK-type II). Docenten van PCK-type I zijn voornamelijk gericht op het aanleren van vakvaardigheden (skills). Zij waren bezorgd dat leerlingen niet voldoende vakvaardigheden zouden bezitten, zoals onderzoeksvaardigheden. PCK-type III docenten bekenden dat hun leerlingen niet geïnteresseerd zijn in het vak en daarom ook slecht scoorden. Hun doel was voornamelijk om leerlingen te motiveren om hun vak aantrekkelijk te vinden, zodat zij het vak wilden leren. Uit dit onderzoek werd geconcludeerd dat 'teaching concerns' en 'teaching goals' de PCK van docenten sterk beïnvloeden, wat uiteindelijk resulteert in een bepaald PCK-type.

Hoofdstuk 4: PCK-ontwikkeling van bètadocenten

In de derde deelstudie werd de ontwikkeling van PCK onderzocht. Dezelfde twaalf docenten als in deelstudie 2 participeerden ook in deze studie. Er werd gebruik gemaakt van het IMTPG (Interconnected Model for Teachers' Professional Growth) van Clarke en Hollingsworth (2002). Met dit model zijn de veranderingen in de PCK van de docenten aan de hand van een zogenaamde 'pathway' te beschrijven. Een pathway geeft aan welke stappen een docent volgt en in welke volgorde, om verandering te brengen in zijn of haar PCK. Met andere woorden: welke ´weg´ in het IMTPG-model volgt de docent om te leren? De onderzoeksvraag luidt: Welke mogelijke paden (of 'pathways') leiden tot veranderingen in de PCK van bètadocenten wanneer zij participeren in het MSP-programma? Het IMTPG-model kent vier verschillende domeinen die met elkaar interacteren om de professionele ontwikkeling van docenten te stimuleren: (1) het persoonlijke domein, (2) het externe domein, (3) het praktische domein en (4) het domein van de gerealiseerde uitkomsten (ofwel het domein van consequenties). In deze studie is gebruik gemaakt van de actieonderzoeksrapporten, de lesplannen en de interviews van de docenten om de ontwikkeling van PCK te onderzoeken. Met behulp van het IMTPG-model zijn drie verschillende typen pathways waargenomen die leiden tot PCK-ontwikkeling (zie Figuur I).



Figuur I. De verschillende pathways

In de eerste 'pathway' is een verandering waargenomen in de verschillende domeinen, eindigend in een verandering van het praktische domein. In deze 'pathway' is geconcludeerd dat er geen verandering is opgetreden in de PCK van de docenten, omdat er geen terugkoppeling met het persoonlijke domein (PCK-domein) is gevonden. In de tweede en de derde pathway zijn wel veranderingen gevonden in de PCK van de docenten. Deze 'pathways' worden aangeduid als 'growth networks' en geven aan dat er een verandering is geweest in PCK. Clarke en Hollingsworth (2002) hebben in hun studie aangegeven dat 'growth networks' een blijvende verandering aangeven in de praktijk van de docenten en hun kennis. In deze studie zijn twee typen 'growth networks' waargenomen: een 'simple growth network' waarbij het domein van consequenties niet is opgenomen en een 'complex growth network' waarbij het domein van consequenties wel een rol speelt. Bij een 'simple growth network' heeft de docent wel gereflecteerd over de lessen, maar heeft niet expliciet gereflecteerd over de uitkomsten (van de les). In een 'complex growth network' gebeurt dit wel (zie figuur I-3). Docenten met zulke 'complex growth networks' reflecteerden voornamelijk over hun lesgeven en wat leerlingen geleerd hebben. Deze docenten waren in staat om aan te geven wat en hoe de leerlingen geleerd hebben en dat leidde tot nieuwe inzichten en een verandering van hun PCK. In sommige gevallen zijn docenten in staat geweest om hetgeen zij geleerd hebben (een veranderde PCK) te gebruiken in een vervolgaanpak. Dit werd waargenomen in het praktische domein: zie pijlen 9 t/m 11 in Figuur I-3.

In deze studie zijn onderdelen van het MSP-programma belangrijk geweest voor de ontwikkeling van PCK. Volgens het IMTPG-model wordt het MSP-programma gezien als een onderdeel van het externe domein. Vanuit het externe domein is geconstateerd dat de rol van de universiteitsdocenten van de 'school of math' en de 'school of science' een belangrijke factor heeft gespeeld in het bevorderen van de vakkennis bij de docenten. De universiteitsdocenten van de 'school of education' hebben bijgedragen in kennis over hoe leerlingen leren. Dit fenomeen werd geconstateerd in beide 'growth networks'. Andere onderdelen van het MSP-programma bleken ook heel belangrijk in de PCK-ontwikkeling van de docenten. Zo is ook gebleken dat kennis over nieuwe onderwijsstrategieën en assessmentmethoden werd opgedaan wanneer docenten literatuuronderzoek deden en de resultaten bespraken met hun collega's.

Hoofdstuk 5: De relaties tussen PCK-componenten en de praktijk van de docenten

Dit hoofdstuk beschrijft de vierde deelstudie van het laatste cohort in het MSP-programma. De onderzoeksvraag voor deze studie was: Wat is de relatie tussen de 'teaching concerns', de oriëntaties en het niveau van 'inquiry instructions' wanneer docenten lessen ontwerpen en verzorgen? Met ‘inquiry instructions’ wordt bedoeld de mate waarin docenten instructies geven aan hun leerlingen om onderzoek te (leren) doen.

Voor deze deelstudie werden data van onderzoeksrapporten, lesplannen en reflective journals gebruikt. Om het niveau van ‘inquiry instructions’ van 24 docenten te bepalen, werd gebruik gemaakt van het onderzoeksmodel van Bell et al. (2005). Dit model kent vier niveaus: (1) confirmatie niveau, (2) gestructureerd niveau, (3) begeleidend niveau en (4) open (of vrij) niveau. In deze studie werden de eerste twee niveaus beschouwd als lagere niveaus van ‘inquiry instructions’ en de laatste twee niveaus als de hogere niveaus van ‘inquiry instructions’. Duidelijk werd dat de concerns en de oriëntaties van de lagere niveaus verschilden van de oriëntaties en concerns van de docenten die een hoger niveau van ‘inquiry instructions’ gebruikten.

Docenten die een lager niveau van ‘inquiry instructions’ gebruikten, waren meestal bezorgd over de slechte resultaten van hun leerlingen. Zij constateerden in hun onderzoeksrapport dat de leerlingen weinig vakkennis en vakvaardigheden bezitten. Hun oriëntaties waren gericht op vakkennis, vakvaardigheden en activiteiten. Docenten met een lager niveau voor ‘onderzoek instructies’ waren ook meer geneigd om docentgestuurde activiteiten te plannen voor hun eigen les. Docenten die een hoger niveau gebruikten voor hun ‘inquiry instructions’ vonden dat hun leerlingen te weinig onderzoeksvaardigheden bezitten en te weinig mogelijkheden hebben om onderzoekservaring op te doen met authentieke problemen. Deze docenten hebben ook vakkennis-gerichte en vakvaardigheden-gerichte oriëntaties, maar combineren deze met andere oriëntaties uit de lijst van Magnusson et al. (1999) zoals onderzoek (inquiry), ontdekkend leren (discovery) en projectgebonden (project-based). Verder hebben deze docenten vooral gebruik gemaakt van studentgecentreerde activiteiten in hun lessen.

Hoofdstuk 6: Conclusies en discussie

De conclusies en de discussie zijn gebaseerd op de resultaten van de vier empirische deelstudies. Uit de eerste deelstudie werd geconcludeerd dat docenten die hebben geparticipeerd in het MSP-programma verschillende oriëntaties hebben. Uit de tweede deelstudie is geconcludeerd dat PCK van bètadocenten het best getypeerd kan worden wanneer men rekening houdt met de teaching concerns en de teaching goals van deze docenten. In de derde deelstudie is gebleken dat de ontwikkeling van PCK over verschillende 'pathways' kan gaan. In de laatste deelstudie bleek dat de concerns en oriëntaties in relatie staan tot het plannen van inquiry-gerichte instructies. Uit het onderzoek is gebleken dat het PCK-model van Magnusson et al. (1999) een belangrijk en bruikbaar model is bij PCK-onderzoek. In de tweede deelstudie is gebruik gemaakt van PCK-representaties om de verschillende typen PCK te identificeren. Deze PCK-representaties zijn ontwikkeld op basis van de vijf PCK componenten in het model van Magnusson et al. (1999). De PCK representaties zijn van grote waarde gebleken om de relatie tussen deze PCK-componenten te begrijpen. Aan de andere kant lieten deze PCK representaties ook de doelgerichtheid van PCK-typen zien. De doelen van Hodson (1992) bleken erg bruikbaar om te onderzoeken welke doelen bètadocenten nastreven. Een additioneel doel, motiveren van leerlingen in het bètaonderwijs, bleek ook een waardevol doel te zijn in het beschrijven van de oriëntaties van bètadocenten in relatie tot andere PCK-componenten. Uit het onderzoek werd ook duidelijk dat zowel oriëntaties als concerns belangrijke factoren zijn die PCK beïnvloeden. Vooral de 'teaching concerns' van bètadocenten verdienen meer aandacht in vervolgonderzoek naar PCK. In eerdere literatuur zijn de 'teaching concerns' nauwelijks beschreven, alhoewel sommige onderzoekers er wel aan refereren. In een vervolgonderzoek is het wellicht belangrijk om na te gaan welke plek 'teaching concerns' hebben in relatie tot PCK.

Omdat PCK niet meteen herkenbare kennis is, is gebruik gemaakt van meerdere databronnen, zoals onderzoeksrapporten, lesplannen, 'reflective journals' en interviews met docenten, om deze kennis te kunnen beschrijven. Geconstateerd werd dat deze instrumenten waardevol zijn in het begrijpen van de inhoud van PCK. Het gebruik van klassenobservaties zou de mogelijkheid hebben geboden te laten zien, hoe deze PCK getransformeerd wordt in de klas en hoe leerlingen daarop reageren. Naast het gebruik van klassenobservaties zijn longitudinale en grootschaliger schaal onderzoeken gewenst als vervolgonderzoek. Een groter aantal respondenten kan een nadere precisering geven van de PCK-typen zoals deze nu beschreven zijn in dit proefschrift.

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105-1149). Mahwah, NJ: Lawrence Erlbaum Associates.

Abell, S. K. (2008). PCK twenty years later: Does it remain a useful idea? *International Journal of Science Education, 30*, 1405-1416.

American Association for the Advancement of Science (1993). *Benchmarks for science literacy*. New York: Oxford University Press

Anderson, C. W. & Smith, E. L. (1987). Teaching science. In V. KoeWer (Ed.), *The educator's handbook: A research perspective* (pp. 84-111). New York: Longman.

Anderson, R. D. (2007). Inquiry as on organizing theme for science curricula. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 807-830). Mahwah, NJ: Lawrence Erlbaum Associates.

Andrews, P. & Hatch, G.(1999). A new look at secondary teachers' conceptions of mathematics and its teaching. *British Educational Research Journal*, 25(3), 203–223.

Arons, A. B. (1989). What science should we teach? In *A BSCS thirtieth anniversary symposium: curriculum development for the Year 2000* (pp. 13-20). Colorado Springs, CO: BSCS.

Ball, D. M. & Cohen, D. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional development. In L. Darling- Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 3-32). San Francisco,CA: Jossey-Bass.

Barnett, J. & Hodson, D. (2001). PCK: Toward a fuller understanding of what good science teachers know. *Science Teacher Education, 85,* 426-453.

Beijaard, D. & Verloop, N. (1996). Assessing teachers' practical knowledge. *Studies in Educational Evaluation, 22*(3), 275-286.

Beijaard, D., Verloop, N., Wubbels, T., & Feiman-Nemser, S. (2000). The professional development of teachers. In R. J. Simons, J. Van der Linden, & T. Duffy (Eds.), *New learning* (pp. 261–274). Dordrecht: Kluwer Academic Publishers.

Bell, B. (1998). Teacher development in science education. In B. J. Frazer & K. G. Tobias (Eds), International handbook of science education, Part II Kluver Academic Publishers. (pp. 681-693).

Bell, B. & Gilbert, J. (1996). *Teacher development – A model from science education*, London: Falmer Press.

Bell, R., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher, 72*(7), 30–34.

Berliner, D. C. (1986). In pursuit of the expert pedagogue. *Educational Researcher, 15*, 5-13.

Berliner, D. C. (2001). Learning about and learning from expert teachers. *International Journal of Educational Research, 35,* 463-482.

Berry, A., Loughran, J., Smith, K., & Lindsay, S. (2008). Capturing and enhancing science teachers' professional knowledge. *Research in Science Education, 39*, 575-594.

Bianchi, H. & Bell, R. (2008). The many levels of inquiry. *Science and Children, 46*(2), 26-29.

Black, A. L. & Halliwell, G. (2000). Accessing practical knowledge: How? Why? *Teaching and Teacher Education*, *16*, 103-115.

Boaler, J. (1998). Open and closed mathematics: Student experiences and understandings. *Journal for Research in Mathematics Education, 29*(1), 41-62.

Bolhuis, S. (2006). Professional development between teachers' practical knowledge and external demands. Plea for a broad social-constructivist and critical approach. In F. K. Oser, F. Achtenhagen, & U. Renold (Eds.), *Competence oriented teacher training. Old research demands and new pathways*. Rotterdam/Taipei: Sense Publishers.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3-15.

Borko, H. & Putnam, R. (1996). Learning to teach. In D. C. Berliner & R. C. Calfee (Eds), *Handbook of educational psychology* (pp. 673-708). New York: Macmillan.

Bryant, A. & Charmaz, K. (2007). Grounded theory research: Methods and practices. In A.Bryant & K. Charmaz (Eds.), *The Sage handbook of grounded theory*. Thousand Oaks, CA: Sage.

Bybee, R. W. (1993). *Reforming science education: Social perspectives and personal reflections*. New York: Teacher's College Press.

Bybee, R. W. (2004). Scientific inquiry and science teaching. In L. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science* (pp. 1-14). Dordrecht: Kluwer Academic Publishers.

Calderhead, J. (1996). Teachers: Beliefs and knowledge. In D. C. Berliner & R. C. Chaffee (Eds.), *Handbook of educational psychology* (pp. 709-725). New York: Macmillan.

Carey, N. & Frechtling, J. (1997). *Best practice in action: Follow-up survey on teacher enhancement programs.* Washington, DC: National Science Foundation.

Carter, K. (1990). Teachers' knowledge and learning to teach. In W. R. Houston (Ed.), *Handbook of research on teacher education* (pp. 291-310). New York: Macmillan.

Clarke, D. J., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education*, *18*(8), 947-967.

Clermont, C. P., Borko, H., & Krajcik, J. S. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. *Journal of Research in Science Teaching, 31,* 419–441.

Cochran, K. F., DeRuiter, J. A., & King, R. A. (1993). Pedagogical content knowing: An integrative model for teacher preparation. *Journal of Teacher Education, 44*, 263- 272.

Cohen, D.K. & Hill, H.C. (2000). Instructional policy and classroom performance: The mathematics reform in California. *Teachers College Record, 102*(2), 294–343.

Cohen, L., Manion, L., & Morrison, K. (2000). *Research Methods in Education* (5th ed.). London: Routledge Falmer.

Corbin, J. & Strauss, A. (2003). Grounded theory research. In N. Fielding (Ed.) *Interviewing* (vol. 4). London, Sage.

Corbin, J. & Strauss, A. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage Publications.

Crawford, B. A. (1999). Is it realistic to expect a pre-service teacher to create an inquiry-based classroom? *Journal of Science Teacher Education*, *10*, 175-194.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, *37*, 916–937.

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, *44*(4), 613–642.

Crawford, B. A., Zembal-Saul, C., Munford, D., & Friedrichsen, P. (2005). Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of Research in Science Teaching*, *43*(6), 613-637.

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 209–240). Thousand Oaks, CA: Sage.

Darling-Hammond, L. (2008). Teacher learning that supports student learning. In B.Z. Presseisen (Ed.) *Teaching for Intelligence* (3rd ed., pp. 91-100). Thousand Oaks, CA: Corwin Press.

Dawkins, K. R. & Dickerson, D. L. (2003). *Pre-service teachers' pedagogical content knowledge regarding density*. Paper presented at the annual meeting of the American Educational Research Association in Chicago, IL.

De Heus, P., Van der Leeden, R., & Gazendam, B. (1995). *Toegepaste data-analyse: Technieken voor niet-experimenteel onderzoek in de sociale wetenschappen* [Applied data-analyses: Techniques for non-experimental research in the social sciences]. Utrecht, the Netherlands: Uitgeverij Lemma.

De Jong, O. (2000). The teacher trainer as researcher: exploring the initial pedagogical content concerns of prospective science teachers. *European Journal of Teacher Education, 23*, 127-137.

De Jong, O. & Van Driel, J. H. (1999). The development of pre-service teachers concerns about teaching chemistry topics at a macro-micro representational interface. In: M. Komorek et al. (Eds.). *Research in science education: Past, present and future* (596-598). Dordrecht: Kluwer Academic Publishers.

De Jong, O., Van Driel, J. H., & Verloop, N. (2005). Pre-service teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching, 42,* 947-964.

Deboer, G. E. (2004). Historical perspectives on inquiry teaching in schools. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 17-35). Dordrecht: Kluwer Academic Publishers.

Delpech, R. (2002). Why are school students bored with science? *Journal of Biological Education, 36*(4), 156-157.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*, 181–199.

Desimone, L. M., Porter, A. C., Garet, M., Yoon, K. S., & Birman, B. (2002). Does professional development change teachers' instruction? Results from a three-year study. *Educational Evaluation and Policy Analysis, 24*(2), 81-112.

Doyle, W. (1985). Recent research on classroom management. *Journal of Teacher Education, 36,* 31-35.

Duschl, R. (1988). Improving science teacher education programs through the inclusion of history and philosophy of science. In J. Barufaldi (Ed.), 1987 *Association of educators of teachers of science yearbook* (pp. 1-24). Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education.

Ebenezer, J. V., & Zoller, U. (1993). Grade 10 students' perceptions of and attitudes toward science teaching and school science. *Journal of Research in Science Teaching, 30*(2), 175-186.

Eraut, M. (1994). *Developing professional practice and competence*. London: Falmer Press.

Feiman-Nemser, S. (2001). Helping novices learn to teach: Lessons from an exemplary support teacher. *Journal of Teacher Education, 52,* 17-30.

Feldman, A. (1996). Enhancing the practice of physics teachers: Mechanisms for the generation and sharing of knowledge and understanding in collaborative action research. *Journal of research in science teaching, 33*(5), 513-540.

Feldman, A. (2007). Validity and quality in action research. *Educational Action Research, 15*(1), 21-32.

Fennema, E., Carpenter, T., Franke, M., Levi, L., Jacobs, V., & Empson, S. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for Research in Mathematics Education, 27*, 403-434.

Fernández-Balboa, J. M. & Stiehl, J. (1995). Effective professors' pedagogical processes. *Teaching and Teacher Education, 11,* 293-306.

Fielding, G. & Schalock, H. (1985). *Promoting the professional development of teachers and administrators*. Eugene, OR: Center for Educational Policy and Management.

Fishman, J. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education, 19*, 643-658.

Fraser, C., Kennedy, A., Reid, L., & McKinney, S. (2007). Teachers' continuing professional development: Contested concepts, understandings and models. *Journal of In-service Education*, *33*(2), 153–169.

Friedrichsen, P. M., Abell, S., Pareja, E., Brown, P., Lankford, D., & Volkmann, M. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching, 46*, 357–383.

Friedrichsen, P. M., & Dana, T. M. (2003). Using a card sorting task to elicit and clarify science teaching orientations. *Journal of Science Teacher Education, 14*(4), 291-301.

Friedrichsen, P. M., & Dana, T. M. (2005). A substantive-level theory of highly-regarded secondary biology teachers' science teaching orientations. *Journal of Research in Science Teaching, 42*(2), 218-244.

Friedrichsen, P. M., Van Driel, J. H., & Abell, S. (2011). Taking a closer look at science teaching orientations. *Science Education, 95*(2), 358-376.

Furio, C., Vilches, A., Guisasola, J., & Romo, V. (2002). Spanish teachers' views of the goals of science education in secondary education. *Research in Science and Technological Education, 20,* 936-960.

Ganser, T. (2000). An ambitious vision of professional development for teachers. *NASSP Bulletin, 84*, 6-12.

Gess-Newsome, J. (1999a). PCK: An introduction and orientation. In J. Gess-Newsome & N. G. Lederman (Eds.) *Examining pedagogical content knowledge: The construct and its implications for science education (pp. 3-20).* Dordrecht: Kluwer Academic Publishers.

Gess-Newsome, J. (1999b). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: the construct and its implications for science education (pp. 51-94)*. Dordrecht: Kluwer Academic Publishers.

Gifi, A. (1990). *Nonlinear multivariate analysis*. Chichester: John Wiley & Sons Ltd.

Glaser, B.G. & Holton, J. (2004). Remodelling grounded theory. *Forum Qualitative Social Research*, 5, 4.

Glaser, B. & Strauss, A. (1967). *The discovery of grounded theory*. Chicago: Aldine

Grossman, P. L. (1989). A study in contrast: Sources of pedagogical content knowledge for secondary English. *Journal of Teacher Education*, *40*(5), 24-31.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Grossman, P. L., Wilson, S., & Shulman, L. S. (1989). Teachers of substance: subject matter knowledge for teaching. In M. Reynolds (Ed.), *Knowledge base for the beginning teacher* (pp. 23-36). Oxford, England: Pergammon Press.

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation. *Field Methods, 18*(1), 58-82.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher, 15*(5), 5-12.

Guskey, T. R. (2000). *Evaluating professional development programs*. Thousand Oaks, Ca: Corwin Press.

Guskey, T. R. (2002a). Does it make a difference? Evaluating professional development. *Educational Leadership, 59*(6). 45–51.

Guskey, T. R. (2002b). Professional development and teacher change. *Teachers and Teaching: Theory and Practice, 8*(3/4), 381-391.

Halim, L. & Meerah, S. M. (2002). Science trainee teachers' pedagogical content knowledge and its influence on physics teaching. *Research in Science and Technology Education, 20*(2), 215-226.

Haney, J. J., Czerniak, C. M., & Lumpe, A. T. (1996). Teacher beliefs and intentions regarding the implementation of science education reform strands. *Journal of Research in Science Teaching, 33*, 971-993.

Hashweh, M. Z. (1987). Effects of subject matter knowledge in the teaching of biology and physics. *Teaching and Teacher Education, 3*, 109-120.

Hashweh, M. Z. (2003). Teacher accommodative change. *Teaching and Teacher Education, 19*, 421-434.

Hashweh, M. Z. (2005). Teacher pedagogical constructions: a reconfiguration of PCK. *Teachers and Teaching: Theory and Practice, 11*, 273-292.

Henze, I., Van Driel, J. H., & Verloop, N. (2008). The development of experienced science teachers' pedagogical content knowledge of models in the solar system and the universe. *International Journal of Science Education, 30*(10), 1321-1342.

Hewson, P. W. & Hewson, M. G. (1987). Science teachers' conception of teaching: Implications for teacher education. *International Journal of Science Education*, *9*, 425–440.

Hewson, P. W. & Hewson, M. G. (1989). Analysis and use of a task for identifying conceptions of teaching science. *Journal of Education for Teaching, 15*(3), 191-209.

Hewson, P. W., Kerby, H. W., & Cook, P. A. (1995). Determining the conceptions of teaching science held by experienced high school science teachers. *Journal of Research in Science Teaching, 32*(5), 503–520.

Hickey, D. T., Moore, A. L., & Pellegrino, J. W. (2001). The motivational and academic consequences of elementary mathematics environments: Do constructivist innovations and reforms make a difference? *American Educational Research Journal, 38*(3), 611–652.

Hodson, D. (1992). In search of a meaningful relationship: An exploration of some issues relating to integration in science and science education. *International Journal Of Science Education, 14*(5), 541-566.

Jacobs, J. K., Hiebert, J., Givvin, K. B., Hollingsworth, H., Garnier, H., & Wearne, D. (2006). Does eighth-grade mathematics teaching in the United States align with the NCTM Standards? Results from the TIMSS 1995 and 1999 video studies. *Journal for Research in Mathematics Education, 37*(1), 5-32.

Johnston, J. & Ahtee, M. (2006). What are primary student teachers' attitudes, subject knowledge and pedagogical content knowledge needs in a physics topic? *Teaching and Teacher Education, 22*(4), 1-10.

Johnston, S. (1992). Images: A way of understanding the practical knowledge of student teachers. *Teaching and Teacher Education*, *8*, 123-136.

Jones, M. T. & Eick, C. J. (2007). Implementing inquiry kit curriculum: Obstacles, adaptations, and practice knowledge development in two middle school science teachers. *Science Education*, *91*, 492-513.

Justi, R. & Gilbert, J. K. (2002). Models and modelling in chemical education. In J. K. Gilbert, O. D. Jong, R. Justi, D. F. Treagust & J. H. Van Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 47-68). Dordrecht: Kluwer.

Justi, R. & Van Driel, J. H. (2006). The use of the Interconnected Model of Teacher Professional Growth for understanding the development of science teachers' knowledge on models and modelling. *Teaching and Teacher Education*, *22,* 437-450.

Kagan, D. M. (1992). Professional growth among pre-service and beginning teachers. *Review of Educational Research, 62*(2), 129-169.

Kaya, O. N. (2009). The nature of relationships among the components of pedagogical content knowledge of preservice science teachers: 'Ozone layer depletion' as an example', *International Journal of Science Education, 31*(7), 961-988.

Kennedy, M. (1999). *Form and substance in mathematics and science professional development. National Institute for Science Education Brief* (November 1999): 1-7.

Kesidou, S. & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. *Journal of Research in Science Teaching, 39,* 522-549.

Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. *Studies in Science Education, 45*(2), 169-204.

King, B. M. & Newman, F. M. (2000). Will teacher learning advance school goals? *Phi Delta Kappan, 81*(8), 576-580.

Klinger, D. (2000). Hierarchical linear modelling of student and school effects on academic achievement. *Canadian Journal of Education, 25*, 41-55.

Koballa, T. R., Glynn, S. M., Leslie, U., & Coleman, D. (2005). Conceptions of teaching science held by novice teachers in an alternative certification program. *Journal of Science Teacher Education, 16*, 287-308.

Koballa, T. R. & Gräber, W. (2001). *Prospective science teachers' conceptions of teaching and learning: A methodological reconsideration.* Paper presented at the 3rd International Conference on Science Education Research in the Knowledge, Thessaloniki, Greece.

Koballa, T. R., Gräber, W., Coleman, D., & Kemp, A. C. (1999). Prospective teachers' conceptions of the knowledge base for teaching chemistry at the gymnasium. *Journal of Science Teacher Education, 10*(4), 269–286.

Korthagen, F. A. J., Kessels, J., Koster, B., Lagerwerf, B., & Wubbels, T. (2001). *Linking practice and theory: The pedagogy of realistic teacher education*. Mahwah, NJ: Lawrence Erlbaum Associates.

Lankford, D. (2010). *Examining the pedagogical content knowledge and practice of experienced secondary biology teachers for teaching diffusion and osmosis*. Unpublished doctoral dissertation. University of Columbia, Missouri.

Lantz, O. & Kass, H. (1987). Chemistry teachers: Functional paradigms. *Science Education, 71*, 117-134

Lederman, N. G., & Niess, M. L. (1997). Action research: our actions may speak louder than our words. *School Science & Mathematics, 97*(8), 397-399.

Lee, E., Brown, M. N., & Luft, J. A. (2006). *Assessing beginning secondary science teachers' PCK: Pilot year results.* A paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Lee, E., & Luft, J. A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education, 30*(10), 1343-1363.

Lemberger, J., Hewson, P. W., & Park, H. (1999). Relationship between prospective secondary teachers' classroom practice and their conceptions of biology and of teaching science. *Science Education, 83*(3), 347-371.

Little, J. W. (2001). Professional development in pursuit of school reform. In A. Lieberman & L. Miller (Eds.), *Teachers caught in the action: Professional development that matters* (pp. 28-44). New York: Teachers College Press.

Lotter, C., Harwood, W. S., & Bonner, J. J. (2006). Overcoming a learning bottleneck: Inquiry professional development for secondary science teachers. *Journal of Science teacher Education, 17*, 185-216.

Loucks-Horsley, S., Love, N., Styles, K. E., Mundry, S., & Hewson, P. (2003). *Designing professional development for teachers of science and mathematics (2nd ed.).*California: Corwin.

Loughran, J., Berry, A., & Mulhall, P. (2006). *Understanding and developing science teachers' pedagogical content knowledge.* Rotterdam: Sense Publications.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs, *Research in Science Education, 31*, 289-307.

Loughran, J., Mulhall, P., & Berry, A. (2008). Exploring pedagogical content knowledge in science teacher education: a case study*. International Journal of Science Education, 30*(10), 1301-1320.

Lumpe, A., Haney, J., & Czerniak, C. (2000). Assessing teachers' beliefs about their science teaching context. *Journal of Research in Science Teaching*, *37*, 275–292.

Lyons, L., Freitag, P. K., & Hewson, P. W. (1997). Dichotomy in thinking, dilemma in actions: Researcher and teacher perspectives on a chemistry teaching practice. *Journal of Research in Science Teaching, 34*(3), 239-254.

Magnusson, S., Krajacik, J., & Borko, H. (1999). Nature, sources, and development of PCK for science teaching. In J. Gess-Newsome and N.G. Lederman (Eds.) *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-120). Dordrecht: Kluwer Academic Press.

Marks, R. (1990). Pedagogical content knowledge: From a mathematical case to a modified conception. *Journal of Teacher Education, 41*, 3-11.

Meijer, P. C. (1999). *Teachers' practical knowledge: teaching reading comprehension in secondary education.* Doctoral dissertation. Leiden University.

Melnick, S. A. & Meister, D. G. (2008). A comparison of beginning and experienced teachers' concerns. *Educational Research Quarterly*, *31*(3), 39-56.

Meyer, H., Tabachnick, R., Hewson, P., Lemberger, J., & Park, H. (1999). The relationship between prospective elementary teachers' classroom practices and their conceptions of biology and of teaching science. *Science Education, 83*(3), 324–346.

Mulholland, J. & Wallace, J. (2005). Growing the tree of teacher knowledge: Ten years of learning to teach elementary science. *Journal of Research in Science teaching*, *42*(7), 767-790.

National Research Council (1996). *National science education standards: Observe, interact, change, learn*. Washington, DC: National Academy Press.

National Research Council (1997). *Science teaching reconsidered.* Washington, D.C.: National Academy Press.

Nilsson, P. (2008). Teaching for Understanding: The complex nature of pedagogical content knowledge in pre-service education. *International Journal of Science Education, 30*(10). 1281-1299.

National Science Teachers Association (2000). *NSTA position statement: The nature of science*. http://www.nsta.org/about/positions/natureofscience.aspx. Last accessed: November 2011

Pajares, M. F. (1992). Teachers' beliefs and educational research: cleaning up a messy construct. *Review of Educational Research, 62*(3), 307-333.

Patton, M. (2002). *Qualitative research and evaluation methods*. 3rd ed. Thousand Oaks,CA: Sage Publications.

Ponte, P. (2002). How teachers become action researchers and how teacher educators become their facilitators. *Educational Action Research, 10*(3), 399-422.

Ponte, P., Ax, J., Beijaard, D., & Wubbels, T. (2004). Teachers' development of professional knowledge through action research and the facilitation of this by teacher educators. *Teaching and Teacher Education*, *20*, 571-588.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66,* 211-227.

Putnam, R. T., & Borko, H. (1997). Teacher learning: Implications of new views of cognition. In B. J. Biddle, T. L. Good & I. F. Goodson (Eds.), *International handbook of teachers and teaching* (Vol. 2, pp. 1223-1296). Dordrecht, The Netherlands: Kluwer.

Ramsden, J. M. (1998). Mission impossible?: Can anything be done about attitudes to science? *International Journal of Science Education, 20*(2), 125-137.

Rezba, R. J., Auldridge, T., & Rhea, L. (1999). *Teaching and learning the basic science skills.* www.pen.k12.va.us/VDOE/instruction/TLBSSGuide.doc. Last accessed: September 2010.

Rhine, S. (1998). The role of research and teachers' knowledge base in professional development. *Educational Researcher, 27*(5), 27-31.

Richardson, V. & Placier, P. (2002). Teacher change. In V. Richardson (Ed.), *Handbook of research on teaching* (4rd Ed., pp. 905-947). Washington, DC: American Educational Research Association.

Roehrig, G. H., & Garrow, S. T. (2007). The impact of teacher classroom practices on student achievement during the implementation of a reform-based chemistry curriculum. *International Journal of Science Education, 29,* 1789-1811.

Roehrig, G. H., & Luft, J. A. (2004). Inquiry teaching in high school chemistry classrooms: The role of knowledge and beliefs. *Journal of Chemical Education, 81*, 1510-1516.

Rushton, G. T., Lotter, C., & Singer, T. (2011). Chemistry teachers' emerging expertise in inquiry teaching: The effect of a professional development model on beliefs and practice. *Journal of Science Teacher Education, 22*(1), 23-52.

Sanger, M. J. (2008). How does inquiry-based instruction affect teaching major's views about teaching and learning science? *Journal of Chemical Education, 85*(2), 297-302.

Schneider, R. M., & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of Research in Science Teaching, 13,* 221-245.

Schön, D. (1983). *The reflective practitioner. How professionals think*. New York: Basic Books.

Schwab, J. J. (1962). The teaching of science as inquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3–103). Cambridge, MA: Harvard University Press.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the New Reform. *Harvard Educational Review, 57*(1), 1–22.

Shulman, L. S. & Grossman, P. (1988). *The intern teacher casebook*. San Francisco, CA: Far Wets Laboratory for Educational Research and Development.

Shulman, L. S. & Shulman, J. H. (2004). How and what teachers learn: A shifting perspective. *Journal of Curriculum Studies, 36*(2), 257–271.

Simmons, P. E., Emory, A., Carter, T., Coker, T., Finnegan, B., Crockett, D., et al. (1999). Beginning teachers: Beliefs and classroom actions. *Journal of Research in Science Teaching, 36*(8), 930-945.

Sprinthall, N. A., Reiman, A. J., & Thies-Sprinthall, L. (1996). Teacher professional development. In J. Sikula, T. J. Buttery, and E. Guyton (Eds.), *Handbook of research on teacher education(pp. 666- 703)*. New York: Macmillan

Spronken-Smith, R. & Walker, R. (2010). Can inquiry-based learning strengthen the links between teaching and disciplinary research? *Studies in Higher Education, 35*(6), 723–740.

Steckler, A., McLeroy, K. R., Goodman, R. M., Bird, S. T., & McCormick, L. (1992). Toward integrating qualitative and quantitative methods: An introduction. *Health Education Quarterly, 19*, 1-8.

Stigler, J. W., Gallimore, R., & Hiebert, J. (2000). Using video surveys to compare classrooms and teaching across cultures: Examples and lessons from the TIMSS video studies. *Educational Psychologist, 35,* 87–100.

Stigler, J. W. & Hiebert, J. (2004). Improving mathematics teaching. *Educational Leadership, 61*(5), 12-17.

Strauss, A. & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. London: Sage.

Talanquer, V, Novodvorksy, I, & Tomanek, D. (2010). Factors influencing entering teacher candidates' preferences for instructional activities: A glimpse into their orientations towards teaching. *International Journal of Science Education, 32*(10), 1389 -1406.

Thompson, A. G., Philipp, R. A., Thompson, P. W., & Boyd, B. (1994). Calculational and conceptual orientations in teaching mathematics. In A. Coxford (Ed). *1994 Yearbook of the National Council of Teachers of Mathematics* (pp. 79-92). Reston, VA: National Council of Teachers of Mathematics.

Towers, J. (2010). Learning to teach mathematics through inquiry: a focus on the relationship between describing and enacting inquiry-oriented teaching. *Journal of Mathematics Teacher Education, 13*, 243–263.

Trigwell, K., Prosser, M., & Taylor, P. (1994). Qualitative differences in approaches to teaching first year university science. *Higher Education, 27*, 75-84.

Tsui, C. Y. & Treagust, D. (2010). Evaluating secondary students' scientific reasoning in genetics using a two-tier diagnostic instrument. *International Journal of Science Education, 32*(8), 1073-1098.

Tsur, C. & Crawford, B. A. (2001). *Prospective science teachers' knowledge of inquiry-based instruction in a secondary methods course.* Paper presented at the annual international meeting of the Association for the Education of Teachers in Science, Costa Mesa, CA.

Van der Rijst, R. M. (2009). The research-teaching nexus in the sciences: *Scientific research dispositions and teaching practice.* Doctoral dissertation. Leiden University.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practice and knowledge. *Journal of Research in Science Teaching, 38,* 137-158.

Van Driel, J. H., De Jong, O., & Verloop, N. (2002). The development of pre-service chemistry teachers' PCK. *Science Education, 86,* 572-590.

Van Driel, J. H. & Verloop, N. (1999). Teachers' knowledge of models and modeling in science. *International Journal of Science Education, 21,* 1141-1153.

Van Driel, J. H. & Verloop, N. (2002). Experienced teachers knowledge of teaching and learning of models and modelling in science education. *International Journal of Science Education, 24,* 1255-1272.

Van Driel, J. H., Verloop, N., & De Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*, 673-695.

Van Driel, J. H., Verloop, N. Van Werven, H. I., & Dekkers, H. (1997). Teachers' craft knowledge and curriculum innovation in higher engineering education. *Higher Education, 34(1)*, 105-122.

Van Veen, K., Zwart, R., Meirink, J., & Verloop, N. (2010). *Professional development of teachers: a review study on the effective characteristics of professional interventions of teachers.* (Professionele ontwikkeling van leraren: een reviewstudie naar effectieve kenmerken van professionaliseringsinterventies van leraren). Leiden: ICLON/ Expertisecentrum: Leren van Docenten.

Verloop, N. (1992). Praktijkkennis van docenten: een blinde vlek van de onderwijskunde. [Practical knowledge of teachers: a blind spot on educational sciences]. *Pedagogische studiën, 69*, 410-423.

Verloop, N., Van Driel, J. H., & Meijer, P. C. (2001). Teacher knowledge and the knowledge base of teaching. *International Journal of Educational Research, 35*, 441-461.

Viiri, J. (2003). Engineering teachers' pedagogical content knowledge. *European Journal of Engineering Education, 28*(3), 353-359.

Wallace, J. (2003). Introduction: Learning about teacher learning: reflections of a science educator. In J. Wallace and J. Loughran (Eds.), *Leadership and professional development in science education: New possibilities for enhancing teacher learning* (pp. 1-16). London: RoutledgeFalmer.

Wallace, J. & Louden, W. (1992). Science teaching and teachers' knowledge: prospects for reform of elementary classrooms, *Science Education, 76*, 507–521.

Weinstein, C. S. (1989). Teacher education students' preconceptions of teaching. *Journal of Teacher Education, 40(2),*53-60.

Weinstein, C. S. (1990). Prospective elementary teachers' beliefs about teaching: Implications for teacher education. *Teaching and Teacher Education, 6*(3), 279-290.

Wiley, D. & Yoon, B. (1995). Teacher reports on opportunity to learn: Analyses of the 1993 California learning assessment systems. *Educational Evaluation and Policy Analysis, 17*, 355-370.

Wilson, S. M. & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: A review of research on contemporary professional development. *Review of Research in Education, 24*, 173-209.

Wubbels, T. (1992). Taking account of student teachers' preconceptions *Teaching and Teacher Education, 8*(2), 137-150.

Zwart, R. C. (2007). *Teacher learning in a context of reciprocal peer coaching.* Doctoral dissertation. Radboud University Nijmegen.Zwart, R. C., Wubbels, T., Bergen, T. C. M., & Bolhuis, S. (2007). Experienced teacher learning within the context of reciprocal peer coaching. *Teachers and Teaching: Theory and practice, 13*(2), 165–187.

Appendices

Appendix A: **Interview outline**

	Interview questions
Purpose of teaching (Hodson, 1991)	What was the purpose of your lessons: a) teach science, b) teach how to do science, or c) learn about science? Have you used this purpose before? Please explain your answers.
Science curriculum	What was the topic of your lessons? What were the objectives of your science topic? Please explain why you have these objectives.
Instructional strategies	What kinds of classroom strategies did you use to teach the content? Have you used these strategies before in your classroom? Please explain your answer.
Students' understanding	What was necessary for your students to understand your lessons? What was successful in your lessons? And what learning difficulties did you encounter during your lessons? Were you aware of these things before? Please explain.
Goals and objectives	What were the goals and objectives of your lessons? How did you create these objectives? Have you used these goals and objectives before?
Assessment	How did you assess your students, and why did you assess them in that way? Have you used these assessment methods before?

Appendix B: Spreadsheet with an overview of data of the 24 participating science teachers

Source:	Progress report	Progress report	Progress report	Progress report	Progress report	Progress report	Lesson plans
Teacher	years of experience	class	students	Topic	Concerns	Orientations of science teaching (purposes and goals)	**Inquiry level**
Ada	1	10th	2 classes of 18 each	community ecology	low tests scores	content driven/didactic/activity-driven	confirmation
Ali	11	4th	11 students	ecosystems	low tests scores	content driven/didactic/activity-driven	confirmation
Ben	12	5th	19 students	general ecology	lack of any hands-on activity	content driven hands-on/didactic	confirmation
Dan	16	13th	2 classes (20 and 25)	bio fuels	lack of content knowledge	content driven activity-driven/academic rigor	confirmation
Don	31	8th	25 students	chemical equations	lack of content knowledge	content driven activity-driven/academic rigor	confirmation
June	16	6th	17 students	ecology	lack of content knowledge	content driven didactic/activity-driven	confirmation
Kim	8	5th	24 students	tropical rainforest	lack of inquiry knowledge	content driven activity-driven/academic rigor	confirmation
Vicky	13	2nd	14 students	lifecycles of insects	low tests scores	content driven activity-driven/conceptual change	confirmation
Agnes	4	3rd	21 students	plant lifecycles	lack of science experience	skills driven/activity-driven	structured
Carla	10	2nd	15 students	animal habitat	lack of science experience	skills driven/activity-driven	structured
Debra	19	4th	24 students	owl habitat	lack of inquiry experience	skills driven/activity driven	structured

Deon	15	4th	7 students	ecology	low test scores and lack inquiry experience	content driven/skills driven/process/ activity-driven	structured
Kathy	4	8th	18 students	soils of prairielands	lack of inquiry experience	skills driven/activity driven	structured
Rose	26	6th	15 students	biomes	lack of inquiry experience	skills driven/activity-driven	structured
Shannon	22	6th	15 students	lifecycle of plants	low tests scores	content driven activity-driven	structured
Valery	13	7th		biomes	lack of inquiry experience	skills driven/activity-driven	structured
Bertha	4	5th	24 students	ecosystems	lack of inquiry experience	content driven/skills driven/discovery/ inquiry	guided inquiry
Bill	3	8th	10 students	medicinal plants	lack of science and inquiry experience	content driven/skills driven/project-based/inquiry	guided inquiry
Christy	5	7th	28 students	prairie lands	lack of real world inquiry experience	content driven/skills driven/inquiry	guided inquiry
Delia	10	8th	8 special ed students	biomes	lack of real world inquiry experience	content driven/skills driven/inquiry	guided inquiry
Jaclyn	26	5th	24 students	aquatic ponds	lack of real world inquiry experience	content driven/skills driven/inquiry	guided inquiry
Judy	7	5th	20 mixed students	aquatic ponds	lack of enthusiasm in science	content driven/skills driven/inquiry earning	guided inquiry
Brenda	3	7th	17 students	animals on prairieland	lack of real world inquiry experience	content driven/skills driven/ inquiry/ discovery learning/projects	open inquiry
Lila	12	4th		recycling	lack of real world inquiry experience	content driven/skills driven/discovery learning	open inquiry

Curriculum Vitae

Dirk Wongsopawiro was born in Paramaribo, Suriname on November 8th, 1971. He attended the Ewald P. Meyer Lyceum, secondary school as well as the Instituut voor de Opleiding van Leraren (Advanced Teacher Training Institute), in Paramaribo, where he received his teaching degree in 1994. He worked as a biology teacher for several years before he started his master study in environmental sciences at the Wageningen University in 1999. After his graduation in 2001, he worked as a science teacher and researcher for the University of Suriname. In 2004 he started his PhD project at the school of education of the Southern University in Carbondale, IL, USA. In that year, he became interested in teachers' pedagogical content knowledge (PCK), which caused him to shift his research to that topic. Working for the Regional Office of Education in Mount Vernon as an external evaluator for several years, he collaborated with ICLON, University of Leiden to supervise him in his thesis overseas. His research focused on the pedagogical content knowledge of science teachers from secondary education to improve the understanding of how these teachers use and develop their PCK while participating in The Mathematics and Science Partnership Program, professional development program for teachers. During his PhD project he took master classes on teaching and teacher education, curriculum and instructional development, and quantitative and qualitative data analyses. He presented some of his research at the annual conference of the Netherlands Education Research Association (NERA).

Currently, Dirk works as a teacher educator and researcher for both the teacher college and the graduate school of the university of Suriname. His research interests are pedagogical content knowledge, action research, and science education.

Dankwoord

Aan het eind van dit proefschrift maak ik graag van de gelegenheid gebruik om degenen te bedanken die hebben bijgedragen aan de totstandkoming van dit proefschrift. Er zijn veel mensen die mij hebben ondersteund tijdens mijn onderzoek en die ik wil bedanken. Ik kan helaas niet een ieder bij naam noemen, maar wil graag enkele mensen hier persoonlijk dankzeggen.

Ten eerste mijn promotor Jan van Driel, die mij steeds heeft bijgestaan in mijn onderzoek en die mij steeds weer aan het denken kon zetten over de bruikbaarheid en ontwikkeling van PCK. Rosanne Zwart voor haar inzicht in het professionaliseringsmodel. Ed Suddarth, die mij de gelegenheid heeft geboden om het project uit te voeren bij de Regional Office of Education in Mt. Vernon, VS. 'Many thanks for giving me this wonderful opportunity Ed.' Nico Verloop die het mogelijk maakte dat ik bij het ICLON verder kon werken aan mijn onderzoek. Archie Marshall die mij steeds de noodzaak van onderzoek in het onderwijs liet inzien. Alle docenten die hebben geparticipeerd in dit onderzoek, zonder wie dit onderzoek letterlijk niet uitgevoerd had kunnen worden. Nelleke Belo, mijn kamergenoot, met wie ik eindeloos kon nadenken over onderwijsonderzoek. Ben Smit voor zijn adviezen en hulp in de statistiek. Dave Abeleven voor zijn hulp bij de tekeningen en Gerda Visser-Wijnveen voor het laatste commentaar op mijn proefschrift. De onderzoeksgroep van het ICLON, waar ik mijn onderzoek mocht presenteren en waar ik veel heb geleerd over onderzoek doen. Mijn familie en vrienden in Nederland en Suriname die mij op allerlei manieren hebben gesteund in mijn onderzoek en ook voor de nodige ontspanning zorgden en John Roberscheuten voor zijn nimmer falende steun gedurende het gehele promotietraject.

Aan al deze mensen:

BEDANKT!

ICLON

Leiden University Graduate School of Teaching

PhD dissertation series

Hoeflaak, A. (1994). *Decoderen en interpreteren: een onderzoek naar het gebruik van strategieën bij het beluisteren van Franse nieuwsteksten.*

Verhoeven, P. (1997). *Tekstbegrip in het onderwijs klassieke talen.*

Meijer, P. C. (1999). *Teachers' practical knowledge: Teaching reading comprehension in secondary education.*

Zanting, A. (2001). *Mining the mentor's mind: The elicitation of mentor teachers' practical knowledge by prospective teachers.*

Uhlenbeck, A. M. (2002). *The development of an assessment procedure for beginning teachers of English as a foreign language.*

Oolbekkink-Marchand, H. W. (2006). *Teachers' perspectives on self-regulated learning: An exploratory study in secondary and university education.*

Henze-Rietveld, F. A. (2006). *Science teachers' knowledge development in the context of educational innovation.*

Mansvelder-Longayroux, D. D. (2006). *The learning portfolio as a tool for stimulating reflection by student teachers.*

Meirink, J. A. (2007). *Individual teacher learning in a context of collaboration in teams.*

Nijveldt, M. J. (2008). *Validity in teacher assessment: An exploration of the judgement processes of assessors.*

Bakker, M. E. J. (2008). *Design and evaluation of video portfolios: Reliability, generalizability, and validity of an authentic performance assessment for teachers.*

Oonk, W. (2009). *Theory-enriched practical knowledge in mathematics teacher education*.

Visser-Wijnveen, G. J. (2009). *The research-teaching nexus in the humanities: Variations among academics.*

Van der Rijst, R. M. (2009). *The research-teaching nexus in the sciences: Scientific research dispositions and teaching practice.*

Platteel, T. L. (2010). *Knowledge development of secondary school L1 teachers on concept-context rich education in an action-research setting*.

Kessels, C. C. (2010). *The influence of induction programs on beginning teachers' well-being and professional development*.

Min-Leliveld, M. J. (2011). *Supporting medical teachers' learning: Redesigning a program using characteristics of effective instructional development.*

Dobber, M. (2011). *Collaboration in groups during teacher education.*

Wongsopawiro, D. (2012). *Examining science teachers' pedagogical content knowledge in the context of a professional development program.*