Chapter 5

The development of experienced science teachers’ pedagogical content knowledge of ‘Models of the Solar System and the Universe’

Abstract: In this study, we investigated the developing pedagogical content knowledge (PCK) of nine experienced science teachers in their first few years of teaching a new science syllabus in Dutch secondary education. We aimed to identify the content and structure of the PCK for a specific topic in the new syllabus, ‘Models of the Solar System and the Universe’, describing the PCK development in terms of relations between four different aspects: PCK of instructional strategies, PCK of students’ understanding, PCK of assessment of students, and PCK of goals and objectives of the topic in the curriculum. Semi-structured interviews were conducted in three subsequent academic years. From the analysis of the data, two qualitatively different types of PCK emerged. Type A can be described as oriented towards model content, while Type B can be typified as oriented towards model content, model production, and thinking about the nature of models. The results also indicate that the two types of PCK were developed in qualitatively different ways.
5.1 Introduction

Pedagogical content knowledge (PCK) has held an important position since it was introduced to describe the “missing paradigm” in research on teaching several decades ago (Shulman, 1986). While PCK has been a subject of research since the 1980’s, and much has been written about its characterization and its importance as a foundational knowledge base for teaching, little is known about the process of PCK development, especially in experienced teachers and in the context of educational innovation. Up to now, few empirical investigations have been conducted into how different aspects of this knowledge are connected and may influence each other’s growth.

The innovation in this study concerned the introduction of Public Understanding of Science (PUSc.) as a new science subject for all students in upper secondary education in the Netherlands. Among its other objectives, the new syllabus is intended to make students aware of the ways in which scientific knowledge is produced and developed. Students should gain a clear understanding of a scientist’s activities, for example, designing and using models, developing theories, and carrying out experiments (De Vos & Reiding, 1999). In this respect, the introduction of PUSc. is close to the vision on science education reform in many other countries, such as Canada (Aikenhead & Ryan, 1992), the USA (AAAS, 1994), and the UK (NEAB, 1998), which requires students to become knowledgeable in varied aspects of scientific inquiry and the nature of science. A better understanding of the scientific community and how scientists work should enhance understanding of science’s strengths and limitations, social decision making, instructional delivery, and the learning of science content (McComas, Clough, & Almazroa, 1998). Another aim of the PUSc. syllabus is to educate students in dealing with everyday situations that involve science and technology (cf. LORST, Aikenhead, 1991, and SATIS, Hunt, 1990). To this end, subject matter is introduced and practiced in the framework of real-life issues. In many cases, these issues are taken from what students know from their own everyday lives, but social or professional science and technology contexts are also used. This ‘context approach’ (cf. Salter’s Approaches: Campbell, Lazony, Millar, Nicolson, Ramsden, & Waddington, 1994; Chemie in Kontext: Eikls, Parchmann, Grasel, & Ralle, 2004) is inspired, among other things, by the need to raise students’ interest in science and science classes (Bennet & Holman, 2002). Finally, the introduction of the new science syllabus overlaps with a move towards a social constructivist view on knowing and learning in Dutch secondary education (cf. Greeno, Collins, & Resnick, 1996), as a result of which science teachers have their students learn the subject matter through classroom activities which support the active construction of knowledge and understanding in social interaction with other students, instead of providing all the answers themselves (cf. Van der Valk & Gravemeyer, 2000).

5.1.1 Aim of the study

We aimed to investigate the developing PCK of a small number of experienced science teachers in their first few years of teaching the new syllabus on Public Understanding of Science. We followed these teachers for a period of three years in
their natural settings to see if, and how, their initial PCK developed. We aimed to identify the content and structure of their PCK of a specific topic in the PUSE syllabus, namely, ‘Models of the Solar System and the Universe’, describing its development in terms of relations between its different components. Our definition of PCK as incorporating different elements of knowledge is explained in the next section. We did not intend to describe in detail the PCK development of each individual participant, but to chart the possible common patterns across the knowledge (development) of different teachers (Verloop, Van Driel, & Meijer, 2001).

5.2 Pedagogical Content Knowledge

Shulman (1986) introduced the concept of pedagogical content knowledge (PCK) as an element of what he called “the knowledge base for teaching” (p. 4). Shulman described PCK as “that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding” (Shulman, 1987, p. 8), developed through an integrative process rooted in classroom practice. Key elements in Shulman’s conception of PCK are knowledge of representations of subject matter, on the one hand, and understanding of specific learning difficulties and student conceptions, on the other hand. Shulman did not mention how these two elements were intertwined or used.

In attempting to clarify the nature and features of PCK, various scholars (e.g., Cochran, deRuyter, & King, 1993; Marks, 1990; Grossmann, 1990) elaborated on Shulman’s work and described PCK in different ways, that is, incorporating different attributes or characteristics (Van Driel, Verloop, & De Vos, 1998, p. 676). We defined PCK as teacher knowledge about (a) instructional strategies concerning a specific topic, (b) students’ understanding of this topic, (c) ways to assess students’ understanding of this topic, and (d) goals and objectives for teaching the specific topic in the curriculum. In this, we largely agree with the categorizations of Grossman (1990) and Magnusson, Krajcik, and Borko (1999, p. 99). Compared with Shulman’s original construct, described above, these authors adopted a somewhat broader definition of PCK. Acknowledging that the various components of teachers’ PCK may interact in very complex ways, Magnusson et al. (1999) claimed, “Effective teachers need to develop knowledge with respect to all of the aspects of pedagogical content knowledge, and with respect to all of the topics they teach” (p. 115).

The recognition of PCK as a foundational knowledge base and an indicator of teachers’ quality has recently been emphasized in American standards for professional development of teachers (National Research Council, 1996; National Science Teaching Associations, 1995) and for beginning teachers (Interstate New Teacher Assessment and Support Consortium, 2002), and also by the National Council of Accreditation for Teacher Education (1998). Consequently, evaluation of the utility of using PCK as a framework for the design of teacher education courses is an emerging area of research, and not only of concern in the USA. There is also a strong call within the science education community itself to pay more attention to the explication and sharing of science teachers’ professional knowledge. The theoretical lens of PCK offers one approach to understanding and portraying this knowledge. Different tools
have been developed for documenting science teachers’ understanding of their own professional practice and their students’ learning of particular science content (Berry, Loughran, & Mulhall, 2006). Little is known, however, about the process of PCK development in experienced science teachers in the context of educational innovation, and how different components of this knowledge are connected and may influence each others’ expansion.

Although teachers’ PCK is strongly related to individual experiences and circumstances, there are aspects which are shared by groups of teachers in similar situations with regard to variables such as subject matter, level of education, and age group of students (Meijer, Verloop, & Beijaard, 1999). As indicated in the introduction, the aim of this study was to identify common patterns in the PCK development of a small number of experienced science teachers in the context of the introduction of Public Understanding of Science (PUSc). The specific topic focused on was ‘Models of the Solar System and the Universe’.

We put the following research question central:

*How can science teachers’ PCK of the learning and teaching of ‘Models of the Solar System and the Universe’ in the PUSc syllabus be typified at a time when they still have little experience of teaching PUSc, and how does this PCK develop when teachers become more experienced in teaching this particular topic?*

### 5.3 Context of the study

In 1999, a new syllabus on Public Understanding of Science was introduced in secondary education in the Netherlands. The program (curriculum) of this new syllabus is divided into six domains, A to F (SLO Voorlichtingsbrochure ANW, 1996).

General skills (*Domain A*), such as language skills (e.g., discussing, debating, reporting), computer skills, and research skills (e.g., posing a problem, formulating research questions, making relevant observations) should be developed in combination with the learning of specific subject matter that is introduced in relevant context issues of Life, Biosphere, Matter, and Solar System and Universe (*i.e.*, *Domains C to F*).

The development of students’ capacity to reflect critically on scientific knowledge and procedures (*Domain B*) requires them to become able, among other things, to explain how scientists obtain a specific kind of knowledge which (by its very nature) is always limited and context bound, and how observation, theory formation, and technology are influenced by each other as well as by cultural, economic, and political factors. Students’ reflection on scientific knowledge and procedures should be linked to specific science topics, for example, ‘Health care’ (*Domain C: Life*), ‘The Earth climate’ (*Domain D: Biosphere*), ‘Radiation risks’ (*Domain E: Matter*), and ‘Understanding the universe’ (*Domain F: Solar System and Universe*).

See also Figure 2.1, Chapter 2.3.2, this thesis.
5.3.1 Models and modelling in PUSc.

Aiming to improve the comprehensive nature of students’ understanding of the main processes and products of science, Hodson (1992) proposed three purposes for science education: (i) to *learn science*, that is, to understand the ideas produced by science: concepts, models, and theories; (ii) to *learn about science*, that is, to understand important issues in the philosophy, history, and methodology of science; and (iii) to *learn how to do science*, that is, to be able to take part in those activities that lead to the acquisition of scientific knowledge.

In general, all natural sciences can be thought of as an attempt to model nature in order to understand and explain phenomena. Models and modelling are, as a consequence, applied and used extensively by natural scientists. Therefore, the key to Hodson’s purposes (i.e., students’ comprehensive understanding of science) is a central role for models and modelling in science education (cf. Justi & Gilbert, 2002).

In this light, the subject PUSc. may offer an appropriate framework (see Table 5.1). To help students gain a rich understanding of the main products and processes of science, *the learning of scientific models* (Domains C to F) and the act of modelling, that is, *the production and revision of models* (Domain A) should go hand in hand with critical reflection on *the role and nature of models in science* (Domain B).

<table>
<thead>
<tr>
<th>PUSc. Domains</th>
<th>A</th>
<th>C to F</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hodson (1992)</td>
<td>Learn how to do science</td>
<td>Learn science</td>
<td>Learn about science</td>
</tr>
<tr>
<td>Justi &amp; Gilbert (2002)</td>
<td>Learn to produce and revise models</td>
<td>Learn the major models</td>
<td>Learn the nature of models</td>
</tr>
</tbody>
</table>

The above implies, for example, that in the PUSc. domain titled the ‘Solar System and Universe’ (Domain F), students could be asked to compare and discuss several models for the solar system from the history of science (Domain B). In addition, students could be challenged to design models (Domain A) for the earth’s seasons, or the phases of the moon. Reflecting on such an assignment, students could be encouraged to discuss the functions and characteristics of models in general (Domain B). From a constructivist view on knowing and learning, models can be used as cognitive tools to promote students to think deeply, instead of the teacher supplying all the answers. Moreover, students’ modelling activities may offer valuable opportunities for teachers to monitor students’ progress in changing their initial mental models to an understanding of particular models (i.e., ‘consensus models’, Gilbert and Boulter, 2000), which are generally accepted in physics, chemistry, or (bio)technology (Duit & Glynn, 1996).

Traditionally, science teachers have devoted little explicit attention to the nature of scientific models, that is, their hypothetical character and the ways in which they gradually develop (Vollebregt, Klaassen, Genseberger, & Lijnse, 1999). Science
textbooks for secondary education contain many examples of scientific models, usually presenting these models as static facts or as final versions of our knowledge of matter (Erduran, 2001). Although various teaching strategies have been described in the literature, designed specifically to promote students’ understanding of ‘consensus models’, current textbooks rarely include assignments inviting students actively to construct, test, or revise their own models as part of the learning process.

De Jong, Van Driel, and Verloop (2005) explored pre-service science teachers’ pedagogical content knowledge of models and modelling. The research findings indicated, among other things, that a majority of the teachers intended to pay attention to models as constructs, invented by scientists, but in their teaching practice appeared to have discussed models as objects or facts that are given. As a similar discrepancy has also been found among experienced teachers (Koulaidis & Ogborn, 1989), De Jong, et al., (2005) suggested that pre-service and experienced teachers generally lack sufficient knowledge of strategies for teaching models as constructs.

Owing to the emphasis the new syllabus places on new content and new teaching strategies concerning the role and nature of scientific models, teachers’ PCK of models and modelling in science may be subject to change. We followed nine experienced teachers over a period of three years to investigate their developing PCK in the context of teaching a chapter on the ‘Solar System and Universe’. The teachers were questioned about the four above-mentioned knowledge elements of PCK. The topic focused on was ‘Models of the Solar System and the Universe’. In contrast to the content of other subjects of PUSc., for instance, ‘Genetic engineering’ (Domain C: Life) and the ‘Greenhouse effect’ (Domain D: Biosphere), which are close to the disciplines of biology and chemistry, ‘Models of the Solar System and Universe’ (Domain F: Solar System and Universe) is one of the more unusual and difficult topics in the entire syllabus. Before they started to teach the new syllabus, most science teachers were not familiar with it.

### 5.4 Method and research design

This section starts with a description of the participants in the study and how they were selected. We then turn to the description of the research instrument to investigate the teachers’ pedagogical content knowledge, and the research procedure followed.

#### 5.4.1 Participants in the study

This study was conducted among nine PUSc. teachers working at five different schools. They were users of the teaching method ‘ANstWoord’ (in English: ‘Answer’). We selected this method to be used by the participants in our study because it contains many teaching strategies emphasizing the role and nature of scientific models. This method has, for instance, a chapter on ‘Solar System and Universe’ (Domain F), in which students have to develop models to describe and explain the earth’s seasons, and discuss them in the classroom afterwards. Students also learn different models of the solar system, such as Ptolemy’s geocentric model and
Chapter 5

Copernicus' heliocentric model, and debate their strengths and weaknesses. The nine teachers responded to a written invitation we sent to ten different schools using the ANwWoord method. After meetings we organized at their schools (to explain the purposes and conditions of the study), they all agreed to take part in the study. The teachers, all male, varied with regard to their backgrounds, years of teaching experience, and original teaching disciplines (cf. Table 2.1, Chapter 2.4.1, this thesis). Among the participants were three teachers of physics, three teachers of chemistry, and three teachers whose original discipline was biology. Their teaching experiences ranged from 9 to 24 years at the start of the study. To become qualified to teach the new science subject, the teachers had taken part in a one-year course, which was conducted nationwide. They were all among the first PUSe. teachers at their schools.

5.4.2 Data collection

The data collection consisted of a semi-structured interview to investigate the teachers' pedagogical content knowledge (PCK) of models and modelling. The interview was conducted among the teachers by the first author of this article, in three subsequent academic years.

5.4.2.1 Semi-structured interview

A semi-structured interview was held with all teachers in 2002, 2003, and 2004. The interview questions were developed on the basis of the results of a study of the relevant literature on PCK, on the one hand, and models and modelling in science education, on the other hand. The initial interview schedule was tested on four PUSe teachers (not among the nine participants in the study). As a result of this pilot study, some interview questions were rephrased or replaced in the schedule, and some new questions were added to the scheme.

The final interview included questions which aimed at eliciting the teachers' PCK of the learning and teaching of models and modelling in PUSe. (Table 5.2). In the context of teaching Chapter 3 of the ANwWoord workbook, titled 'Solar System and Universe', the teachers were questioned about the four knowledge elements of PCK mentioned earlier (in section 5.2 'Pedagogical content knowledge'), namely, knowledge about (a) instructional strategies concerning a specific topic, (b) students' understanding of this topic, (c) ways to assess students' understanding of this topic, and (d) goals and objectives for teaching this topic in the curriculum.

All interviews took place privately in a place chosen by the teacher (e.g., the teacher's classroom or a small office), each year shortly after he had finished the lessons about the chapter on the solar system and universe. An audiotape recorder was used to tape the conversation. The interviews took thirty minutes to one hour. Afterwards, all interviews were transcribed verbatim.
The development of experienced science teacher’s PCK …

Table 5.2 Some general phrasings of interview questions on PCK

<table>
<thead>
<tr>
<th>PCK elements</th>
<th>Questions on the teachers’ PCK</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) PCK of instructional strategies</td>
<td>1. In what activities, and in what sequence, did your students participate in the context of this chapter? Please explain your answer</td>
</tr>
<tr>
<td></td>
<td>2. What was (were) your role(s) as a teacher, in the context of this chapter? Explain your answer</td>
</tr>
<tr>
<td>(b) PCK of students’ understanding</td>
<td>3. Did your students need any specific previous knowledge in the context of this chapter? Explain your answer</td>
</tr>
<tr>
<td></td>
<td>4. What was successful for your students? Explain your answer</td>
</tr>
<tr>
<td></td>
<td>5. What difficulties did you see? Explain your answer</td>
</tr>
<tr>
<td>(c) PCK of ways to assess students</td>
<td>6. On what, and how, did you assess your students in the context of this chapter? Explain your answer</td>
</tr>
<tr>
<td></td>
<td>7. Did your students reach the learning goals with regard to this chapter? How do you know? Explain your answer</td>
</tr>
<tr>
<td>(d) PCK of goals and objectives of</td>
<td>8. What was (were) your main objective(s) in teaching the topic of ‘Models of the Solar System and the Universe’? Explain your answer</td>
</tr>
<tr>
<td>the topic in the curriculum</td>
<td></td>
</tr>
</tbody>
</table>

5.5 Analysis

The analysis of the data started with the interviews conducted in 2002. First, the interview fragments involved were read a few times, thoroughly. Next, codes were developed for the four elements of PCK and tested on the interview data of two different teachers, to see if all the variations in the statements could be covered. As a result, some codes had to be reformulated. The final codebook (cf. Table 2.5, Chapter 2.5.2, this thesis) was the result of different steps of testing and adapting the codes, until the first and second authors reached consensus on all codes to be used.

5.5.1 PCK of instruction and PCK of students’ understanding

The authors concluded that similar codes could be employed for knowledge about instructional strategies concerning ‘Models of the Solar System and the Universe’ and knowledge about students’ understanding of ‘Models of the Solar System and the Universe’ (PCK elements a. and b.). These knowledge elements were typified by three codes: (i) one code representing the content of models (teachers have knowledge about the teaching of specific concepts in relation to certain models, and have knowledge about students’ understanding of these concepts), (ii) one code standing for thinking about the nature of models (teachers know how to make students reflect on the nature of models, and have knowledge about their students’ understanding of the nature of models), and (iii) one code related to the production of models (teachers know how to stimulate students’ model production and testing, and have specific knowledge about
students’ modelling skills). These three codes can be linked, roughly, to the PUSc. Domains C to F (i), B (ii), and A (iii), respectively.

5.5.2 PCK of ways to assess students’ understanding

After reading and discussing the teachers’ responses to the interview questions about ways of assessment in the context of teaching ‘Models of the Solar System and the Universe’, it was found that the teachers’ knowledge about ways to assess students’ understanding (PCK element c.) of this topic could be typified using the following codes referring to various ways of assessment: (i) written test on model content; (ii) oral and poster presentation, or account, as products of self-directed work; (iii) a paper or an essay on the students’ reflection upon the nature of models; (iv) students’ modelling activities; (v) classroom debate on the heliocentric and geocentric models; (vi) portfolio on the preparation of the debate on models; (vii) observation of group work.

5.5.3 PCK of goals and objectives of the topic in the curriculum

Regarding the knowledge about goals and objectives in the curriculum (PCK element d.), it was decided, following repeated reading and discussion of the teachers’ responses, to typify their answers using two different kinds of codes. First, generally speaking, the teachers expressed their epistemological perspectives. In analysing these perspectives, Nott and Wellington’s classification of epistemological views (1993) was applied, on the basis of which three codes were developed: (i) positivist, in which models are seen as simplified copies of reality, (ii) relativist, in which models are seen as one way to view reality, and (iii) instrumentalist, in which the question is whether models ‘work’, instead of ‘being true’. Second, teachers’ statements about the purposes of using models in the classroom were coded in terms of the various functions of models in science (Giere, 1991): (i) to visualize and describe phenomena, (ii) to explain phenomena, (iii) to obtain information about phenomena which cannot be observed directly, (iv) to derive hypotheses which may be tested, and (v) to make predictions about reality.

After coding the teachers’ interview responses, we put together, per PCK element, the coded statements (see Table 5.3, columns). With this, the variety of statements within each PCK element became clear. We examined carefully the various sets of statements and identified for each teacher the combinations of codes that arose across the different elements (see Table 5.3, rows). Next, we compared these combinations across the nine teachers, and two patterns (i.e., specific combinations of codes, which recurred -more or less - strictly) emerged. Using these, we constructed two types of PCK: Type A and Type B (see Results section, Table 5.4). To see how these types of PCK developed over the years 2003 and 2004, the interview fragments involved were read a number of times, and we used the same codebook that was developed to code the interview data from the year 2002. Finally, we examined the combinations of codes applied, per teacher, over the years. It appeared from the results that Type A and Type B of PCK developed in different ways. In section 5.6.1, we describe Types
The development of experienced science teacher's PCK …

A and B of PCK, with regard to the learning and teaching of 'Models of the Solar system and Universe', in 2002. In section 5.6.2, we describe the knowledge development of two teachers, each of whose knowledge was to a large extent representative of one of the PCK types. In section 5.6.3, finally, we present our general conclusions with regard to the PCK development of the teachers.

Table 5.3 Codes applied to the teachers’ interview responses

<table>
<thead>
<tr>
<th>PCK-instruction</th>
<th>PCK-students’ understanding</th>
<th>PCK-assessment</th>
<th>PCK-goals and objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Model content</td>
<td>Model content</td>
<td>Exams on model content; Oral presentations; Reports on group work; Essay</td>
</tr>
<tr>
<td>T2</td>
<td>Model content</td>
<td>Model content</td>
<td>Exams on model content; Oral presentations</td>
</tr>
<tr>
<td>T3</td>
<td>Model content; Model production; Thinking about the nature of models</td>
<td>Model content</td>
<td>Exams on model content; Observation of modelling and debating activities; Portfolio</td>
</tr>
<tr>
<td>T4</td>
<td>Model content</td>
<td>Model content</td>
<td>Exams on model content; Oral presentations; Poster presentations</td>
</tr>
<tr>
<td>T5</td>
<td>Model content; Model production; Thinking about the nature of models</td>
<td>Model content</td>
<td>Exams on model content; Observation of group work, modelling and debating activities;</td>
</tr>
<tr>
<td>T6</td>
<td>Model content; Model production; Thinking about the nature of models</td>
<td>Model content</td>
<td>Exams on model content; Observation of group work, modelling and debating activities;</td>
</tr>
<tr>
<td>T7</td>
<td>Model content</td>
<td>Model content</td>
<td>Exams on model content; Reports on group work</td>
</tr>
<tr>
<td>T8</td>
<td>Model content Thinking about the nature of models</td>
<td>Model content</td>
<td>Exams on model content; Oral presentations; Reports on group work</td>
</tr>
<tr>
<td>T9</td>
<td>Model content Model production;</td>
<td>Model content</td>
<td>Exams on model content; Observation of group work, modelling and debating activities; Reports on group work</td>
</tr>
</tbody>
</table>

5.6 Results and conclusions

As a result of the analysis of the interview data from the year 2002, we constructed two types of teachers’ PCK of the learning and teaching of ‘Models of the Solar
System and the Universe’ (Table 5.4). Type A of PCK appeared to be focused mainly on model content, while Type B of PCK was focused on model content, model production, and thinking about the nature of models (cf. Henze, Van Driel, & Verloop, 2005). Following a comparison of the answers and reactions of the nine teachers with both Types of PCK, we considered the knowledge of five teachers to be indicative of Type A, while the knowledge of four teachers was qualified as indicative of Type B.

5.6.1 Two types of PCK: Type A and Type B

Below, we present a general description of Type A and Type B with regard to the teachers’ pedagogical content knowledge of the learning and teaching of ‘Models of the Solar system and the Universe’

5.6.1.1 Type A: Focused on model content

In Type A, PCK of instructional strategies includes knowledge that is aimed at the transmission of the content of certain models (of the solar system) and knowledge about effective methods and materials to support students’ understanding of the content of these models and to help students connect the models with reality. PCK of students’ understanding is not very specific (e.g., knowledge about students’ abilities to think 3D in general, or to connect models with reality). PCK of ways to assess students’ understanding includes knowledge of exams and (oral) presentations to assess both students’ content knowledge of models and their use of models as ‘tools’. PCK of goals and objectives in the curriculum with regard to models and modelling reflects a combination of positivist and instrumentalist views: models are seen as reductions of reality, aimed at visualising and explaining different phenomena.

5.6.1.2 Type B: Focused on model content, production, and thinking

In Type B, PCK of instructional strategies includes knowledge about motivating and challenging tasks that are aimed at supporting students’ understanding of model content and model production or comparison (e.g., debating), and about effective ways to promote students’ creativity in thinking about the nature of models and model production. PCK of students’ understanding includes knowledge about students’ motivation, specific difficulties, and abilities concerning scientific models and modelling activities, and knowledge about students’ affinity with specific models. PCK of ways to assess students includes knowledge of exams, students’ presentations, reports, modelling and debating activities, and portfolios to assess students’ knowledge about the content of models, the production of models, and thinking about models. In the PCK of goals and objectives for teaching models and modelling in the curriculum, not only the visualisation and explanation of phenomena are emphasised, but also how to formulate and test hypotheses, and how to obtain information about phenomena. Models are conceived of as instruments but also as ways to view reality (i.e., a relativist epistemological view).
### Table 5.4 PCK Types A and B (2002).

<table>
<thead>
<tr>
<th>PCK elements</th>
<th>Type A of PCK</th>
<th>Type B of PCK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PCK-instructional strategies</strong></td>
<td>Knowledge about specific multi-media (film, video) and concrete materials to support students' understanding of model content, and knowledge of ways to connect models with reality</td>
<td>Knowledge about motivating and challenging assignments to promote students' learning of model content; Knowledge about effective ways/methods to promote students' thinking about the nature of models (e.g., debating, modelling activities, computer simulation); Knowledge about ways to stimulate students' creativity</td>
</tr>
<tr>
<td><strong>PCK-students' understanding</strong></td>
<td>Knowledge about students' difficulties with the content of specific models, and inability to connect models with reality</td>
<td>Knowledge about students' motivation to discover things themselves; Knowledge about students' motivation and abilities to participate in modelling and related thinking activities; Knowledge about student's affinity with specific models</td>
</tr>
<tr>
<td><strong>PCK-ways to assess students' understanding</strong></td>
<td>Knowledge about examinations of model content and application using written exams, oral presentations, posters, and reports</td>
<td>Knowledge about how to evaluate model content, model production, and thinking about models using exams, oral presentations, reports, portfolios, and group observations</td>
</tr>
<tr>
<td><strong>PCK-goals and objectives in the curriculum</strong></td>
<td>Epistemological views which can be understood as positivist and instrumentalist. Knowledge about the use of models to visualize and explain phenomena</td>
<td>Epistemological views: Instrumentalist and relativist Knowledge about the use of models to visualize and explain phenomena, to formulate and test hypotheses, and to obtain information about phenomena</td>
</tr>
</tbody>
</table>

### 5.6.2 The development of PCK

Comparison of the data from the years 2002, 2003, and 2004 revealed the following with respect to the development of the teachers' PCK. Type A of PCK continued to be mainly focused on model content, while Type B of PCK remained focused on model content, model production, and thinking about the nature of models. In addition, the ways in which the two types of PCK developed over the years appeared to be qualitatively different in terms of relations between the four components. Finally, the results of the study indicated that, in developing their PCK, the teachers extended their initial knowledge, over time. To illustrate our findings, we describe the PCK development of two teachers in the following sections. We have called one teacher ‘William’ (representing PCK Type A, in 2002) and the other teacher ‘Andrew’ (representing PCK Type B, in 2002).
5.6.2.1 PCK development of William (Type A)

In this section, we discuss the PCK development of William (T8, Table 5.3) between 2002 and 2004, based on his reactions to the interview questions about the learning and teaching of models and modelling with regard to the solar system and the universe, in the context of AnRiWoord Chapter 3 on ‘Solar System and Universe’.

PCK of instructional strategies:

In 2002 and 2003, William’s instruction in models of the solar system started with the observation of phenomena (positions of moon, sun, stars) by his students. From this, he explained Copernicus’ heliocentric model of the solar system using a PowerPoint presentation and a variety of concrete examples and visual tools, applied in front of the class. Next, the students set to work, carrying out different tasks, for example, building the model (constructing it using foam balls, or creating it from cardboard), and manipulating wooden sticks and balls and a lamp. These activities were aimed at connecting students’ observations of phenomena with the heliocentric model. Students, however, did not design their own models (based on their observations). According to William, a classroom debate on the geocentric and heliocentric models of the solar system was also of no use: his students lacked the knowledge, the understanding, and the level of abstract reasoning required. In 2002 and 2003, William also paid attention to other models of the solar system (ideas of Pythagoras, Aristotle, and Ptolemy), and to the key roles played by Tycho Brahe, Johannes Kepler, and Galileo Galilei in getting the heliocentric model accepted in preference to the geocentric model by astronomers.

In 2004, his lessons on the solar system were confined to the teaching of the heliocentric model. The teaching of other (historic) models appeared to be too time-consuming for him, and too difficult for his students: “I hardly understand the geocentric models myself, so, what about the students’ understanding?” Due to a lack of time, he had also stopped reflecting on ideas of an expanding universe that began in a ‘big bang’. He still emphasized students’ observations of natural phenomena (stars, planets, eclipses of sun and moon). Observations (and, in addition, computer simulations) of the phases of Venus appeared to be very helpful in finding arguments in favour of the heliocentric model.

Over the years, William put much time into developing various materials, tools, and instruction methods to explain the content of the heliocentric model to his students.

PCK of students’ understanding:

In 2002, William showed little specific knowledge of his students’ understanding of the different models of the solar system. He said, “All they need to learn from the models is some basic knowledge of geometry”, and “Some students’ general inability for three-dimensional thinking hinders their gaining in-depth understanding”. Over the years, he mainly based his knowledge about students’ understanding of, and difficulties with, specific concepts on the results of written exams. William: “Some pupils really didn’t get what I meant when I asked questions like ‘Why are the observations about the phases of Venus along with its relative size the main
arguments in favour of the heliocentric model? This made me feel dissatisfied with my teaching and with the teaching materials I’ve been using”. To address this problem, William introduced the computer simulation programme ‘Red-shift’ to have students “observe (by manipulation of time) the phases of Venus, showing that Venus is sometimes on the opposite side of the sun, just as the heliocentric model predicts (and in contrast to the geocentric model)”. In addition, William understood that some students had difficulties with the scientific contingency of models, that is, their hypothetical character, and the ways in which they gradually develop. He said that these students complained, “Why should we learn something that will change, anyway?”.

**PCK of ways to assess students’ understanding:**

In 2002, William evaluated every task (observations, practical work) of his students in order to get them working and keep them working. To save time, he gradually diminished the number of students’ oral and poster presentations in the lessons, and reports on practical work to be evaluated. In 2004, his assessment of students’ work was confined to a written report of a group study on a specific topic, and a written exam, which consisted of questions on knowledge of facts (model content) and on application of this knowledge (e.g., the interpretation of newspaper reports). The topics and questions in his exams did not change significantly throughout the years. From his interpretations of the results of the exams, William realized that, “to better understand the heliocentric model, the students need more concrete experiences”. For this reason, he started to use a number of planetaries, a solar scope, and a computer programme in his lessons.

**PCK of goals and objectives in the curriculum:**

From 2002 to 2004, William insisted that his students understood that knowledge of the structure and the size of the universe was not based on solid data drawn from experiments: “It is only if you start from certain assumptions that the models will work” (i.e., relativist and instrumentalist epistemological views). In 2002, William held the view that students had to know that models of the solar system were not the same as reality: “It is always a simplified reduction”, which is aimed at describing and explaining certain phenomena (i.e., positivist epistemological view). He emphasized in his lessons that ideas about the age (approximately 15 billion years) of the universe are “not based on accurate measurements, but on extrapolations and on presumptions”.

In the course of time, William became aware of his understanding that, in the case of the heliocentric model of the solar system, the model is simply a smaller copy of reality: “I think that we know rather precisely how planets rotate around the sun, for example. Actually, I don’t believe that reality is any different from the model. Speaking of atoms, neutrons, and electrons, however, I do understand that reality is much more complex than the model. I really think that it’s due to my lack of knowledge of the universe’s complexity”.

In 2004, William was satisfied with the results of his lessons: “Students look at the starry sky, more often; they show more interest in that part of reality. So, one of my
teaching objectives has been achieved (i.e., students’ wonderment and respect for the creation of ‘heaven and earth’)

5.6.2.2 PCK development of Andrew (Type B)

Below, we discuss the PCK development of Andrew (T5, Table 5.3) from 2002 to 2004, based on his reactions to the interview questions about teaching models and modelling with regard to the solar system and the universe, in the context of ANtWoord Chapter 3 on ‘Solar system and universe’.

PCK of instructional strategies:

In 2002, Andrew and his colleagues had developed their own workbook (which they used alongside the ANtWoord book) “to stimulate the students to go deeply into the material, being aware that they are really learning things”. The ANtWoord workbook did not meet their requirements on this point. Over the years, Andrew developed knowledge to adapt his lessons on the solar system and universe to suit students of different ages and levels of education and with different interests: “I really like to talk to young people about their motives. So what I like to do is just to sit down with my class or have a classroom discussion about how the topic relates to their own lives. I introduce the assignments from there”.

Andrew insisted from the beginning that his students designed and understood their own models: “Making different models from the same data. I really pushed them to think about it themselves: for example, making and testing their models to explain the phases of the moon, using two balls (moon and earth) and a lamp (sun)”.

Andrew spent much time introducing the heliocentric and geocentric models of the solar system, putting a ‘House of Commons-like’ classroom debate on the models’ strengths and weaknesses central: “It’s a good experience for them that the ‘best’ model doesn’t always win. In the history of science this has happened, too: the ‘best’ science hasn’t always been recognised”.

Over the years, he improved the organizational part of the debate: “Small things count, like how I arrange the tables. Or how I use the blackboard or where I am myself, standing or sitting”. In summary, Andrew developed his knowledge about instructional strategies with regard to model content, model production, and thinking about the nature of models mainly based on his interpretation of students’ responses to his lessons, indicating their motivation, abilities, and understanding.

PCK of students’ understanding:

According to Andrew, in 2002, his students were not generally used to thinking on a high level of abstraction. It was difficult for them to understand that a phenomenon can be modelled in more than one way, and that different models can be ‘true’: “For instance, one model is more complex than another, allowing for prediction of different things”. Students did not need specific previous knowledge for the learning of models of the solar system and the universe. Andrew added: “Some pupils have a natural inclination to look around and notice things. Some pupils are interested in reading what others have written. And you do have some who are just not interested
at all….During the last lessons on a Friday, the eighth and ninth periods, it's really hard to keep them going.”

Over the years, Andrew mainly developed his knowledge about students’ understanding by observing their work in the classroom as part of his instruction. In their making and testing of different models to explain the seasons on earth, for example, Andrew noticed that the students showed more sympathy for an earth (or a sun) that moves up and down than for a tilting earth’s axis. “They (the students) explained the earth’s seasons as being caused by differences in the distance from the sun through the year, instead of different parts of the globe facing towards the sun, at different times of the year, which is caused by a tilt of the earth’s axis”.

**PCK of ways to assess students’ understanding:**

In 2004, Andrew’s knowledge development of ways to assess his students’ understanding was mainly based on his interpretation of the students’ willingness to engage in activities. He said, “To add some external motivation, I give them marks for work in class and for their workbook tasks, too. At first (in 2002 and 2003), we did not, but people who say that it all can be done on (students’) ‘intrinsic’ motivation never taught a lesson themselves”. In addition, he stated, “Did they achieve the goals? Well, they did do the exercises, but for some it’s just too abstract. So they, uh, sort of cooperate with others to get some kind of answer….”

From the beginning, Andrew and his colleagues held only one major test (not on separate chapters, but on the whole book) in June. “As a part of this test, they (the students) just have to know how the model works and be able to reproduce it, that’s all. But that is still hard for a lot of pupils who can’t explain the eclipses of the sun and moon. I don’t think it’s really a problem, they pass anyway because they know other things.”

**PCK of goals and objectives in the curriculum:**

In 2002, Andrew had a relativist and instrumental epistemological view on models, which did not change over the years:

“I want them (the students) to understand that a model doesn’t have to be real and true to be useful. It’s an interesting thought that an ‘incorrect’ model can still predict things (phenomena) correctly”. This was important to him, because, “In the end, pupils have to understand how science works and the impact it has on society and especially on their daily lives”.

### 5.6.3 Conclusions

From the results of the study, we conclude that the contents of the PCK Types A and B were qualitatively different (see Table 5.4). In 2002, in Type A of PCK about ‘Models of the Solar System and the Universe’ the PCK of instructional strategies, PCK of students’ understanding, and PCK of ways to assess students all reflected a focus on model content, which was consistent with PCK of goals and objectives of the topic in the curriculum. In particular the knowledge about instructional strategies was found to be well developed. In Type B, the different PCK elements appeared to be
more extended and integrated with each other. PCK of instructional strategies, PCK of students’ understanding, and PCK of ways to assess students all reflected a view in which model content was combined with model production and thinking about the nature of models, consistent with PCK of goals and objectives of the topic in the curriculum.

With regard to the development of PCK Type A over the years, we conclude that in particular the PCK of instructional strategies developed. The results of the study indicate that this development was mainly influenced by the teachers’ interpretation of students’ results of written exams (focusing on facts and application of knowledge) and reports on group work. In 2004, the teachers’ PCK Type A was still mainly focused on model content. PCK of goals and objectives of the learning and teaching of ‘Models of the Solar System and Universe’ did not change significantly, that is, this knowledge still reflected a combination of positivist and instrumentalist epistemological views (models were seen as reductions of reality, aimed at visualizing and explaining different phenomena).

Figure 5.1 illustrates the way PCK Type A developed over time. The teachers’ ideas with regard to instruction in the content of ‘Models of the Solar System and the Universe’ were related to their PCK of goals and objectives (i.e., their view on models as reductions of reality; arrow 1). The way the teachers preferred to assess their students, that is, mainly using written exams on knowledge and facts about model content (e.g., the phases of the moon) was related to their knowledge about instruction in the content of models (arrow 2). The teachers’ knowledge of their students’ understanding of specific topics (e.g., the rotations of the planets, or the concept of ‘parallax’) was related to their interpretations of students’ responses in written exams (arrow 3). Finally, the teachers’ developing knowledge about instruction methods was related to their knowledge about the students’ difficulties with specific topics (arrow 4). Although the teachers’ knowledge of instructional strategies developed substantially over time, their ways of assessment did not change significantly. The relationship between the PCK of students’ understanding and the PCK of assessment (represented by arrow 3) and the relationship between the PCK of instruction and the PCK of students’ understanding (represented by arrow 4), however, appeared to be strong over time.

With regard to the development of PCK Type B over the years, we conclude that changes in the PCK of instruction, the PCK of students’ understanding, and the PCK of assessment were mutually related.

Figure 5.2 illustrates the way PCK Type B developed over time. The results of the study indicate that the development of the PCK of instruction was related to the PCK of goals and objectives (i.e., the teachers’ focus on students’ model production and thinking about the nature of models in the lessons was related to a relativist and instrumentalist view on models and modelling), and also to the PCK of students’ understanding (i.e., ideas about the organization of students’ activities in the lessons were mainly related to an interpretation of the students’ responses to this activities). See Figure 5.2, arrows (a) and (b). The development of PCK of students’ understanding was related to the teachers’ knowledge about instructional strategies
The development of experienced science teacher's PCK …

(i.e., the teachers’ knowledge about their students’ learning was related to student-directed instruction methods), as well as to the teachers’ knowledge about assessment (i.e., the teachers’ knowledge of students’ understanding was related to their observation of the students’ participation in classroom activities, such as modelling and debating). See Figure 5.2, arrows (c) and (d). The PCK of assessment developed under the influence of the teachers’ developing knowledge with regard to students’ understanding (i.e., the teachers’ ways of assessment were adapted to their interpretations of students’ (lack of) engagement in different activities), and the teachers’ developing PCK of instructional strategies. That is, the teachers’ ways of assessment (e.g., observation of group work) were related to the kind of classroom activities the students were engaged in (e.g., modelling activities). See Figure 5.2, arrows (e) and (f). The PCK of goals and objectives of the learning and teaching of ‘Models of the Solar System and the Universe’ did not change significantly, that is, not only the visualization and explanation of phenomena were still emphasized in this PCK element, but also how to formulate and test hypotheses, and how to obtain information about phenomena. Models were still conceived of as instruments but also as ways to view reality (i.e., a relativist epistemological view).

In sum, Type A and Type B PCK of ‘Models of the Solar System and the Universe’ appeared to be different, both with regard to knowledge content and with regard to knowledge development (see Figures 5.1 and 5.2). In developing their PCK over the years, the teachers did not switch from Type A to B, or vice versa. Teachers representing Type A developed their initial PCK in a way which was different from that of teachers representing Type B.

In the next section, we discuss the results of the study, some implications for the teaching of the subject of PUSc., and some suggestions for future research.
Chapter 5

Figure 5.1 Development of Type A of PCK

Figure 5.2 Development of Type B of PCK
5.7 Discussion

In PCK Type A, the knowledge about instructional strategies was focused on model content. The teachers’ instruction was mainly teacher-directed and aimed at students’ understanding of knowledge of the models of the solar system (i.e., the heliocentric model). In PCK Type B, the knowledge about instructional strategies was focused on model content, model production, and thinking about the nature of models. It was apparent that the teachers’ instruction was mainly student-directed and aimed at the students’ acquiring of knowledge about the models of the solar system and universe, as well as the development of their own ideas about the nature of models.

In the theoretical models of Grossman (1990) and Magnusson, Krajcik, and Borko (1999, p. 99), the development of PCK is seen as (mostly) an autonomous process, influenced, among other things, by the teachers’ general pedagogical knowledge (PK) and relevant subject matter knowledge (SMK). From this, we hypothesized that both Type A of PCK development and Type B of PCK development were related to the teachers’ general pedagogical knowledge and beliefs (PK), that is, teacher-directed pedagogical perspectives for Type A, and more or less student-directed pedagogical perspectives for Type B. Furthermore, both the PCK of goals and objectives of teaching ‘Models of the Solar System and the Universe’ in the curriculum, and the PCK of instructional strategies of teachers representing Type A were mainly restricted to an explanation of the heliocentric model of the solar system. Based on this, it may be suggested that Type A of PCK development was related to a teacher’s limited subject matter knowledge (SMK) and his positivist/instrumentalist view on models and modelling. In the same way, the more extended PCK of goals and objectives of teaching ‘Models of the Solar System and the Universe’ in the curriculum and the PCK of instructional strategies, shown by the teachers representing Type B of PCK development, may be related to a more comprehensive SMK and a relativist/instrumentalist view on models and modelling in science.

With regard to the specific topic of ‘Models of the Solar System and the Universe’, the teachers’ PCK development concerning the learning and teaching of this topic may also be influenced by their general curiosity about the universe, and their personal views and understandings of themselves as part of it (cf. Hunt & Millar, 2000).

5.7.1 Implications

All teachers had developed PCK of models of the solar system and the universe in which they had combined various program domains of the new syllabus for PUSc. Teachers who represented Type A had developed PCK in which they had connected students’ learning of models of the solar system (PUSc. Domain F) with the development of general skills (PUSc. Domain A), such as computer skills (working with a simulation programme), language skills (oral presentations and written reports), and research skills (observation of phenomena). Type B was even more extended and more integrated in terms of PCK. Teachers who represented this Type of knowledge had developed PCK in which they had connected the learning of the content of models of the solar system and universe (Domain F) and the development of general
skills (Domain A), such as language skills (oral presentation, written reports, discussing and debating skills) and research skills (observation, production, and revision of own models), with reflection on the nature of science, that is, the nature of models (Domain B). Although we did not observe the teachers’ behaviour in the classroom, on the basis of the above-mentioned results, we suppose that the teachers representing Type B of PCK may have realized more aims in the curriculum of the new syllabus than those representing PCK Type A.

As the autonomous process of PCK development seems to be determined mainly by the PCK element of knowledge about goals and objectives of teaching ‘Models of the Solar System and the Universe’ in the curriculum (see Figures 5.1 and 5.2), interventions aimed at the teachers’ professional development (especially those teachers representing PCK Type A) could involve the teachers’ participation in systematic reflection on their epistemological views on models and modelling, and their use of models in the classroom, in general. (cf. Schön, 1983, 1987; Fullan & Hargreaves, 1992; Calderhead & Gates, 1993).

In future research, it would be useful to examine the relationship between teachers’ different PCK and their students’ understanding of science strengths and limitations and their motivation to learn science, as these were major aims of the introduction of the new syllabus.

5.8 References

Bennett, J., & Holman, J. (2002). Context-based approaches to the teaching of chemistry:
What are they and what are their effects? In J.K. Gilbert (Ed.), Chemical Education: Towards research-based practice (pp. 165-184). Dordrecht, the Netherlands: Kluwer Academic Press.
The development of experienced science teacher's PCK...


Chapter 5


SLO, (1996) *Voorlichtingsbrochure havo/vwo Algemene natuurrwetenschappen* [Information Brochure on Public Understanding of Science]. Enschede, the Netherlands: SLO.


