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

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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 4th to 8th 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

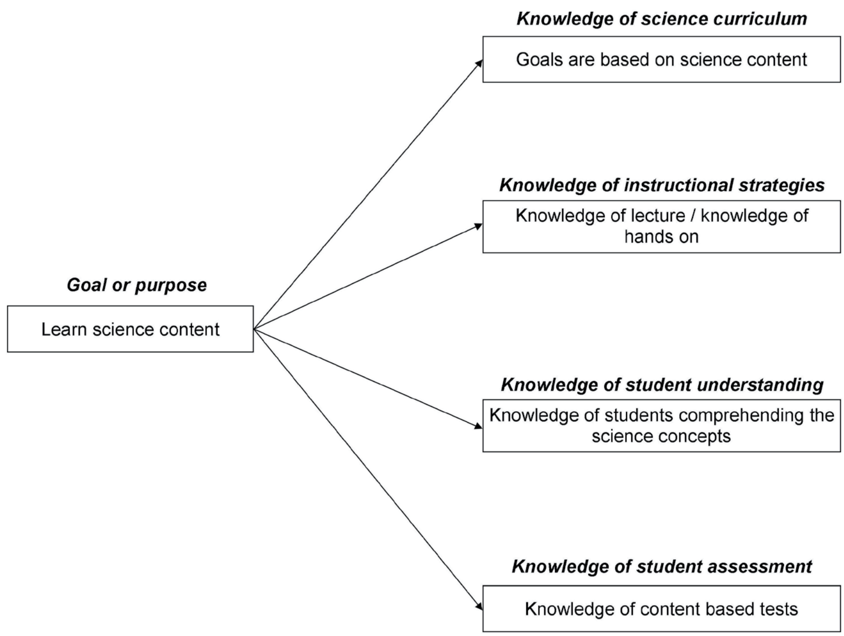

Figure 3.2. An example of a PCK representation level (teacher Diane)

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.