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

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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.

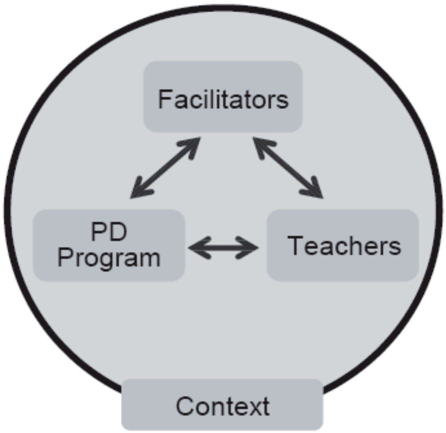


Figure 4.1. Elements of a professional development system (Borko, 2004).

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).

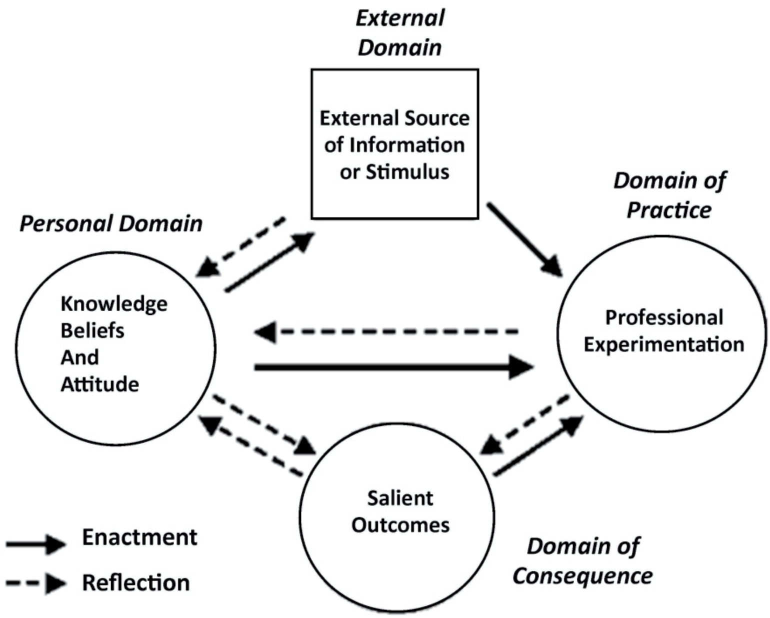


Figure 4.2. Clarke & Hollingsworth's (2002) IMTPG model

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).

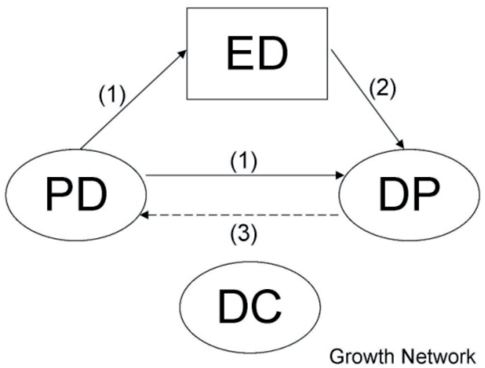


Figure 4.3. Simultaneous process in a growth network

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

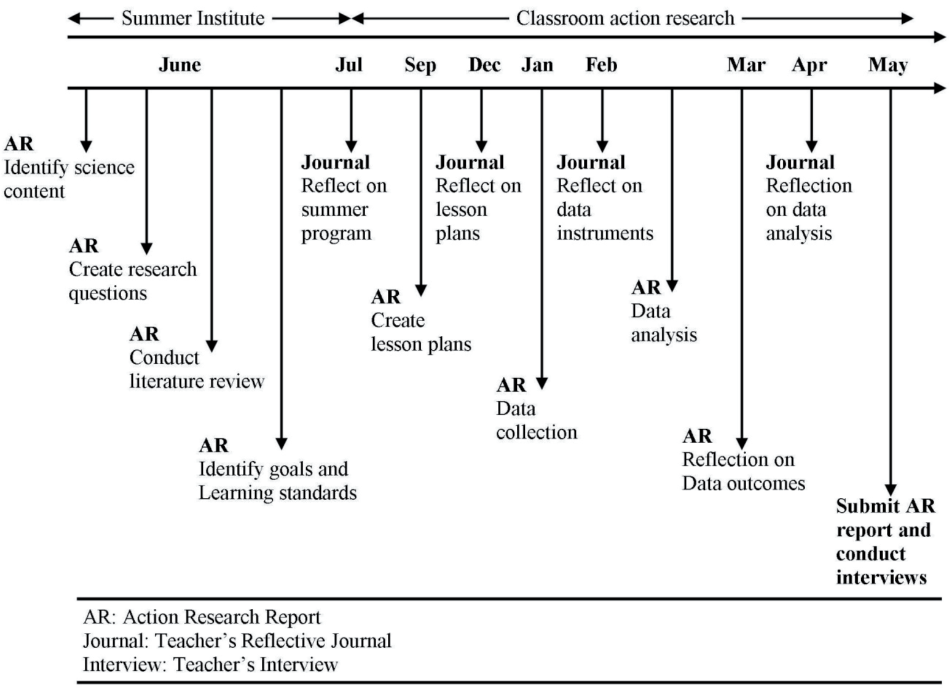


Figure 4.4. Overview of data collection in this study.

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.*

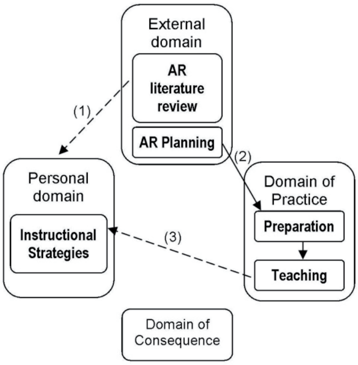
   All the statements from the three different sources were triangulated to ensure reliability and were then linked to each PCK component.

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

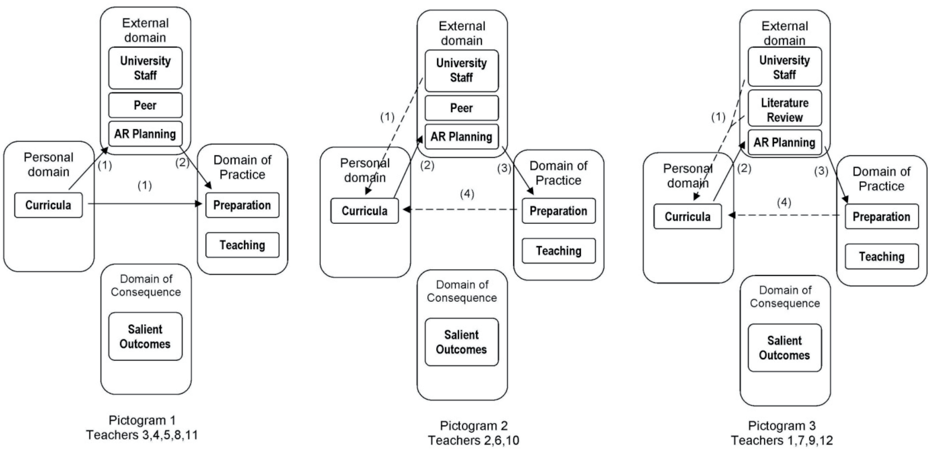


Figure 4.5. Pictorial representations of development of knowledge of science curricula

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 7^{th} -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

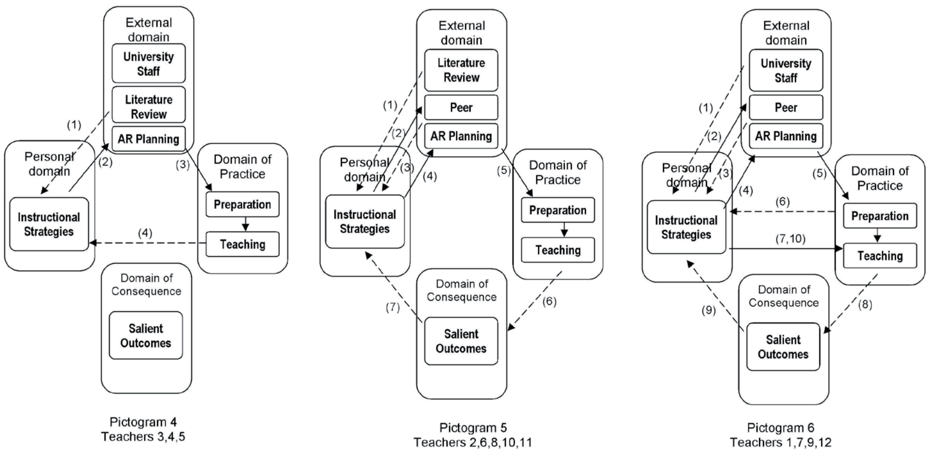


Figure 4.6. Pictorial representations of development of knowledge of instructional strategies

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 6th-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

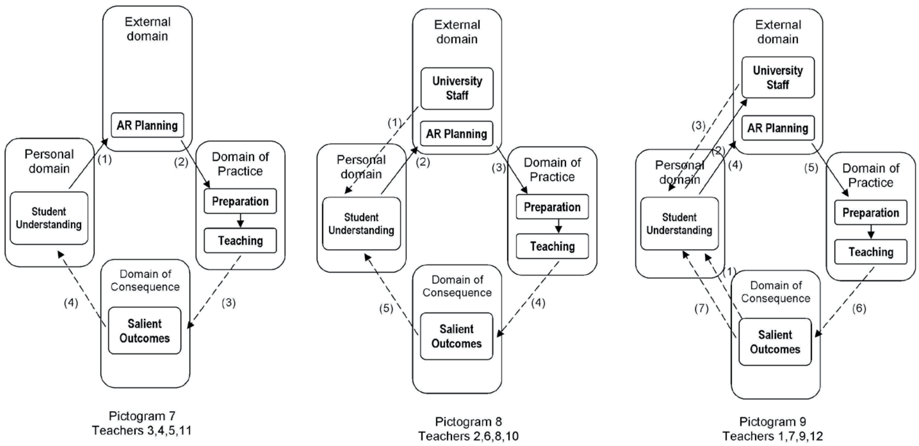


Figure 4.7. Pictorial representations of development of knowledge of student understanding of science.

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

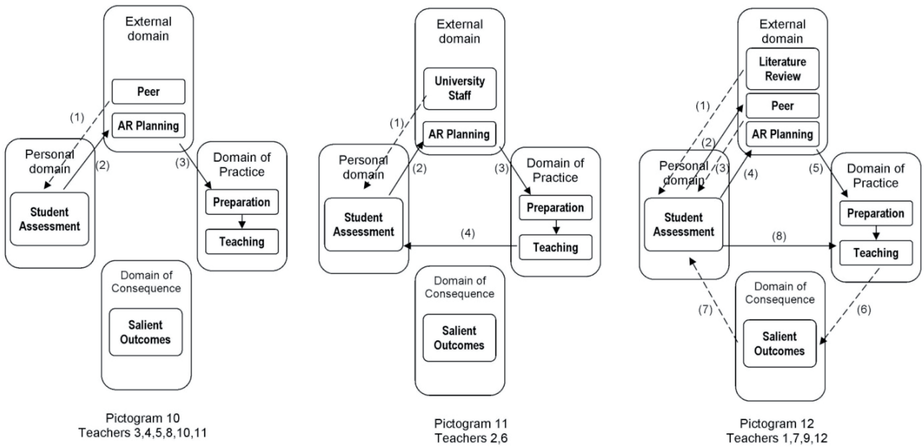


Figure 4.8. Pictorial representations of development of knowledge of student assessment of scientific literacy

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.