Inquiry-based science teaching competence of pre-service primary teachers

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Voorwoord

Wat ik de afgelopen jaren heb geleerd
(en geen stelling werd…)

Tijd is meestal vloeibaar,
stromend van ’s morgens vroeg tot ’s avonds laat
maar soms bevriest
of verdampt het
-bij alle drie stadia was jij er-

Stilstand is geen achteruitgang
het geeft de mogelijkheid op adem te komen
het landschap te aanschouwen
en te zien hoe ver men al gekomen is
-fijn dat je meekeek en me daar op wees-

We kunnen ons niet verstoppen
voor de zwaartekracht
Maar we kunnen wel opstaan
elke keer als we vallen
-je hielp me daarbij-

Bergen kunnen hoog zijn
de paden smal en de weg lang
Ondanks dat kan iemand met hoogtevrees
de top bereiken
-je stond beneden me aan te moedigen, liep een stukje met me op of verwelkomde me boven op de berg-

Dank daarvoor!

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Ester Alake-Tuenter
Doetinchem, September 2014

Contents

Chapter 1

General introduction

Current society requires citizens who have a certain degree of science competence. They need science knowledge, skills, and a positive attitude to make personal decisions, and to participate in civic and cultural affairs, and economic productivity (National Research Council 2013). At the level of the individual, science competence can provide people with the ability to make sense of the world around them and be a foundation for success in life.

Primary school pupils are able to learn how to pursue their own answers to questions about the world around them. This pursuit, however, does not happen naturally in the classroom, and pupils need support in their attempts to understand phenomena. Merely telling pupils to research a phenomenon is not a sufficient way to impart inquiry skills potential and hence it does not entirely guarantee successful learning. Pupils need to be taught science in an inquiry-based manner and receive guidance (Banchi & Bell, 2008). This, in turn, necessitates teachers who possess a pedagogical and didactic repertoire to implement classroom interventions which might contribute to pupils' inquiry. For the Netherlands, however, a competence profile for inquiry-based science teaching in primary schools is still lacking. The focus in the present research is on pre-service primary teachers' inquiry-based science teaching competence, and helps to meet the need for such a profile by carefully investigating the required elements in relation to one another.

The context in which the studies were carried out – teacher training colleges in the Netherlands — and the scope of this thesis are described in the next section of this introduction. Subsequently, the problem statement, purpose of the study and research questions of the studies are presented, and the way they are connected is explained. The introduction concludes with an overview of the chapters in which the various research questions are answered.

1.1 Context of the study

The Dutch educational system involves eight years of general primary education, from 4 to 12 years of age. Primary school teachers have earned a certificate from a four-year teacher training program at the professional Bachelor's level, allowing them to teach all subjects including science.

1.1.1 History of science education in the Netherlands

In the 1970s and 1980s, science competence received little attention in Dutch primary schools, and the focus was on gaining morphological, systematic knowledge, and facts and determination of plants and animals (Praamsma, 1997; van Berkel, 1998). Therefore, pre-service training placed emphasis on the SMK, mainly of biology (Rohaan, 2009) and its transmission. This was criticized by researchers and practitioners in the field. Heimans and Thijsse (in Praamsma, 1997) for example, wrote about reform necessary in primary education and in teacher training, with regard to science. They argued that children should be brought into nature and nature should be brought into the school, in order to familiarize children with the experience of observing, touching, and smelling plants and animals. They advised all teacher training colleges to take their students out of the school and let them experience nature in at least two different landscapes with different types of soil, vegetation, and fauna. They argued that books and pictures alone are not able to educate teachers (Praamsma, 1997). In 1991, an influential report on primary science education was published in the Netherlands (Kamer-Peeters, 1991). Science education was introduced as a compilation of physics, biology, and chemistry in primary education (Kamer-Peeters, 1991). Seven years later, the national standards of primary education were revised by the Dutch Ministry of Education. Technology education was added to the previously mentioned disciplines. From that moment on, science was presented as an integrated subject called “human and world orientation” (Ministry of Education, 1998). In 2004 the total number of curriculum goals was reduced from 118 to 58, of which seven were formulated for science. A short description of each dimension of science was added. In essence, less goals meant more autonomy for the schools with regard to content.

Although reports on science education were written by Dutch policymakers (Kamers-Peeters, 1991; Ministry of Education, 1998; Inspectie van het Onderwijs. 2005) the subject received little attention in practice. Despite the integrative approach in curriculum documents, the subjects were taught separately in most schools (TIMMS, 2003). In 2002 the CITO group concluded that the content and organization of technology education were diverse among primary schools, and sometimes not taught at all (Thijssen, van der Schoot, Verhelst, & Hemker, 2002). When it was included in the curriculum, it tended to be hands-on, and the main focus was on constructing products, while designing, analyzing and evaluating products got little or no attention even though these were mentioned in the objectives. In addition, reflection on the activities undertaken was often lacking. These findings were confirmed by the national school inspection in the Netherlands (2005) in a monitor study of a representative sample of all Dutch primary schools.

Many studies undertaken in different countries revealed the difficulties encountered by pupils in making the link between experiment and theory (Andersson, 1990; Dewey & Dijkstra, 1992; Joshua & Dupin, 1993). The criticism and suggestions for teachers were suggestive of two main strands for the development of experimental work, moving from hands-on towards minds-on. First, it was proposed that primary teachers should provide a richer and more diverse picture of what doing science involves, including the prerequisites of formulating and reformulating a question or a problem; formulating a hypothesis; planning experiments; improving a protocol; controlling a range of variables; gathering, analyzing, and interpreting data; and communicating results. Second, it was proposed that teachers should be able and willing to engage pupils in activities of higher order thinking. Both suggestions required teachers to be competent in questioning pupils and stimulating class room discussion (Harlen, 1993).

A range of studies showed that there are links between teachers' science SMK (SMK) and the way they teach science. It seems that a low level of SMK is linked with teaching approaches that leaves little room for questions or discussion (Osborne & Dillon, 2008; Harlen & Holroyd, 1997). Work of this kind led to an emphasis on the science content component of teacher training. However, no priority used to be given to science teaching competencies in most Dutch primary schools and in teacher training programs.

During this period, several national programs were started. The general aim was to stimulate the introduction of science and technology activities in primary education. Verbreding Techniek Basisonderwijs (VTB: "Broadening Primary Technology Education") was the national program running from 2004 to 2007, designed to help primary schools to integrate science and technology into their teaching. The subsidy provided by VTB, however, was used to buy methods and materials, not to professionalize teachers. Thus, teachers in the field neither changed their attitude towards science nor gained science pedagogical content knowledge.

After the VTB project, gone was the illusion that the teacher education process could be controlled through the concomitant production of improved teaching content, more efficacious and sophisticated methods and materials or better-articulated strategies. Instead, it was becoming increasingly evident that it was impossible to neglect teachers' responsibility and their science teaching competencies within this teacher education process. In other words, their knowledge, attitudes and pedagogical didactic knowledge and skills within the field of science needed to be addressed. Additionally, the program VTB-professional (VTB-pro) was in place from May 2007 till December 2010. One-third of all 7500 primary schools in the Netherlands received financial, organizational, and subject-specific support to professionalize the teachers and to embed science and technology in their curriculum. Professional development activities and research were developed and conducted by consortiums of primary schools, teacher training colleges, and universities.

These consortiums were organized into what were called “Knowledge Centers”, of which five were in the Netherlands. A project management group was responsible for the organization of the project; a program council was installed to safeguard the scientific quality of the project and two external assessments organizations were hired to monitor the project (Harlen & Léna, 2011).

The educational paradigm in the past decade could be characterized as a shift away from the view that ideas are formed by individuals in isolation towards reconstructing knowledge collaboratively. In thinking about learning, sharing and discussing ideas had been emphasized (Harlen, 2011). This meant a greater emphasis was placed on communication through language, on the influence of cultural factors, and on linking pupils as well as teachers into a community of learners.

1.1.2 History of the concept of science teaching competence

The reality of professional practice, including teaching, is dynamic, but quality requirements in professional domains require a certain level of standardization (Mulder, 2014, p. 18). A teacher is competent when he or she acts responsibly and effectively according to given standards of performance. Professional competence is seen as the generic, integrated, and internalized capability to deliver sustainable, effective (worthy) performance in a certain professional domain, job, role, organizational context, and task situation. Competence consists of various competencies: integrated clusters of knowledge, skills, and attitudes which can be utilized in real performance contexts (Mulder, 2014, p. 3).

Historically, three main conceptualizations of competence can be distinguished: functional behaviorism; generic, or integrated, occupational approach; and situated professionalism.

Functional behaviorism

The US competency tradition started in the 1960s and can be characterized as the functional behaviorism approach. As a result of the launch of the Russian Sputnik, the need for more scientists became obvious, as well as the need for everyone to be able to relate to the rapid changes that science and technology brought to the world (Harlen, in de Vries, van Keulen, Peters and Walma van der Molen, Eds., 2011; Hodge, 2007).

In the public debate about the crisis in education in the United States, attention turned to the quality of teacher preparation in the sixties of the former century. Existing teacher education programs were criticized on the grounds that they were not based on actual work requirements, that instruction was not tailored to individual requirements, and those outcomes were not being evaluated (Hodge, 2007). As a response, the US Department of Education created the Elementary and Secondary Education Act, which called for "comprehensive elementary teacher education models, including the use of behavioral objectives and systems analysis." The models produced were characterized by the precise specification of atomized task elements and competencies or behaviors to be learned, the modularization of instruction, evaluation and feedback, personalization, and field experience. The theory of behaviorism with its emphasis on observable behavior has strongly influenced the development and general approach of competency-based training. In the United States, teaching competencies were perceived and prescribed from this behaviorist angle. At present, one of the main criticisms of this conceptualization is that, by fragmentizing tasks into a list of atomized work descriptions, teachers' identity and autonomy are ignored completely and the role of tacit knowledge is undervalued (Hodge, 2004; Mulder, 2014). Furthermore, this mechanistic view of work does not leave room to recognize that different teachers accomplish their job with different degrees of efficiency. Functional behaviorism, in which skills training is seen as a way to acquire isolated teaching competencies, was not adopted in continental Europe (Mulder, Wiegel & Collins, 2007).

Integrated, occupational approach

In England, Stenhouse (1975) played a significant role in emancipating teachers from paternalism and dependence within the context of education, strengthening their skills, the self-management of their teaching practice, and the decision-making processes involved. Developments of Ausubel's (1978) theory on meaningful learning also exerted influence on the role of teachers. Teachers were regarded as more than mere programmed organizers, as they had been from a behaviorist perspective. Teachers' tasks also involved finding suitable previous organizers, potentially meaningful content, and context capable of bridging the gap between pupils' prior knowledge and the knowledge to be acquired.

During the 1980s, the integrated, occupational approach to science teaching competencies was adopted in teacher training colleges in the United Kingdom. After recognizing endemic deficiencies of skill formation, the ministry of education introduced a competence-based approach to teacher training and other vocational training in order to establish a nationwide unified system of work-based qualifications. This reform was driven by the adoption of a competence-based qualifications framework, which subsequently influenced similar developments in other countries in the Commonwealth. Knowledge, skills, and attitudes were seen as influencing one another in teaching professions and were thus taught and learned together in teacher training colleges and universities.

The fundamental criticism of the integrated, occupational approach is the lack of relationship to context. Generic competencies were defined in terms of personal qualities or traits, assuming there is a single type of good practitioner, independent of the context (Eraut, 1994). Gonzi (1994) stated that evidence was lacking for the extent to which such generic competencies could make the difference between average and excellent performers. He also expressed doubts about the transferability of competencies from one situation to another.

Situated professionalism

Internationally, in view of globalization and increased migration across cultural and national boundaries (OECD, 2008), studies were conducted to analyse which competencies teachers need in order to teach science to highly heterogeneous classes containing pupils with different linguistic, social, economic, cultural, and religious backgrounds. A radical change in pedagogy was widely advocated, with greater use of inquiry-based methods and consideration of children's pre-existing ideas (NRC, 1996; Michaels et al, 2008; Harlen & Allende, 2006; 2009). These changes share elements of constructivist pedagogy and of formative assessment. In essence, teachers must understand and respond to individual students' needs and to context variables, such as availability of materials, time, and the common vision and mission of the school team. Thus even the integrated occupational approach, in which knowledge, skills, and attitude are taught and learned simultaneously, was no longer seen as sufficient in preparing pre-service teachers for their future role. For learning, mastering, and applying science teaching competencies in practice, situated professionalism was and is seen as the answer (Bhattacharyya et al., 2009). From this point of view, competencies are mastered through integrated application in the classroom. Within the tradition, the concept of competence is defined as follows: "competence is the integrated performance-oriented capability of a person or an organization to reach specific achievement. These capabilities consist of clusters of knowledge structures and cognitive, interactive, affective and, where necessary, psychomotor skills, as well as attitudes and values, which are conditional for carrying out tasks, solving problems and effectively functioning in a certain profession, organization, position, and role (Mulder, 2001, p. 76).
In approximately 2000, French, Dutch and other European educational systems adopted a 'situated professionalism' approach, moving from subject (inputs) to competence (outcomes) and curricula specifying learning fields in certain contexts, rather than

occupation-related knowledge and skills content (Hoffmann, 1999). As a result, in Europe, competence-based teacher education was implemented, in which teaching skills, attitudes, and SMK are integrated and developed in context (Korthagen, 2004).

A standard typology of competences now appears at the beginning of every new teacher training curriculum in the Netherlands, elaborating professional action competence in terms of domain or subject (matter) competence, pedagogical content knowledge, and attitude in a certain professional context. Subject matter knowledge consists of science content knowledge and research skills. Pedagogical content knowledge is “the knowledge of subject matter for teaching, including: ‘the most powerful analogies, illustrations, examples, explanations, and demonstrations — in a word, the ways of representing and formulating the subject that make it comprehensible for others’ (Shulman, 1986, p. 9). Attitude deals with an individual's prevailing tendency to respond with a positive or negative feeling to an object, people, institutions, events, ideas, and things (Bursal & Paznokas, 2006). Self-efficacy is defined as “belief in one’s capabilities to organize and execute the courses of action required to produce given attainments” (Bandura, 1997, p.3).

1.2 Problem statement and purpose of research

During the last ten years, much attention has been paid to the improvement of primary science education. As a result of research advocating inquiry-based education, inquiry-based science teaching and learning has become a focus of policy documents (Luera & Otto, 2005; Akerson & Hanuscin, 2007; Dietz & Davis, 2009; Howes, Lim & Campos, 2009).

Recent research has indicated that primary school teachers have difficulty being effective inquiry-based science teachers. They tend to lack knowledge concerning how science inquiry works, and particularly, how to implement inquiry-based teaching in their classrooms (Lee, Hart, Cuevas & Enders, 2004; McDonald, 2009; Van Zee et al., 2005). Without these competencies, qualitatively poor or insufficient guidance and feedback might be offered during pupils’ discovery process, which is both less effective and less efficient (Kirschner, Sweller, & Clark, 2006) than scaffolding pupils’ learning process (Lee, Lewis, Adamson, Maerten-Rivera & Secada, 2007; Shymanski, Yore & Anderson, 2004). Competent teachers are essential to increasing pupils’ learning and interest in science, and form the basis of any system of formal science education. However, agreement between policymakers, researchers, teacher educators and teachers is lacking regarding what competencies teachers should develop or master to be able to teach inquiry-based primary science (Kim & Tan, 2011). Therefore, there is a need for investigating which inquiry-based science teaching competencies pre-service primary teachers and primary teachers require in order to implement a powerful learning environment in primary schools.

Another crucial issue in inquiry-based science teaching is the relation between the components of inquiry-based science teaching competence. Do pre-service teachers who possess sufficient subject matter knowledge differ with respect to their attitude or Pedagogical Content Kowledge (PCK)with those whose SMK is limited? A handful of empirical studies have revealed that there might be qualitative differences among pre-service teachers with high or low subject matter knowledge, in terms of attitude or pedagogical content knowledge. These studies, however, have not explicitly unraveled the differences in science self-efficacy, science teaching self-efficacy, or preferred science teaching strategy between pre-service teachers with high or low Subject Matter Knowledge.

In-depth analysis of pre-service teachers' SMK in relation to their science teaching attitude and PCK could reveal the relationships between these components. Empirical research is therefore needed in this area.

In sum, the following general research questions are answered in this dissertation:

1. Which inquiry-based science teaching competencies are required to teach inquiry-based science in primary schools?
2. What is the relation between the inquiry-based science teaching competence components?

1.3 Research questions and overview of the dissertation

In this dissertation, four studies are presented in chapters 2 to 5, respectively. These studies investigate the previously specified research questions, divided into sub questions. The chapters are written as independent articles; as a consequence, there is some overlap between them.

1.3.1 Required inquiry-based science teaching competencies: a literature review

As stated above, from the 1960s onwards, comprehensive elementary teacher education models with behavioral objectives were developed in the United States. Under the influence of developing learning and instructional theories, these were adapted several times by a diverse group of professionals, representing teachers, teacher educators, researchers, and policymakers. Thus, the standards reflect a broad consensus reached 18 years ago about the elements of quality science education and science teaching competence. They are based on an interpretation of competence derived from the situated professional conceptualization. In the Netherlands, a science teaching competence profile for primary school teachers is lacking. In order to address the first research question of this dissertation, the second chapter evaluates the US National science teaching standards (NRC, 1996) in light of the latest theories, published in peer-reviewed journals. Many researchers of inquiry-based science education, both in the United States (see for example: Choi & Ramsey, 2009; Eick & Stewart, 2010; Park Rogers, 2009; Varma, Volkmann & Hanusci, 2009) and elsewhere (see for example Avraamidou & Zembal-Saul, 2010; Lin, Hong & Cheng, 2009; Shymanski, Yore & Anderson, 2004) have used these standards to define inquiry-based education and to study inquiry-based science teaching competencies. Our purpose was to investigate whether additions or changes should be made to the standards, based on research findings published in the period 2004-2011. The study might be helpful in the future for specifying guidelines in the European context.

The research questions are as follows:

1. What elements of competencies required by primary school teachers who teach inquiry-based science are mentioned, discussed, and researched in recent literature?
2. To what extent are the American National Science Education Standards consistent with elements of competencies found in recent literature?

The systematic literature study resulted in a conceptual framework in the form of a competence profile. This profile comprises three components: Subject Matter Knowledge (SMK), Attitude and Pedagogical Content Knowledge (PCK), and twenty-three underlying competencies. Thus, the second chapter provides the theoretical foundation of this dissertation and is the starting point for the empirical part of the PhD research.

1.3.2 Required inquiry-based science teaching competencies: a Delphi study

The competence profile resulting from the review study was presented to Dutch experts in the field of primary science education. These were delegates from research and policy-making institutes; teacher educators and teachers who are all seen as leading in the field of primary science teaching. By means of a Delphi study, the experts indicated to what extent they agreed on the importance of those previously identified competencies. Also, they distinguished between the importance of mastering these competencies for novice and for experienced teachers.

Two research questions were formulated in accordance with the research purpose:

1. To what extent do Dutch experts agree or disagree with the importance of inquiry-based science teaching competence elements as derived from the literature (Alake-Tuenter et al., 2012) and the United States' National Science Teaching Standards (NRC, 1996)?
2. According to experts, are there any differences between the importance of competencies for novice and for experienced teachers?

Experts confirmed the importance of the twenty-three competency elements, further proposed to add one competency, and to differentiate between novice and experienced teachers.

1.3.3 The relation between pre-service primary teachers' science Subject Matter Knowledge and Attitudes

The next studies in this dissertation addressed the search for relationships between pre-service teachers' science-teaching competence components. Until now, the relationships between SMK on all five science systems (living, earth and space, physical, technological, and mathematical systems) and attitudes towards science teaching have not been studied among pre-service primary student teachers in the Netherlands. The purpose of this study was to help clarify the relations (if any) between SMK, science teaching attitude and science teaching self-efficacy, by using a sample of Dutch pre-service primary school teachers. The focus of the study is science teaching attitude elements (importance, pleasure, and tendency to competence development), Science Self-Efficacy (S-SE) and Science Teaching Self-Efficacy (ST-SE), and the SMK elements of pre-service teachers in their first year of study.

The research questions read as follows:

1. What characterizes first-year pre-service teachers' Science Teaching Attitudes (ST-A), Science Self-Efficacy (S-SE) and Science Teaching Self-Efficacy (ST-SE), and their science Subject Matter Knowledge (SMK)?
2. Is there an association between a) first-year pre-service teachers' Science Teaching Attitudes (ST-A), (consisting of pleasure, importance, and competence development) and b) their Science Teaching Self-Efficacy beliefs (ST-SE)?
3. What is the relation between pre-service teachers' Science Self-Efficacy (S-SE) and Science Teaching Self-Efficacy (ST-SE)?
4. What is the relation between a) pre-service teachers' science Subject Matter Knowledge (SMK), b) their Science Teaching Attitudes (pleasure, importance, competence development), and c) their Science and Science Teaching Self-Efficacy (S-SE and ST-SE)?

The findings of the empirical study are presented in chapter 4 of the thesis, followed by explanations for these results, implications, limitations and recommendations for further research.

1.3.4 The relation between pre-service primary teachers' science Subject Matter Knowledge and Pedagogical Content Knowledge

Several researchers have studied the relation of PCK (in terms of quantity and quality) to the teaching practice of experienced teachers (Loughran, Mullhall & Berry, 2008; Nilsson & Loughran, 2011) and to pupil learning (Hanuscin, Lee, Akerson, 2010; Rohaan, Taconis & Jochems, 2010). They concluded that PCK components result in conscious or unconscious preferred science teaching strategies which teachers apply depending on the context, the content to be taught, the context in which the content is taught, and the way individual pre-service teachers reflect on their experiences (Davis, 2004; Nilsson, 2008). The continuum of preferred science teaching approaches runs from didactic direct, to active direct, guided inquiry, and open inquiry. These approaches differ in the amount of autonomy given to pupils, and in the way new theory is presented: deductively or inductively. In the case of directive strategies, the content to be learned is explained at the beginning of the lesson. Inquiry approaches use the findings of the children to generalize and conclude on phenomena.

Research results and policy reports advocating inquiry-based teaching might cause teacher training institutes and pre-service teachers alike to feel pressured into using these approaches.

It is known that experienced teachers with low science SMK tend to use more direct teaching strategies, to avoid being confronted with pupils' questions which they cannot answer. Those with adequate science SMK tend to use more inquiry-based strategies (Davis & Petish, 2005; Kim & Tan, 2011). As far as known, this has not been studied with regard to students in teacher education for primary education. The question remains whether the level of pre-service primary teachers' SMK is related to preferred science teaching approaches as found with regard to experienced teachers. Thus, research is needed on the relation between pre-service teachers' science SMK and their preferred science didactic strategies, as part of PCK.

This study aims to contribute to the body of knowledge on the relation between pre-service teachers' science SMK and science PCK. Research questions are:

1. How can the reported preferred Science Teaching Approaches of pre-service primary teachers be characterized?
2. Is there a relationship between reported preferred Science Teaching Approaches and science SMK of these pre-service teachers?

Results reveal the differences between primary pre-service teachers with and without sufficient SMK, with regard to their preferred science teaching approach. The results are discussed in terms of limitations of the study, practical implications, and recommendations for future research.

1.4 Overview of the thesis

In this dissertation, four studies are presented. Chapters 2 and 3 explore the separate required science teaching competencies of primary school teachers. Chapters 4 and 5 present findings on how components of science teaching competencies are related. Finally, in the last chapter of this thesis the overall conclusions are described and discussed. This chapter opens with the main findings, followed by discussions of all chapters in concert. Next, the strengths and weaknesses of the studies are discussed along with methodological and theoretical issues. The chapter concludes with a presentation of challenges and recommendations for future research, and implications for theory and practice. Figure 1 shows how the four studies reported in chapters 2, 3, 4, and 5 come together along with their corresponding variables. The four chapters of the thesis can be read independently; these have partly been published as separate articles in international peer-reviewed scientific journals. Furthermore, figure 1 provides a summary of the different phases and the main variables of the studies in relation to one another.

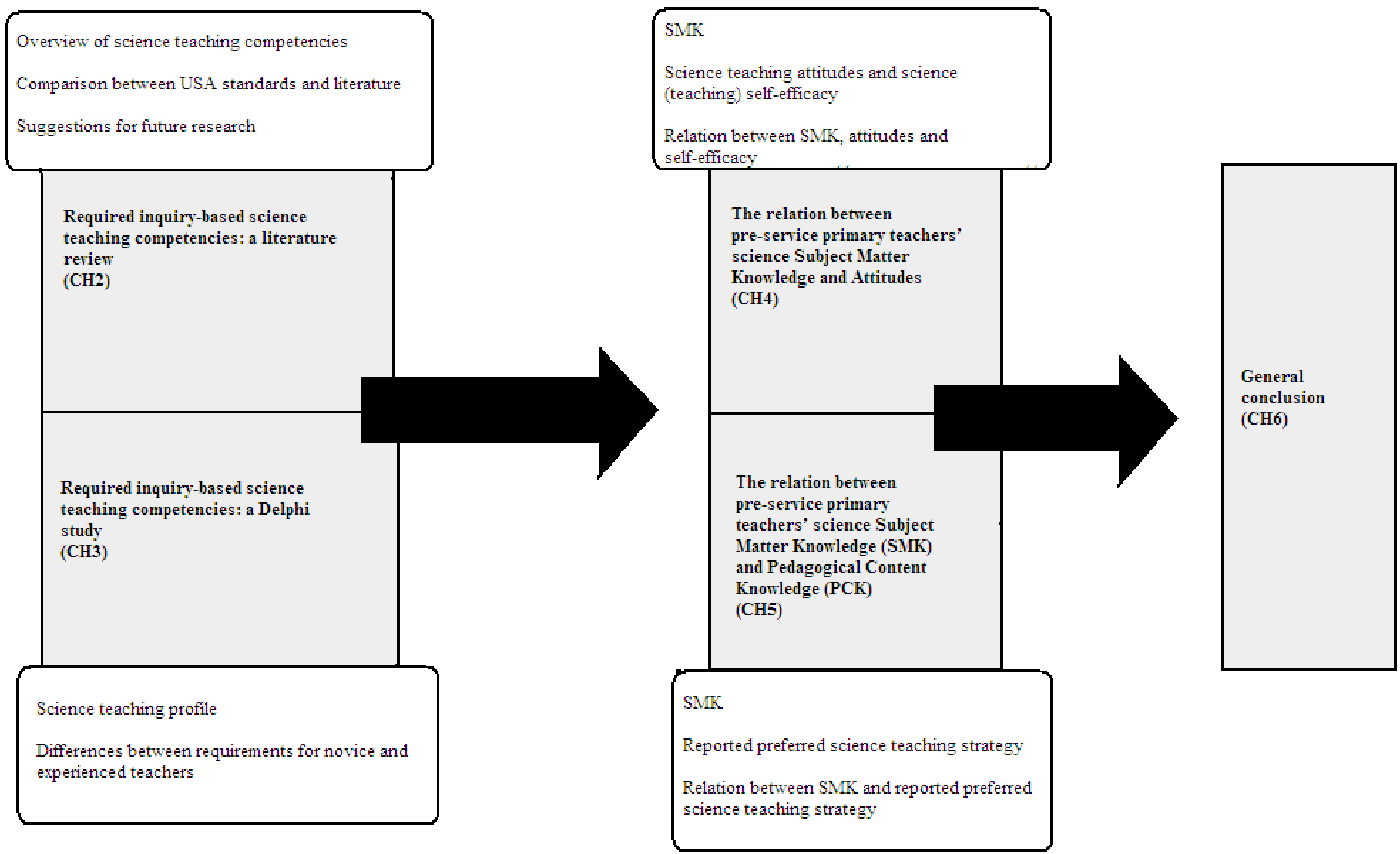


Figure 1 Core foci of this thesis and the different studies represented by chapter numbers

Chapter 2

Inquiry-based science education competencies of primary school teachers: A literature study and critical review of the American National Science Education Standards

This chapter is based on:
Alake-Tuenter, E., Biemans, H.J.A., Tobi, H., Wals, A.E.J., Oosterheert, I., & Mulder, M. (2012). Inquiry-Based Science Education Competencies of Primary School Teachers: A literature study and critical review of the American National Science Education Standards. *International Journal of Science Education*, 34 (17), pp. 2609-2640.

Abstract

Inquiry-based science education is an important innovation. Researchers and teachers consider it to be stimulating for pupils' application of research skills, construction of meaning and acquiring scientific knowledge. However, there is ambiguity as to what competencies are required to teach inquiry-based science. Our purpose is to develop a profile of professional competence, required for effective inquiry-based science teaching in primary schools in the Netherlands. This article reviews literature and compares the outcomes to the American National Science Education Standards (NSES). In so doing, it seeks to answer the following research questions: What elements of competencies required by primary school teachers who teach inquiry-based science are mentioned, discussed and researched in recent literature? To what extent are the American NSES (introduced 15 years ago) consistent with elements of competencies found in recent literature? A comprehensive literature review was conducted using Educational Resources Information Centre and Google Scholar databases. Fifty-seven peer-reviewed scientific journal articles from 2004 to 2011 were found using keyword combinations. Analysis of these articles resulted in the identification and classification of 22 elements of competencies. This outcome was compared to the American NSES, revealing gaps in the standards with respect to a lack of focus on how teachers view science teaching and themselves as teachers. We also found that elements International Journal of Science Education of competencies are connected and poor mastery of one may affect a teacher's mastery of another. Therefore, we propose that standards for the Netherlands should be presented in a non-linear, holistic, competence-based model.

2.1 Introduction

Good-quality teachers, with up-to-date knowledge and skills, are the foundation of any system of formal science education. Systems to ensure the recruitment, retention and continuous professional development of such individuals must be a policy priority in Europe (Osborne & Dillon, 2008). Many stakeholders hold the expectation that the gap between labor market and education can be reduced through competence-based education. When the emphasis is on developing competencies, and not just acquiring a diploma, the accent of education needs to be on capabilities, not on qualifications (Biemans, Nieuwenhuis, Poell, Mulder, & Wesselink, 2004). However, there is no nationally accepted science teaching competence standard in the Netherlands and now that several courses of teacher training colleges for primary education are (or will soon be) competence-based, such a standard is needed.

National science teaching standards have been used in the USA since 1996. Many researchers of inquiry-based science education both in the USA (see for example: Choy & Ramsey, 2009; Eick & Stewart, 2010; Park Rogers, 2009; Varma, Volkmann, & Hanuscin, 2009) and outside the USA (see for example Avraamidou & Zembal-Saul, 2010; Lin, Hong, & Cheng, 2009; Shymanski, Yore, & Anderson, 2004) have used these standards to define inquiry-based education and to study inquiry-based science teaching competencies. Considering that these standards are referred to in international journals, and that they are the product of an open, iterative process involving different groups of stakeholders, thus reflecting a broad consensus reached 15 years ago about the elements of science education, we decided to evaluate whether they can still be used as an example for the current European context. Specifically, we aimed to investigate whether additions or changes should be made to the standards based on research findings published in the period 2004–2011. American pupils of the age of 10 years score higher than average on international comparative research and higher than most Western European pupils (Gonsalez et al., 2009), which is not necessarily a result of the standards, but the standards might have had a positive effect on the quality of education and the pupils' results. The context in which science is taught: culture of education with its pluralistic views, culture of society as a whole and how science is represented are comparable between these continents, both being Western industrialized societies (Erikson, 2005). Both education systems recognize plurality, not a unitarian approach, which requires a generic model. Thus, the American standards and additions or changes based on current literature might be helpful in future for a better understanding of what is required in the Dutch context concerning inquiry-based science competencies of primary school teachers.

This article presents the findings of a literature study conducted to answer the questions:

1. What elements of competencies required by primary school teachers who teach inquiry-based science are mentioned, discussed and researched in recent literature?
2. To what extent are the American NSES consistent with elements of competencies found in recent literature?

This article reviews recent international scientific literature and the American NSES to compare the elements of teacher competencies that are considered to be required for teaching inquiry-based science. The aim is to provide a better understanding of what is required in the current Dutch context concerning inquiry-based science competencies of primary school teachers, resulting in a profile for primary school teachers existing of elements of professional competence.

The study was part 1 of 4 projects of a network of research on inquiry-based science teaching. Study 2 aims to validate the outcomes of this literature study for the context of the Netherlands, using a Delphi approach. Study 3 aims to report the design of an instrument to assess teachers on inquiry-based science teaching, and study 4 aims to find characteristics of effective professional development programs aiming to improve inquiry-based science teaching.

The first section of this article considers and reviews literature on inquiry-based science education and on teacher competencies with respect to inquiry-based education; the second section presents the methodology, the third, major section reports on the results of the study; and the fourth, final section discusses the conclusions that can be drawn from this work and their implications for future research and future practice.

2.2 Theoretical framework

2.2.1 Inquiry-based science education

Inquiry-based science education is considered to be an important current trend in science education reform. Scientific inquiry generally refers to the diverse ways in which scientists study the natural world (Liang & Richardson, 2009, p. 51). More than a procedure or a method, it is a process of investigating how, why or what, and then making sense of the resultant findings (Bhattacharayya, Volk, & Lumpe, 2009). Based on standards developed by the American National Research Council (NRC, 1996, 2000), many researchers (Avraamidou & Zembal-Saul, 2010; Cuevas, Lee, Hart, & Deaktor, 2005; Dietz & 9, 2006; Howes, Lim, & Campos, 2009; Liang & Richardson, 2009; Lin et al., 2009; Park Rogers, 2009; Smolleck, Zembal-Saul, & Yoder, 2006; Varma et al., 2009) mention six essential features of classroom inquiry that apply across grade levels. Learners address scientifically oriented questions; plan and carry out investigations to gather evidence; give priority to evidence in responding to questions; formulate explanations for evidence; connect explanations to scientific knowledge; and communicate and justify explanations.

Scientific inquiry includes investigating natural phenomena through experimentation and higher thinking. This refers to thinking that goes beyond mere recording of data or mechanically applying concepts. The focus of inquiry is on the creation, testing and revision of scientific models and explanations, to create new knowledge and scientific reasoning

(Schwarz & Gwekwerere, 2007). NRC describes inquiry as 'a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations and predictions; and communicating results' (NRC, 1996, 2000, p. 23). Other definitions also encompass processes such as using investigative skills; actively seeking answers to questions about specific science concepts; and developing the ability to engage, explore, consolidate and assess information. Inquiry is not a linear process; rather, aspects of inquiry interact in complex ways (Cuevas et al., 2005). Classroom inquiry introduces pupils to the content of science as well as the process of investigation. It provides the logical framework that enables students to understand scientific innovations (Smolleck et al., 2006).

Inquiry learning 'refers to the activities of pupils in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world' (Luera & Otto, 2005, p. 243). Inquiry teaching is defined as 'providing a classroom where learners can engage in scientific-oriented questions to formulate explanations based on evidence' (Luera & Otto, 2005, p. 243). The aim of inquiry-based science education is to help pupils develop scientific skills and a deep understanding of the subject matter and the nature of science. Encouraging pupils' questions and aiding them in learning to utilize evidence from the real world to address these questions are essential to inquiry-based education (Howes et al., 2009).

Inquiry-based education may include different degrees of inquiry learning depending on the learning environment. Science education researchers have developed an inquiry continuum that classifies classroom inquiry into different levels from structured inquiry to open inquiry. To determine whether a lesson activity can be categorized as full or partial inquiry, one must consider the amount of student and teacher involvement in each of the essential features of classroom inquiry (Smolleck et al., 2006; Varma et al., 2009). Leonard, Boakes, and Moore (2009) and Liang and Richardson (2009) refer to Bonstetter (1998) and Windschitl (2003) who described several levels of science inquiry: (1) traditional laboratory confirmation experiences providing pupils with step-by-step procedures to verify known principles in structured inquiry; (2) structured inquiry in which the teacher presents a question, lab equipment and procedures for pupils to discover an unknown answer; (3) guided inquiry through which teachers allow pupils to investigate a prescribed problem using their own methods of gathering and analyzing data and drawing conclusions; (4) student-directed inquiry, in which the teacher presents a topic and lets pupils develop their own questions and design their own investigations; (5) open inquiry through which pupils form their own questions and conduct independent investigations.

There is empirical and theoretical evidence to support the assumption that inquiry-based science is a starting point first for increasing the motivation of pupils to learn about science (Lin et al., 2009); second, for applying research skills (Cuevas et al., 2005) and third, for personal construction of meaning and deeper learning of content knowledge (Luera & Otto, 2005; Weld & Funk, 2005). School science courses are often seen as dull and unexciting by pupils (Bhattacharayya et al., 2009); and science as inquiry is considered to be an important part of the solution to that problem. Pupils are offered more hands-on activities, with the aim of making science dynamic and physical and allowing pupils to feel comfortable with the subject (Howes et al., 2009). Giving them more opportunities to carry out investigations does not guarantee their engagement in learning; however, if pupils are encouraged to plan their own learning activities, they are more likely to get involved in a task (Lin et al., 2009).

Inquiry-based science education complements the natural curiosity of pupils by encouraging them to ask questions, try things out and evaluate the outcomes (Howes et al., 2009). Pupils should know how to pursue their own questions about the world around them. This pursuit, however, does not happen naturally in the classroom, and pupils will need to be supported in their attempts to understand phenomena. When science is taught through the process of inquiry, pupils have the opportunity to pose questions and seek answers based on observation and exploration. Pupils can then use the evidence gathered throughout this process to answer their own questions that may arise. Inquiry allows pupils the opportunity to explore, yet simultaneously requires them to learn something about how science research is conducted.

Many educational theories presume that people learn best through direct personal experience and by connecting new information to what they already know (Bhattacharayya et al., 2009). Therefore, corresponding educational paradigms have shifted from reproducing knowledge towards asking scientifically oriented questions and searching for evidence in responding to questions (van Zee, Hammer, Bell, Roy, & Peter, 2005) and towards active, self-regulated learning aimed at (co-) construction of knowledge (Marble, 2007; Piaget, 1985). Thus, a rich learning environment, with a focus on inquiry-based learning, creates opportunities for pupils to identify their assumptions, use critical and logical thinking, internalize or transform new information, which then allows them to create and expand their individual cognitive structures (Smolleck et al., 2006). Through these activities, pupils develop their understanding of science by combining science knowledge with reasoning and thinking skills (Cuevas et al., 2009). Inquiry learning supports (long-term) conceptual understanding by supplementing the learning of scientific concepts and facts. Thus, inquiry-based science can lead to better performance in science classrooms. In summary, inquiry-based education might lead to a higher degree of scientific literacy, i.e. the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity. Scientific literacy includes specific types of abilities (NRC, 1996), and it expands and deepens over a lifetime, not just during the years in school. But, the attitudes and values established towards science in the early years will shape a person's development of scientific literacy as an adult. Primary school teachers influence pupils' attitude and values towards science and the development of pupils' scientific literacy (Shymanski et al., 2004).

2.2.2 Teacher competencies with respect to inquiry-based education

As described, young pupils can develop a complex understanding of science when sufficient opportunities to learn are presented. Teachers' competencies influence pupils' learning (Vikström, 2008). In this research, we use the integrated, holistic and relational broad development approach on competencies. We view competence as the integrated performance-oriented capability of a person to reach specific achievements (Biemans et al., 2004, 2009; Mulder, 2001). Personal competencies comprise integrated performance-oriented capabilities, which consist of clusters of knowledge structures and also cognitive, interactive, effective and where necessary psychomotor capabilities, and attitudes and values, which are required for carrying out tasks, solving problems and, more generally, effectively functioning in a certain profession, organization, position or role (Mulder, 2007). We acknowledge the cultural context and social practices involved in competent performance, reflecting how personal attributes are used to achieve outcomes in teaching within specific schools and within broader relationships with society. Thus, competencies have a strong relationship with organizational effectiveness (Mulder, Weigel, & Collins, 2006).

Competencies are assumed to be recognizable, assessable relevant for practice, and can be developed and learned (Mulder et al., 2006). Competence is not trained behavior but thoughtful capabilities and a developmental process. A competence profile can be described as the overview of the essential elements of professional competence required for effective performance in a job (du Chatenier, Verstegen, Biemans, Mulder, & Omta, 2010). In practice, competence elements are integrated and cannot be separated because of the complexity and indeterminate nature of real-world situations but in theory individual competence elements can be distinguished.

Recent research has indicated that primary school teachers have difficulties in being effective inquiry-based science teachers. They tend to lack knowledge concerning how science inquiry works and, particularly, how to implement inquiry-based teaching in their classrooms (Lee, Hart, Cuevas, & Enders, 2004; McDonald, 2009; van Zee et al., 2005). In addition, it depends on teachers' beliefs about the nature of science if scientific inquiry is implemented in the classroom (Eick & Stewart, 2010). If a teacher views science as a body of facts, no or little inquiry is offered to the children. In contrast, when a teacher considers science as inquiry and science knowledge as negotiated and constructed through inquiry, more inquiry experiences are presented in the classroom (Forbes & Davis, 2010). Ford (2008) and Park Rogers (2009) caution that even if inquiry-based science is implemented in the classroom, it does not automatically result in positive effects on pupils' learning. To engage pupils in inquiry and to teach science as exploration is not enough. Pupils need explicit instruction on science as inquiry including how to create knowledge through arguments based on explorations and evidence (Park Rogers, 2009). Teacher competencies are essential to increase pupils' science literacy, consisting of meaningful understanding of SMK of scientific facts and concepts; improvement of their science skills (Bhattacharayya et al., 2009; Smolleck et al., 2006) and interest in science (Lee, Lewis, Adamson, Maerten-Rivera, & Secada, 2008; Shymanski et al., 2004).

The Dutch Parliament passed the 'Professions in Education Act' in 2004 (Ministerie van Onderwijs, cultuur en wetenschappen, 2004). The essence of the act is that educational personnel must not only be qualified but also competent. For this reason, sets of competencies and its requirements have been developed. The framework of competence requirements specifies four professional roles that teachers have: interpersonal, pedagogical, and organizational and the role of an expert in subject matter and teaching methods. The teacher fulfils these professional roles in relation to four groups of actors in education: working with students, colleagues, the school's professional network and himself/herself. The framework specifies competence requirements for each role and in relation to the four mentioned actors in education. However, the guidelines are broadly defined and there are no specific competence requirements formulated for science.

In this research, we aim at giving an overview of the essential elements of professional competence, required for effective inquiry-based science teaching in the classroom. Therefore, we searched for competence requirements for working as an expert in science subject matter and science learning methods with pupils and managing self (development) in this regard (Table2.1).

Table 2.1 Dutch teacher competence matrix (Ministerie van Onderwijs, Cultuur en Wetenschappen, 2004)

	Working with pupils	**Working with colleagues**	**Working with schools' professional environment**	**Working with him/herself: managing self(-development)**
Interpersonal	1	5	6	7
Pedagogical	2			
Expert in subject matter and teaching methods	3			
Organizational	4			

2.3 Methods

In order to answer the research questions, the online sources Educational Resources Information Centre and Google Scholar were searched for relevant articles published in the period of 2004–March 2011 (see appendix). The various searches and corresponding literature analyses took place from January 2009 to March 2011. The whole search and selection procedure and the most important stages and decisions related to the procedure are described below.

First, to find definitions of inquiry-based primary science teaching, the keywords 'teach' and 'science' were combined with 'inquir'. A second search that combined 'teach', 'science', 'inquir' and 'competenc' was performed to find articles on primary teacher competencies in inquiry-based science education. Based on the definition of competence presented by Mulder (2007) and Mulder and Collins (2006) we replaced 'competenc' with the synonym 'capabilit∗', and 'knowledge', 'attitude∗', and 'skill', since these are seen as clusters of underlying capabilities of competencies. The abstracts of the identified articles included the thesaurus descriptors 'scientific literacy', 'belief', 'PCK' (i.e. referring to pedagogical content knowledge (PCK)) and 'teaching methods', again as underlying capabilities of competencies. To obtain more relevant (peer-reviewed) articles of interest, those words were also used in the search for articles, replacing 'competenc'. 'Journal articles' as a type of source and 'elementary' or 'primary' as a level of education were used in all searches. To reduce the number of articles to a manageable set, while enhancing the chance of including the most important articles, only articles from leading journals found in the Journal Citation Report and the International Science Index of the Web of Science were used. These journals included the International Journal of Science Education, International Journal of Science and Mathematics Education, Journal of Elementary Science Education, Journal of Research in Science Teaching, Journal of Science Teacher Education, Research in Science Education, Research in Science and Technological Education, Science and Education, Science Education, School Science and Mathematics, Teaching Science, Teaching Science and Technological Education. The search with keywords identified 432 papers. After excluding those not published in the scientific journals mentioned above, this number was reduced to 186. We included both larger and small-scale studies, and selected papers that contained any competence expressions. A quick scan of the abstracts of the selected papers was conducted to exclude articles on subjects other than science competencies of primary school teachers. After excluding articles with an emphasis on mathematics; learners and their improvement; the learning environment or the characteristics of professional development programs for teachers as well as those related to contexts other than primary schools, 126 articles remained. Finally, duplicates resulting from two or more searches were excluded, resulting in 57 papers. Those remaining were evaluated for their potential relevance to the topic. The full texts of the resulting articles were acquired from the Wageningen University and Research Centre Library. Articles not available were requested through the interlibrary service.

We looked for any mentioned, required or desirable element of competencies of primary school teachers who teach science. Based on the definition of competence presented by Mulder (2007) and Mulder and Collins (2006), the 22 elements found in the articles were then categorized into three clusters of underlying capabilities: knowledge, attitude and skills. This was helpful, but we realized that the cluster 'knowledge' consisted of different types of knowledge and the cluster attitude' included very different aspects. We then minimized the cluster 'knowledge' to declarative knowledge. This includes knowledge about facts and concepts, and the knowledge of inquiry (isolated as well as applied and related) and resembles what Lee, Maerten-Rivera, Buxton, Penfield, and Secada (2009) and Park Rogers (2009) also call SMK. Other types of knowledge, dealing with pedagogy and/or didactics were moved to the cluster 'skills'. In the literature, this category, together with other aspects, is referred to as 'PCK' (Akerson & Volrich, 2006; Avraamidou & Zembal-Saul, 2005, 2010; Park Rogers, 2009). We renamed this cluster 'science PCK', since this is a more accepted term in recent (science) education research and practice. We subsequently looked through the articles for references to original sources of information on PCK, which led us to Shulman (1986, 1987), Grossman (1990), Magnusson, Krajcik, and

Borko (1999). Based on these articles, we then added two competence elements that we found in the articles, namely, ‘attitude towards science teaching’ and ‘attitude towards science learners and learning’ to the science PCK cluster. We kept aspects of attitude that do not belong to PCK (according to the definition of Magnusson et al., 1999) and those that do influence enacted practice (‘attitude towards science’, ‘attitude towards self as a teacher’ and ‘teachers’ attitudes towards their own professional development’) separate in the cluster ‘attitude’.

2.4 Results

In this section, the underlying capabilities for the competence ‘to be an expert in science subject matter and science learning methods, working with pupils and managing self(development) in this regard’ (Table 2.1), as mentioned and discussed in literature, are reported. The 22 elements that were found are categorized in three clusters of the competence’ underlying capabilities: SMK, attitude and PCK.

2.4.1 Cluster of underlying capabilities 1: Teachers’ science Subject Matter Knowledge

Teachers cannot teach what they do not understand. Teachers therefore need accurate and comprehensive mastery of science content in order to teach science successfully (Katz, Sadler, & Craig, 2005; Lee et al., 2004). Deep and complex understanding of science involves memorizing and understanding factual information and concepts; understanding the relationships between those concepts and knowing when and how to apply them in context (Glen & Dotger, 2009; Lee et al., 2009; Leonard et al., 2009). Both pupils and teachers must be provided with multiple exposures to both definitional and contextual information about vocabulary in order to deeply learn it and use it in their reading, writing and speaking. Language as a labeling system is needed to allow pupils to further understand concepts. In classrooms studied by Glen and Dotger (2009) however, language as a labeling system was overused. Little attention was paid to language as an interpretive system, particularly the transition from interpretive language to the technical terms of science and the role interpretive language plays in debates and controversy used in scientists’ claims (Glen & Dotger, 2009). By not using language as an interpretive system, teachers may carry on the image of science as easy fact finding.

An expert's knowledge is connected and organized around important concepts, while a novice's knowledge is often fragmented. A person with disconnected knowledge will find it more difficult to retrieve relevant information and transfer it to appropriate situations (Luera & Otto, 2005). Moreover, teachers possessing a high level of connected subject matter expertise are more likely to engage in conceptually rich, inquiry-based activities that facilitate student learning. They tend to focus on the core responsibility of teaching: their pupils' understanding of the subject matter (Dietz & Davis, 2009). Science consists of five subsystems: living systems or biology, physical systems, earth and space systems, technological and mathematical systems (Weld & Funk, 2005). Understanding the relation between concepts and knowing when and how to apply them allows teachers to flexibly use knowledge of one system, for example mathematics, to solve or explain problems in another science system, for example biology (Liang & Richardson, 2009). Teachers with weak science content knowledge are more likely to rely heavily on textbooks as the main source of content knowledge and for the preparation of their lessons. This is problematic, since science textbooks often do not address pupils' alternative, non-scientific conceptions and a teacher with weak science knowledge will be unable to clarify pupils' understanding (Lee et al., 2009; Luera & Otto, 2005). Moreover, the extent of teachers' knowledge is tied to their interest in and attitude towards science, for example in geosciences (Leonard et al., 2009) or physics (van Zee et al., 2005).

Research shows that teachers exhibit deficiencies in their science content knowledge (Leonard et al., 2009) and they have alternative conceptions (Isabelle & de Groot, 2008; Trundle, Atwood, & Christopher, 2005). It is important, but not sufficient, for teachers to understand scientific theories and facts well enough to explain phenomena scientifically (Lee et al., 2004). In addition, teachers need knowledge about science and research or investigation skills (Akerson & Volrich, 2006). Various lists of required science process skills and knowledge have been proposed. They generally differ in the way individual items are expressed rather than at a more fundamental level. Each in its own way includes observation; raising questions, hypothesizing, predicting, planning and carrying out investigations using tools, interpretation of information obtained and communication of information (Katz et al., 2005; Lee et al., 2009; Park Rogers, 2009). Thus, teachers must be able to develop arguments and justify their ideas or solutions based on evidence. Doing so, they might acquire SMK concerning facts and concepts and (the purpose of) scientific language (Avraamidou & Zembal-Saul, 2005, 2010; Glen & Dotger, 2009; Liang & Richardson, 2009; Luera & Otto, 2005; Park Rogers, 2009; Schwarz, 2009; Trundle, Atwood, & Christopher, 2007). On the other hand, deepening and connecting SMK of science facts and concepts influences the quality of research skills, such as posing questions (van Zee et al., 2005) and communicating and justifying results (Oliveira, 2009) (Table2.2).

Table 2.2 Elements of teachers' science Subject Matter Knowledge

SMK 1: Knowledge of facts and concepts

SMK 1-1 Teachers' understanding of the meaning of isolated facts and concepts

SMK 1-2 Teachers' understanding of the relation between facts and concepts of:
- the same subject
- different subjects

SMK 1-3 Teachers' understanding of when and how to apply facts and concepts
(related to living;, technological; physical; earth and space; and mathematical systems)

SMK 2: Teachers' understanding of inquiry skills

SMK 2-1 Teachers' understanding of the meaning of isolated research skills

SMK 2-2 Teachers' understanding of the relation between the research skills

SMK 2-3 Teachers' understanding of when and how to apply research skills
(Observe; pose questions and predictions; examine books and other resources of information to see what is already known; plan investigations; carry out investigations using tools to gather, analyse and interpret data; propose answers, explanations and predictions using data; communicate and justify results).

2.4.2 Cluster of underlying capabilities 2: Pedagogical Content Knowledge

Teaching inquiry-based science is challenging. Strong SMK is necessary but not sufficient for affective teaching. Teachers also need knowledge that blends subject matter and pedagogy (Avraamidou & Zembal-Saul, 2010; Davis, 2006). Therefore, the construct of PCK was introduced in 1986 by Shulman. He conceptualized it as the knowledge of subject matter for teaching, including: 'the most powerful analogies, illustrations, examples, explanations, and demonstrations — in a word, the ways of representing and formulating the subject that make it comprehensible for others' (1986, p. 9). Shulmans' work led to a shift in understanding teachers' work such that research began to focus on understanding teaching from the teacher's perspective rather than focusing on evaluation and labelling of teachers and teaching behaviors. Many researchers responded to and further developed the notion of PCK (Grossman, 1990; Magnusson et al., 1999). Although PCK has attracted much attention, there is no universally accepted definition or conceptualization. Abell (2008) encourages researchers to use PCK more explicitly and coherently, grounded on Shulmans' original ideas about teacher knowledge, to frame their studies. Along with the working definition of PCK, we identified five components of PCK for science teaching, mainly drawn from the work of Grossman (1990) and Magnusson et al. (1999):

(1) orientations towards science teaching, (2) knowledge of curriculum, (3) knowledge of assessment, (4) knowledge of pupils' understanding of science and (5) knowledge of instructional strategies (Table 2.3). All categories are of interest to us, given that they are used to define elements of competencies required in order to teach primary science effectively.

2.4.2.1 Science PCK 1: Teachers' pedagogical design capacity. Lesson preparation and adaptation of curriculum

Teachers tend to prepare, carry out and evaluate lessons based on their beliefs about what good science education should involve. Thus, teaching starts with selecting and adapting curriculum materials (Forbes & Davis, 2010; Glynn & Winter, 2004; Marble, 2007). Forbes and Davis (2010), among others, use the concept of pedagogical design capacity (PDC) to make clear that teachers mobilize their knowledge, attitudes and beliefs, as well as science curriculum materials, to make pedagogical decisions that accomplish particular instructional goals in light of affordances and constraints of their professional contexts. According to researchers, three factors must be considered in order to do this successfully: first, the individual pupil's interests, strengths, experiences and needs; second, standard documents; and third, the context (Table 2.3). Several researchers address the topic of adapting science content and science instruction to the prior knowledge, experiences, learning style and interest of pupils. This involves making prior knowledge visible to identify pupils' (alternative) conceptions (Forbes & Davis, 2010; Isabelle & de Groot, 2008; Lee et al., 2004; Williams, Linn, Ammon, & Gearhart, 2004), gaining insight into pupils' general knowledge and its relation to scientific practices, and using these intersections as the basis for instructional practices (Amaral & Garrison, 2006; Cuevas et al., 2005; Weld & Funk, 2005). Teachers who possess a strong understanding of the Piagetian development model of intelligence are more likely to effectively use inquiry-based, learning cycle curricula (Luera, Moyer, & Everett, 2005). Furthermore, teachers who are aware of pupils' cultural and linguistic experiences in relation to science and who are committed to teaching for diversity do not accept inequities as a given condition (Lee et al., 2004, 2009).

A second factor to be considered in selecting and adapting curriculum materials is the aims mentioned in standard documents. To incorporate these successfully, teachers must be aware of national or curriculum standards (Davis, 2006; Glynn & Winter, 2004; Katz et al., 2005; Marble, 2007). On the one hand, these national goals might help the teacher in the search for clearly stated criteria to select content and didactic strategies. On the other hand, teacher might experience the contradiction between effective (inquiry-based) learning, which can be time-consuming, and adherence to standardized test, scheduled on the other (Bhattacharayya et al., 2009).

Thirdly, teachers who understand the constraints and limitations of the teaching context are better able to prepare high-quality lessons in which the available time is used most effectively. These constraints involve time, space, location and materials (Davis, 2006; Dietz & Davis, 2009; Howes et al., 2009). Forbes and Davis (2010) found that the adaptations teachers often made to curriculum materials were insertion of new elements and deletion of existing elements, in order to better support inquiry-based science instruction. Inversions, duplications and relocations were rarely used (Forbes & Davis, 2010) (Table 2.3).

2.4.2.2 Science PCK 2: Teachers' instructional strategies. Facilitating scaffolded inquiry

To create and support constructivist learning, teachers need to have sufficient understanding of the pupils' prior knowledge, including their experiences, prior learning and alternative conceptions or non-scientific ideas (Kang, 2007). To gain insight into the pupils' prior knowledge, they can discuss everyday events that pupils have observed and possibly have partial explanations for, thereby encouraging pupils to apply scientific concepts (Shymanski et al., 2004; van Zee et al., 2005). They can also ask pupils to use learned concepts to explain real-life situations before going on to new materials. Competent, experienced teachers see learning science as pupils changing their ideas into ones consistent with scientific concepts by means of learning activities that enable them to construct their own knowledge in synergy with their existing views (Cuevas et al., 2005). Teachers facilitate this process by asking divergent questions, representing and illustrating scientific facts and concepts and stimulating pupils to use these concepts appropriately while performing investigations (Howes et al., 2009; Lee et al., 2009; van Zee et al., 2005; Weld & Funk, 2005). They also facilitate this by giving four types of feedback during classroom discourse: affirmation instruction; responsive questioning (neutral response and follow-up questions); explicit correction and direct instruction; and constructive challenge (Oliveira, 2009). In order to promote student participation and engagement in science inquiry discussions, they can use oral strategies such as (parallel) repetition, figures of speech, colloquial language, humorous comments and rhetorical questions (Oliveira, 2010). In providing opportunities for pupils to explore their ideas and investigate questions, teachers may follow the model of science as practiced in the scientific community (Cuevas et al., 2005; Trundle et al., 2007). This model includes having the pupils question and predict; form explanations using evidence; and communicate and justify findings (Dietz &

Davis, 2009). With support from their teachers, pupils can take part in small group discussions about research questions and predictions, answers and explanations (Isabelle & de Groot, 2008; van Zee et al., 2005). Dialogic argumentation may help pupils realize that the claims of science are often contested and that knowledge that was once considered reliable can again become controversial (Van Aalst & Truong, 2011). However, pre-service teachers often prefer a whole class discussion, because that is easier to manage than small groups negotiating a question for inquiry (Cavagnetto, Hand, & Norton-Meier, 2011). When pupils are not accustomed to working collaboratively on problems, they might direct their energy into non-productive acting-out behavior, when teachers' classroom management practices are not supportive (Glynn & Winter, 2004). In effective inquiry-based science lessons, teachers assist pupils in making sense out of the data they collect, offer their pupils' explanations based on evidence, or analyze and evaluate pupils' alternative conceptions (Avraamidou & Zembal-Saul, 2005; Lee et al., 2004). This provides pupils with guided opportunities to discuss their understanding of the reasons for differences and similarities in data (Warwick & Siraj-Blatchford, 2006) using the right concepts, and between their predictions and the evidence. However, Howes, Lim, and Campos (2007) argue that this process does not happen automatically. In their research, teachers stated that helping their students how to do science and learn that they could be scientists were more important than learning specific scientific concepts. Thus, learning to do what scientists do did override concerns about content and learning specific scientific concepts.

Scientific inquiry context coupled with the teachers' divergent questions or visualizations of the pupils' thinking (including mistakes) can enhance meta-cognitive awareness (Liang & Richardson, 2009). Pupils are asked to explain their results using clear lines of evidence and reasoning (Amaral & Garrison, 2006; Dietz & Davis, 2009), and are thereby encouraged to improve their research skills (Katz et al., 2005; Lee et al., 2007) (Table 2.3).

2.4.2.3 Science PCK 3: Evaluation and assessment

The ultimate goal of evaluation and assessment is to stimulate pupils' meta-cognitive thinking. At the end of a science lesson, teachers can stimulate higher-level thinking by asking open, strategic questions and giving pupils the opportunity to raise questions themselves. These questions make pupils reflect on their learning process, and can achieve at least three aims. First, teachers' questions can help pupils create a bridge between their prior knowledge and the new evidence and information they have just acquired (Dietz & Davis, 2009; Isabelle & de Groot, 2008; Kang, 2007; Marble, 2007). Second, pupils can get an idea of how to transfer the acquired knowledge and investigation skills to other situations. By being asked questions, the pupils will become conscious of the reasoning process, which can help them become aware of the general aspects of their thinking and investigating. Teachers can help pupils transfer the newly acquired science concepts from the particular context of the classroom to other situations by asking for examples of applications in the pupils' real-world environment (Amaral & Garrison, 2006; Cuevas et al., 2005; Glynn & Winter, 2004; Weld & Funk, 2005). Finally, pupils are stimulated to connect new knowledge and understanding to the overarching science concepts (Amaral & Garrison, 2006). Teachers can use assessment to make their classroom practice more effective and efficient, by improving the preparation of the curriculum materials (Davis, 2006; Dietz & Davis, 2009; Forbes & Davis, 2010), their instructional strategies (Oliveira, 2009) and by changing their attitudes and beliefs about science teaching and learning (Bhattacharayya et al., 2009; Kim & Tan, 2010) (Table 2.3).

2.4.2.4 Science PCK 4 and 5: Teachers' knowledge of and attitudes towards science teaching and science learners and learning

A teacher's approach to science teaching is constructed at a deep level. Changing a teaching approach means examining beliefs and being open to a new identity as a teacher and as a learner (Volkmann & Zgagacz, 2004). Beliefs are created in the process of enculturation into a certain group and agreed upon as information that a person accepts to be true. Beliefs endure unchanged unless deliberately challenged (Hubbard & Abell, 2005). Studies have reported that teachers' beliefs and attitudes are connected to their SMK and the pedagogical and didactical skills they decide to apply in practice (Bhattacharayya et al., 2009; Hubbard & Abell, 2005; Kang, 2009; Leonard et al., 2009; Lewthwaite, 2006; Liang & Richardson, 2009). Attitudes stem from beliefs. An attitude is someone's mental state of readiness that has a dynamic influence upon his or her behavior (Spector, Burkett, & Leard, 2007). In the context of science education, teachers have knowledge of, beliefs about and attitudes towards (1) teaching science; (2) learning and learners of science; (3) the nature of science; (4) themselves as science teachers and (5) developing professionally in order to become better at teaching science. Following the definition of Shulman (1986) and the categories mentioned by Grossman (1990) and Magnusson et al. (1999), the first two (knowledge of and attitudes towards teaching science and learning and learners of science) are part of teachers' PCK (Table 2.3), the latter three are not (Table 2.4).

Many researchers studied attitudes towards teaching science and the role of a science teacher. Teachers who are enthusiastic about science and science education tend to promote science learning and understanding, and teach science more often compared to those who are negative about science (Weld & Funk, 2005). Three concepts about teaching science and the consequent practice can be found among primary school teachers worldwide. First, science education is viewed by many teachers as acquiring science literacy (Kim & Tan, 2010; Moseley, Ramsey, & Ruff, 2004). These teachers see science teaching as possessing and transmitting knowledge. A second group of teachers believes in giving learners a more active role and thus allowing them the excitement of finding things out for themselves. They perceive scientific inquiry as hands-on, or involving didactic demonstrations, but do not engage pupils in 'minds-on' learning (Lee et al., 2007). A third group of teachers believes in inquiry-based science lessons in which they engage their pupils with a question, have them participate in some kind of investigation and involve them in discussions of explanations derived in part from those investigations (Hubbard & Abell, 2005; Schwarz & Gwekwerere, 2007). However, some teachers believe that teaching science as inquiry is too complex to implement and manage within classroom practice because of time and material constraints. Others feel that science as inquiry is possible only with above-average pupils and, therefore, do not attempt to integrate inquiry into their regular education classrooms (Britner & Finson, 2005; Smolleck et al., 2006). Several researchers addressed the topic of beliefs about learners and learning. Teachers differ in seeing pupils as dependent on their teachers or as relatively independent; in seeing them as naturally inquisitive or unmotivated; in understanding the importance (or unimportance) of pupils' prior knowledge and assessment of learning; and in having high or low expectations of their pupils (Dietz & Davis, 2009; Moseley et al., 2004). The researchers argue that teachers should have confidence in pupils' abilities; otherwise they will not have the deliberate intention of making the pupils understand the content. In other words, teachers' beliefs influence their teaching. Often, their practices are congruent with their beliefs and attitude towards pupils. Avraamidou and Zembal-Saul (2010) conclude that supporting the development of teachers' PCK for scientific inquiry is no simple task; rather it is a difficult and complex activity, which requires the combination and interaction of a variety of learning experiences (Table2.3).

Table 2.3 Elements of teachers' PCK

PCK 1: Pedagogical design capacity – Lesson preparation and adaptation of curriculum
Science PCK 1-1 Teachers' understanding and response to an individual student's interests, strengths, experiences and needs in order to teach meaningful content and context (taking into account prior knowledge; cognitive developmental stage; learning style; interest and language level, caused by age, gender, socio-economic, cultural and/or linguistic background; formal science lessons and experience
Science PCK 1-2 Teachers' understanding and response to context: time, space, location, materials
Science PCK 1-3 Teachers' understanding and response to aims mentioned in standard documents
PCK 2: Facilitation of scaffolded inquiry
Science PCK 2-1 Teachers' ability to ask students to make their prior ideas explicit
Science PCK 2-2 Teachers' ability to ask (divergent) questions about facts and concepts; and encourage and help pupils to apply this knowledge
Science PCK 2-3 Teachers' ability to ask questions about appropriate use of research skills; and encourage and help pupils to apply this knowledge
Science PCK 2-4 Teachers' ability to stimulate discourse, debate and discussion in small groups about research questions and predictions, answers and explanations
Science PCK 2-5 Teachers' ability to discuss and/or visualise pupils' thinking (including mistakes) to generate class discussion in order to enhance meta-cognitive awareness
PCK 3: Evaluation and assessment
Science PCK 3-1 Teachers' ability to connect new knowledge and understanding to prior knowledge
Science PCK 3-2 Teachers' ability to connect new knowledge and understanding to real life context
Science PCK 3-3 Teachers' ability to connect new knowledge and understanding to the overarching science concepts
PCK 4 and 5: Attitudes towards science education
Science PCK 4 Teachers' attitudes towards teaching science
Science PCK 5 Teachers' attitudes towards learners and learning science

2.4.3 Cluster of underlying capabilities 3: Teachers' attitudes towards (nature of) science; Themselves as science teachers and professional development

Much has been written about the nature of science. A teacher can take a position on a continuum with two extreme epistemological attitudes: presenting scientific knowledge as given facts or presenting scientific knowledge as competing theories to evaluate in comparison with other ideas (Eick & Stewart, 2010; Ford, 2006; Kang, 2007). Baxter, Jenkins, Southerland, and Wilson (2004) concluded that teachers view science mainly as a product or as a process. Kim and Tan (2010) reported that pre-service teachers believed they needed to teach pupils the correct knowledge of science. As such, any teaching tools and activities need to aim at teaching correct scientific concepts, and any derivation from that would be unacceptable. According to these teachers' understanding, practical work challenged or even contradicted their images of good teaching. For that reason, they were reluctant to implement pupil-centered inquiry-based teaching and practiced teaching, which could be characterized as certainty and authority in knowledge.

Guerra-Ramos, Rijder, and Leach (2010) also studied teachers' ideas about scientists and their work, about scientific inquiry and about measurement. Within each of the three topics, teachers displayed views that were quantitatively different in terms of elaboration of ideas. The researchers identified three patterns in teachers' responses: limited, intermediate or extended contextualization. Teachers with limited contextualization showed a lack of discrimination and gave unclear examples, or no examples, combined with vague or no references to contextual elements in ideas about science. Teachers with an extended contextualization, on the contrary, showed more articulated and clearer responses, including discrimination of aspects related to science and inclusion of arguments recognizing diversity and complexity in ideas about science. Several studies have reported that teachers' epistemological understandings are connected to teaching practices (Kim & Tan, 2010; Lee et al., 2004).

Beliefs about one's self and one's role are based on outcome expectancy beliefs and self-efficacy beliefs. A low level of confidence among teachers about their own science teaching abilities (self-efficacy beliefs) has been well established by research (see for example Bhattacharayya et al., 2009; Dietz & Davis, 2009; Lee et al., 2004; Lewthwaite, 2006; Liang & Richardson, 2009; Luera & Otto, 2005; Spector et al., 2007; Weld & Funk, 2005). The impact of teachers' confidence on pupils' learning opportunities has also been shown by research. High levels of confidence may positively influence teachers' decisions to attend professional development sessions; devote the time necessary to ensure they are actively pursuing the professional development agenda and persevere when faced with a challenging situation (Lewthwaite, 2006). Jung and Tonso (2006) showed that teachers' confidence in their own ability to teach science has a positive impact on their effectiveness and behavior. Lack of confidence, on the other hand, might lead a teacher to limit time spent on science, select specific content themes, restrict classroom activities to simply 'following instructions' and inhibit creativity and questioning. Kim and Tan (2010) also reported that (pre-service) teachers with a limited repertoire of teaching strategies were vulnerable to not being ready or confident enough to deal with unexpected results that may appear during inquiry-based science lessons. This contributed to their anxiety and discouraged them from conducting practical work. Other teachers use coping strategies that enable them to influence their pupils' understanding, while enhancing their own conceptions, such as listening to their pupils and studying science literature.

The above-mentioned aspects of attitudes towards science, science teaching, science learners and learning (Table 2.3) and self-efficacy in teaching science influence the teacher as a learner (see Tables 2.4 and 2.5). Several professional development programs start with a focus on the teachers' current perceptions of themselves as teachers, in order to plan a path towards a goal for the future. This encompasses the image of teachers as potential role models or exemplars of practice (see for example Dietz & Davis, 2009). Epistemological beliefs about science and beliefs about good science teaching might also be an important part of training (Choy & Ramsey, 2009; Kang, 2007).

Most teachers believe that experience, theory or a mixture of both, combined with reflection, helps them to be better teachers (Moseley et al., 2004). Some teachers see learning to teach science as a lifelong process, while others view it as something that can be learnt in a limited period of time or never learnt at all—the latter are those, for example, who see themselves as 'not the science type' (Moseley et al., 2004; Weld & Funk, 2005). This belief of being able (or unable) to learn science and science teaching is dynamic and can be influenced by experiences and guided reflection (Luera & Otto, 2005; Spector et al., 2007). Personalization of science inquiry experiences helps teachers and student teachers realize that they can teach science, use scientific habits of mind and become sensitized to the role of inquiry in solving everyday problems. Approaches that address teachers' perceived problems of practice and serve as a bridge between reform-based goals and pre-service teachers' own goals and practices appear to advance the teachers' PCK (Schwarz, 2009). Becoming aware of using scientific habits of mind can help teachers and student teachers see that teaching science is similar to what they already can do. Helping them become reflective practitioners develops their self-efficacy regarding their ability to teach science and empowers them to teach science using inquiry.

Beliefs can persist even when, logically, they should not. Because teachers invest emotionally and intellectually in their beliefs, they seek to maintain them unless these beliefs are adequately challenged. Since each new experience is filtered through the lens of prior belief, individuals may turn conflicting evidence into support for their beliefs. Thus, the problem for teacher educators is to challenge firmly held beliefs that are often in conflict with the best practice literature (Hubbard & Abell, 2005). Kang (2007) suggests that there is need for long-term support for teachers' learning about conceptual change. Teaching experience does not necessarily bring expertise in science teaching for conceptual learning, thus pointing to the importance of providing ongoing professional development to stimulate teachers' connecting their experience to educational theory and research and teaching for conceptual learning in particular (Table2.4).

Table 2.4 Elements of teachers' attitudes towards science, themselves and professional development

Attitude 1- Teachers' attitude towards (the nature of) science
Attitude 2- Teachers' attitudes towards themselves as science teachers – self efficacy
Attitude 3- Teachers' attitudes towards professional development and becoming better at teaching science

2.4.4 Connected competencies

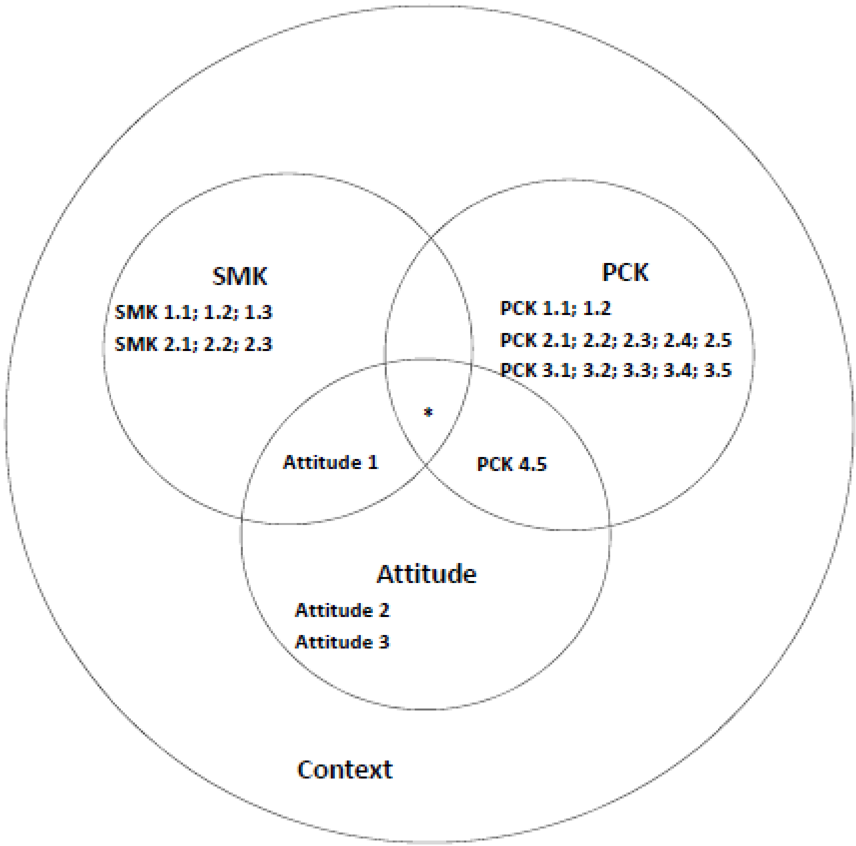
Elements of competencies, as described above, are connected in complex ways. Several researchers assert that teachers' high level of well-connected SMK has a positive influence on their pedagogical and didactical skills related to science (Lee et al., 2009). A well-organized SMK base also affects a teacher's interest in science (Leonard et al., 2009) and their self-efficacy beliefs (Bhattacharayya et al., 2009; van Zee et al., 2005). Higher self-efficacy beliefs contribute to teachers' motivation, commitment to student achievement and teaching performance (Liang & Richardson, 2009). Teachers with a higher self-efficacy also employ inquiry-based methods easier and more effectively in practice (Lee et al., 2009; Luera & Otto, 2005). Furthermore, attitudes towards teaching and learning science are expressed in whether or not teachers implement reform-based curricula (Eick & Stewart, 2010). Curiosity towards science can be a foundation for an investigative approach to learning (Leonard, 2009; van Zee et al., 2005) and teaching science (Eick & Stewart, 2010). However, Liang and Gabel (2005) could not find significant differences in attitudes towards science teaching between prospective teachers with strong content knowledge and those with weak content knowledge. It appeared that the learners' attitudes were influenced by multiple factors, such as their past science learning experiences, the perceived relevance of science to them personally and the discrepancy between the actual and their preferred learning environment. Their classroom practice was influenced not only by content knowledge but also by perceptions of what a good teacher is, of themselves as teachers, of science experiences and of the nature of science.

Research efforts to understand and reduce the complexity of teaching as well as to represent relationships between several teaching competency elements and enacted practice have generated a variety of models. Gess-Newsome (1999) visualized two models, which can be placed on a continuum. On one end, there is the so-called integrative model of teacher in which PCK does not exist and teacher knowledge can be explained by the intersection of three constructs: SMK, pedagogical knowledge and contextual knowledge. Teaching, then, is the integration of these three domains.

On the other end, PCK is seen as the synthesis of all knowledge required to be an effective teacher. In this perspective, PCK is the transformation of subject matter, pedagogical and contextual knowledge into a unique form that impacts teaching practice. Whether teacher knowledge is a compound as in the transformative model or a mixture as in the integrative model has implications for the definition of teaching expertise and competencies; identification and development of competency clusters and competency elements; and concrete implications for teacher preparation both in initial education and post-graduate training. In the transformative model, teachers possess PCK for all topics taught. PCK must be well structured and easily accessible for application. Following the integrative model, the knowledge bases of SMK, pedagogy and context are developed separately, but can best be integrated in the act of teaching. Based on this latter model, teachers are fluid in the active integration of knowledge, and knowledge bases can be taught separately or in a more integrated way. In both cases, teaching experiences are seen as reinforcing the professional development of teachers through the selection, integration and use of the knowledge bases, while in the integrative perspective, reflection on and in practice is also perceived as a source of professional development.

Since SMK and attitudes towards science and science teaching have a nurturing and reciprocal relationship with science PCK and enacted practice, we perceive PCK as a separate cluster, as in the transformative model. At the same time, there is evidence and support for separately developed clusters (attitude, SMK and PCK), which are integrated in practice. Based on our literature study, we combined the two perspectives discussed above and embedded them in context (Figure 2.2). Teacher competence is not fixed and in existence external to teachers. Their competencies influence one another and develop, stabilize or decline in a historical, cultural and organizational context.

Figure 2.2 Competence-based model of inquiry-based science teaching competencies.



Note: ∗Enacted practice

2.4.5 The American National Science Education Standards

The American NSES (NRC, 1996) outlines what knowledge and skills are needed for scientific erudition at different grade levels. It describes an educational system in which all pupils demonstrate high levels of performance and all teachers have sufficient knowledge to create powerful learning environments. The document presents a vision of communities of teachers and pupils who are focused on learning science and supported by educational programs and systems that foster achievement.

The intention of the document is to establish science standards for all pupils. The standards are based on the premise that pupils cannot achieve high levels of performance without access to skilled professional teachers, adequate classroom time, a rich selection of learning materials, accommodating work spaces and the resources of the communities in which their schools are located. Learning science is seen as something that pupils do, not something that is done to them. 'Hands-on' activities, while essential, are perceived as not enough. Pupils must have 'minds-on' experiences as well. Inquiry is believed to be central to science learning, and it is one of many different strategies that teachers need to use to develop their pupils' understanding and abilities to the required level. The standards provide criteria that people at the local, state and national levels can use to judge whether particular actions will serve the vision of a scientifically literate society. The aim is to bring co-ordination, consistency and coherence to the improvement of science education. The standards are divided into six categories: science teaching; professional development for teachers of science; assessment in science education; science content; science education programs and science education systems.

The specific standards for science teaching describe what teachers of science at all grade levels should know and be able to do. They are divided into six areas as described in the box below (Table 2.5).

Standards for professional development activities and goals involve learning science content through inquiry; integrating knowledge about science with knowledge about learners, pedagogy and pupils; and developing the understanding and ability for lifelong learning. The standards for science content are divided into unifying concepts and processes in science; science as inquiry; physical science; life science; earth and space science; science and technology; science in personal and social perspectives; history and nature of science.

Table 2.5 American National Science Education Standards: Science teaching

A. Teachers of science plan an inquiry-based science program for their students. In doing this, teachers: Develop a framework of year-long and short-term goals for students; Select science content and adapt and design curricula to meet the interest, knowledge, understanding, abilities, and experiences of students; Select teaching and assessment strategies that support the development of student understanding and nurture a community of science learners; Work together as colleagues within and across disciplines and grade levels.

B. Teachers of science guide and facilitate learning. In doing this, teachers: Focus and support inquiries while interacting with students; Orchestrate discourse among students about scientific ideas; Challenge students to accept and share responsibility for their own learning; Recognize and respond to student diversity and encourage all students to participate fully in science learning; Encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

C. Teachers of science engage in ongoing assessment of their teaching and of student learning. In doing this, teachers:
Use multiple methods and systematically gather data about student understanding and ability; Analyze assessment data to guide teaching; Guide students in self-assessment; Use student data, observations of teaching, and interactions with colleagues to reflect on and improve teaching practice; Use student data, observations of teaching, and interactions with colleagues to report student achievement and opportunities to learn to students, teachers, parents, policymakers, and the general public.

D. Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. In doing this, teachers:
Structure the time available so that students are able to engage in extended investigations; Create a setting for students work that is flexible and supportive of science inquiry; Ensure a safe working environment; Make the available science tools, materials, and technological resources accessible to students; Identify and use resources outside the school; Engage students in designing the learning environment.

E. Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers:
Display and demand respect for the ideas, skills, and experiences of all students; Enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community; Nurture collaboration among students; Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse; Model and emphasize the skills, attitudes, and values of scientific inquiry.

F. Teachers of science actively participate in the ongoing planning and development of the school science program. In doing this, teachers:
Plan and develop the school science program; Participate in decisions concerning the allocation of time and other resources to the science program; Participate fully in planning and implementing professional growth and development strategies for themselves and their colleagues.

(National Research Committee, 1996, p. 28; 30; 32; 37-38; 43; 45-46; 51)

2.5 Conclusion and discussion

In this section, we first summarize research findings of our literature review; then compare results of literature review with the American Science Teaching standards; third discuss the applicability of the American standards to the Dutch and European context; fourth reflect on the use of competence concept, fifth mention strength and weaknesses of this research and finally present implications for future practice and future research.

This article contributes to a theory of required competencies for inquiry-based science teaching. We found 22 elements of competencies for inquiry-based science teaching and divided them into the following clusters of competence underlying capabilities: SMK;

science PCK and teachers' attitudes towards themselves as science teachers and towards professional development (Table 2.4). To retrieve and transfer relevant information to appropriate situations teachers need well-connected and well-organized knowledge (Luera & Otto, 2005). Learning to teach inquiry-based science also involves clarifying, confronting and expanding one's ideas, beliefs and attitudes about science teaching and learning (Moseley et al., 2004; Volkmann & Zgagacz, 2004). Apart from strong SMK and a positive attitude towards (teaching and learning) science, teachers need knowledge that blends subject matter and pedagogy (Davis, 2006). Science PCK, as part of the science teaching competencies, helps teachers recognize that the knowledge required to teach science is different from the knowledge needed to teach other subjects. The danger with the PCK construct is that it could be seen as objectifying teaching so that the development of teachers' SMK, self-confidence and decision-making skills might be overlooked (Nilsson, 2008).

2.5.1 Comparison of literature review results and American National Science Education Standards

Several of the standards for science teaching correspond to competence elements dealing with PCK extracted from the articles. As mentioned above, 'PDC: lesson preparation and didactical skills and knowledge' (i.e. science PCK1) exists out of three aspects. The first 'teachers' understanding and response to individual needs' is similar to aspects of teaching standard A, that is to 'select science content and adapt and design curricula to meet interests, knowledge, understanding, abilities and experiences of students' as well as to aspects of standard E: 'Display and demand respect for the ideas, skills and experiences of all students'.

The second element of PCK, teachers' understanding and response to context: time, space, location, materials resembles aspects of standards D ('Teachers of science design and manage learning environments that provide pupils with the time, space and resources needed for learning science') and aspects of standard F ('Participate in decisions concerning the allocation of time and other resources to the science program').

The third element of PCK 1, 'teachers' understanding and response to aims mentioned in standard documents' might correspond with elements of standard F 'Plan and develop the school science program' although in the American Standard no limits are given by a prescribed national curriculum. In 2003, these were made more concrete, by the NSTA position statements of 2003, where goals for each level of education were proposed.

‘Facilitation of scaffolded inquiry’ (Science PCK 2) matches teaching standards B (‘Teachers of science guide and facilitate learning’) and D (‘Teachers of science design and manage learning environments that provide pupils with the time, space and resources needed for learning science’). Science PCK 2–1 ‘teachers’ ability to ask students to make their prior ideas explicit’ is a way to ‘recognize and respond to student diversity and encourage all students to participate fully in science learning’. Science PCK 2–2 ‘teachers’ ability to ask (divergent) questions about facts and concepts; and encourage and help pupils to apply this knowledge’ is a method to ‘recognize and respond to student diversity and encourage all students to participate fully in science learning’ as well as a way to ‘encourage and model the skills of scientific inquiry, the curiosity, openness to new ideas and data, and skepticism that characterize science’. Science PCK 2–3 ‘teachers’ ability to ask questions about appropriate use of research skills; and encourage and help pupils to apply this knowledge’ resembles ‘focus and support inquiries while interacting with students’. Science PCK 2–4: ‘teachers’ ability to stimulate discourse, debate and discussion in small groups about research questions and predictions, answers and explanations’ is comparable to ‘orchestrate discourse among students about scientific ideas’. Science PCK 2–5 ‘teachers’ ability to discuss and/or visualize pupils’ thinking (including mistakes) to generate class discussion in order to enhance meta-cognitive awareness is a way to ‘challenge students to accept and share responsibility for their own learning’.

‘Evaluation and assessment’ (Science PCK 3) is similar to teaching standard C (‘Teachers of science engage in ongoing assessment of their teaching and of student learning’). Finally, one element of teachers’ attitudes, namely, ‘attitude towards professional development’ is partly reflected in standard F (‘Teachers of science actively participate in the ongoing planning and development of the school science program’) while the majority of this capability is not described under the teaching standards but in a separate chapter on professional development for teachers of science.

The attitudes of teachers towards science learning are reflected in standard E: ‘Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers model and emphasized the skills, attitudes and values of scientific inquiry’. The attitudes of teachers towards science teaching (science PCK 4) are not mentioned explicitly in the American teaching standards, whereas these aspects of science PCK appeared repeatedly in our literature review.

Finally, teachers' attitudes towards themselves as science teachers (self-efficacy) and towards science are also missing in the American standards, while our review indicated that this aspect is interwoven with other science teaching competencies.

Applicability of American Standards in the Contemporary Dutch and European Context
We can conclude that the majority of the teaching-related American NSES are similar to the elements of teacher competencies found in the reviewed literature. Moreover, both the articles and the American standards emphasized the importance of research skills and competencies in the SMK of teachers.

Our research indicates that the American standards do not mention teachers' attitudes towards themselves as science teachers or their attitudes towards science and science teaching explicitly. We advise that these elements be added, since they do have an impact on teaching practice. This might encourage teacher educators to focus on these aspects and help primary school teachers reflect on their attitudes and gain insight into what helps or hinders their professional development.

Finally, the American standards are presented in a summative way. However, our research indicates that the competencies should be presented in an integrated and holistic way.

The gain of this study is that we can understand our own Dutch situation better, by getting some insight into the situation of USA. Success of implementing the revised American standards in the Dutch context depends on quality and innovative capacity of teacher training institutes, political, economic and cultural factors of the country. All professionals involved have to look for the best opportunities to take action and have effect (Abell, 2000). The question remains, can the outcomes be transferred to the context of Europe, despite the differences between the countries. To a certain extent European researchers and politicians can learn from their US colleagues concerning standardization of inquiry-based science teaching. For now, all European countries either have their own competence profiles or lack these documents. Convergence of competence profiles opens the opportunity to enhance cooperation between institutes in several European countries. On the other hand, there might also be a risk of standardization. In some European countries, competencies are viewed as discrete tasks, identified by functional analysis of work roles and do not take into account the context in which the competencies are applied. Because of the complexity and indeterminate nature of real-world situations, behavioural objectives can never be achieved in practice with the precision they offer in theory. The narrow competence approach might not help but even hinder improvement of the European science education, since research on implementation of innovations shows that success of innovations depends for a greater part on the attitude of those involved. We should recognize the connections between tasks; the meaning, intention and attributes that underlie performance of teachers; the effect of interpersonal and ethical aspects; and the context of performance. Standardization of a competence profile might improve European science education by increased collaboration of researchers and exchange of teachers and teacher educators between countries, despite variations of educational systems and society. We agree with Abell (2000) that although we must think globally (or continental) about the issues and values in science education, we must act locally to affect our particular context.

2.5.2 Reflections on the use of competence concept

The competence concept makes it clear that there are reciprocal relationships between the components, and that professional development of teachers in primary science education is a process of growth in applying a complex and contextualized set of competencies to specific problems in practice. It also illustrates that learning to teach science is not about acquiring a certain number of tricks based on a set of general pedagogical strategies, rewarded with a certificate at the end of that process. Knowledge and beliefs about science teaching and learning guide a teacher's instructional decisions about what content to teach, which instructional strategies and didactic materials to use, which assessment of pupils' learning to apply. Reflection during and on the science lesson can in turn confirm or change a teacher's underlying beliefs and knowledge lifelong.

In order to construct a teacher competence profile for primary level inquiry-based science teaching, we adopted Mulder's (2007) definition of competence as 'the integrated set of knowledge, attitudes and skills of a person' (Mulder, 2007) 'having a strong relationship with organizational effectiveness' (Mulder et al., 2006). This concept was helpful in finding sources that on the one hand provided insight into several aspects of inquiry-based science competencies and on the other hand were homogeneous enough to result in convergent findings. We found that elements of competencies are connected in complex ways. Several researchers assert that teachers' high level of well-connected content knowledge has a positive influence on their pedagogical and didactical skills related to science (Lee et al., 2009). Therefore, we suggest that the role of science PCK as part of teaching science and the role played by teachers' beliefs and attitudes in influencing their practice should be made more explicit in both the text and the organization of the science education standards. A non-linear, holistic, competence-based model can confront the separation and fragmentation of knowledge, skills and attitude and challenges its consumptions. Furthermore, a non-linear model can emphasize the dynamic character of education in which the teacher should have a pro-active attitude, taking into account the needs of the pupils and society as a whole. The use of hypertext and multimedia tools might facilitate a dynamic, representative model of connected, underlying capabilities of science teaching competencies.

2.5.3 Strength and weaknesses

One strength of this research is the systematic way in which it was conducted. Rather than using just one database, two were searched and the findings compared to obtain a larger and more varied set of articles. The keywords used to search for articles were logically derived from the definition of competence. We limited our search and analyses to the preceding seven years (2004–2011), because inquiry-based education is changing rapidly. The use of current publications minimized the risk of including articles based on an out-of-date concept of inquiry-based education and related inquiry-based competencies, or in which competencies are seen as fragmented and isolated aspects of behavior. Another strength is that through literature analysis and synthesis several elements of competencies were brought together and the relationships between these elements and between clusters of competencies were made explicit. A weakness of the literature study might be that all articles were treated equally, despite differences in the qualitative and quantitative methods of research applied and despite differences in the size of the respondent groups. We did not limit the size or kind of studies to be considered in our analysis, in order to find as many elements of competencies as possible and to be able to compare and look for commonalities in different studies.

2.5.4 Implications for future practice

Since the elements of competencies required to teach science successfully are so closely related, a teacher's strength or weakness in one may affect his or her mastery of others, and consequently classroom practice and student performance and success. In other words, the whole is more than the sum of its parts. This conclusion suggests that behavioral functionalism, in which skills training is seen as a way to acquire isolated teaching competencies, is not enough (Mulder et al., 2006). There is a need to go beyond only lecturing teachers on how to teach science and how to become science teachers (Moseley et al., 2004). Teachers have to also understand and respond to individual pupils' needs and to context variables such as available time, space, location and materials. Thus, even the integrated occupational approach, in which knowledge, skills and attitude are taught and learnt simultaneously, is not sufficient in preparing pre-service teachers for their future role. In order to learn, master and apply inquiry-based science teaching competencies in practice, situated professionalism might be the answer (Bhattacharayya et al., 2009). Instructional approaches, which merely advocate inquiry-based teaching without providing direct experience, seem to be insufficient and contrary to inquiry-based learning (Britner & Finson, 2005). From this point of view, competencies are mastered through integrated application in the classroom. It is important for pre-service teachers to build a strongly connected science content knowledge base as well as confidence during their initial studies. Teacher educators need to provide opportunities for pre-service teachers to examine, elaborate and integrate new knowledge and beliefs about teaching and learning into their existing knowledge and beliefs. If teacher training fails to help them build confidence, they might remain unfamiliar and uncomfortable with teaching inquiry-based science when they enter teaching professionally (Liang & Richardson, 2009). Exposure to effective science inquiry models in student teaching programs might partly tackle this problem, but it may not be enough to change the knowledge and beliefs of pre-service teachers. If student teachers only copy 'activities that work' (Appleton, 2003) they may end up teaching a fragmented curriculum; providing pupils with insufficient or inappropriate background information; and considering activities as isolated experiments with a predictable outcome, rather than adopting a (socio-) constructivist view, in which (collective) knowledge making is seen as the central point. To learn to implement the inquiry method, pre-service teachers need mentoring and support within the context of their internship (Moseley et al., 2004) and induction period as a starting teacher (Avraamidou & Zembal-Saul, 2010). Strong partnerships between teacher training institutions and primary schools might contribute to achieving this goal. Pre-service teachers can also gain SMK and PCK by studying independently or in post-academic courses; by reflecting on the images of inquiry within curriculum materials and within educational practice to add ideas to their repertoires, by integrating those ideas with others and by further developing their own identities as teachers (Dietz & Davis, 2009; Park Rogers, 2009). This could help reduce the anxiety often associated with teaching science (Moseley et al., 2004) and could address the concern of Appleton (2003) that only 'activities that work' will be implemented in science lessons. Discussions or assignments that encourage reflection among pre-service elementary school teachers might help teacher educators gain insight into what pre-service elementary teachers know about inquiry-based science teaching, what they think about it and what challenges they face in practice. Such an explicit and reflective approach could help teacher educators adapt the lessons of teacher training colleges to the needs of students.

2.5.5 *Implications for future research*

Discrepancies exist between what is recommended for inquiry-based science education and what is actually happening in practice (Kim & Tan, 2011; Vikström, 2008). Researchers have to consider and understand why teachers have not been using practical examples of inquiry regularly. Such understanding should then have an effect on research on classroom practice and the professional development of teachers. Explanations may lie in differences in how teachers and researchers perceive inquiry-based science education. Reducing the cultural barriers that hinder communication between science researchers, science lecturers in teacher training college and teachers is also an important task for policy-makers and for members of these communities, to be able to develop suitable and effective professional development and engagement systems.

More research is needed to further explore and develop common ground concerning inquiry-based education and required competencies, to gain insight into the relationships between different teaching competencies and their underlying capabilities, and to gain knowledge about the factors influencing the effectiveness of professional development programs. Teacher involvement in teacher preparation is essential. Teachers need a voice in the new establishment of new teacher entry standards and entry courses. Stakeholders, including teachers, should come together in context-specific groups (in terms of geographic location and targeted level of education) to find commonalities in their understanding of inquiry-based education and, ultimately, to define required teacher competencies. In further research, we will involve teachers, policy-makers and researchers in a discussion of specific primary school science education competencies for the Netherlands. We will conduct a Delphi study to examine whether the 22 selected elements of competencies related to SMK, attitudes and PCK are considered by experts to be sufficient to teach science effectively. Sequential questionnaires interspersed with summarized information and feedback derived from earlier responses will be used to develop an accurate, validated shared set of competencies.

Further studies are needed to gain more insight into the relationships between the clusters of underlying capabilities and the elements of competencies. So far, we have only found a limited number of studies about the relationships between SMK and didactical skills, between attitude and classroom practice and between SMK and attitude toward science teaching. It will be interesting to see how the elements of Science PCK, SMK and attitudes grow over time as pre-service teachers advance and progress through their careers. Furthermore, only limited research has been conducted to discover how professional development programs can be most effective in helping students acquire inquiry-based science teaching competencies. Further research is recommended to illustrate specific characteristics and components of effective teacher education programs that contribute to the development and use of teacher Science PCK. The following questions would therefore be interesting for future research. How do beginning teachers employ compensatory strategies to make up for their limited knowledge? What is the optimal set of experiences which will both inspire and enable teachers to be effective in inquiry-based science teaching? How do SMK, science PCK and attitudes influence each other? How can primary teachers develop science-related competencies in addition to (or in combination with) the many other competencies needed for teaching other subjects? Is the process of becoming an expert in science teaching a gradual, continuous and never-ending process or are there certain experiences in teachers' careers which are critical and a motor of sudden change in teachers' beliefs, attitude, knowledge and practices? Longitudinal studies of multiple cases should allow researchers to understand teachers' growth and the sources of growth of a teachers' competencies over time. Such research might be able to identify the variety of factors and conditions that help or hinder teachers in acquiring inquiry-based science teaching competencies and implementing inquiry-based teaching and learning in the classroom.

Chapter 3

Inquiry-based science teaching competence of primary school teachers: a Delphi study

This chapter is based on:
Alake-Tuenter, E., Biemans, H.J.A., Tobi, H., & Mulder, M. (2013). Inquiry-based science teaching competence of primary school teachers: A Delphi study. *Teaching and Teacher Education*, 35, (8), pp. 13-24.
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Abstract

Earlier, extracted inquiry-based science teaching competency elements and domains from the international literature were compared to the United States' National Science Teaching Standards. The present Delphi study aimed to validate the findings for the Netherlands, where such standards are lacking. Experts (N=33) were asked about the importance of 23 identified competencies. They confirmed the importance; proposed to add one competency and to differentiate between novice and experienced teachers. They suggested that teachers be provided with opportunities to integrate competence development regarding science knowledge, attitude and teaching skills throughout their career.

3.1 Introduction

During the past decade, considerable attention has been devoted to the improvement of primary science education. As a result of research advocating inquiry-based education, inquiry-based science teaching and learning has become a focus of policy documents (Luera & Otto, 2005; Akerson & Hanuscin, 2007; Dietz & Davis, 2009; Howes, Lim & Campos, 2009).

Nonetheless, research illuminates the many pedagogical, organizational and didactic difficulties teachers face in providing inquiry-based education (Kim & Tan, 2011). If teachers are convinced that inquiry-based science is more powerful than direct teaching, they need competencies in order to guide the inquiry process. Without these competencies, qualitatively poor or insufficient guidance and feedback might be offered during the discovery process, which is both less effective and less efficient (Kirschner, Sweller, & Clark, 2006).

However, recent formal agreement between professionals is lacking regarding what competencies teachers need to teach inquiry-based primary science (Kim & Tan, 2011). Alake-Tuenter, Biemans, Tobi, Wals, Oosterheert, & Mulder. (2012) identified twenty-three elements of competence. These competencies were categorized in the groups SMK elements, Pedagogical Content Knowledge (PCK) elements, and Attitude elements (Figure1). The purpose of this Delphi study was to determine the extent of agreement among experts on the importance of those previously identified competencies, and to distinguish between the importance of mastering these competencies for novice and for experienced teachers.

Two research questions were formulated in accordance with the research purpose:

1. To what extent do Dutch experts agree or disagree with the importance of inquiry-based science teaching competence elements as derived from the literature (Alake-Tuenter, Biemans, Tobi, Wals. Oosterheert, Mulder, 2012) and the United States' National Science Teaching Standards (NRC, 1996)?
2. According to experts, are there any differences between the importance of competencies for novice and for experienced teachers?"

Significant differences between novice and experienced teachers would suggest the need for continued competence development programs in the field of inquiry-based science teaching.

The process of formulating science teaching competencies, and the resulting competencies, are of value internationally. In America (NSTA, 2003; 2012), Australia and New Zealand (Kleinhenz & Ingvarson, 2007), England (Department of Education, 2012) and Sweden (Nilsson, 2008), groups are working on standards for the teaching profession and on describing the development of science teaching competencies. In New Zealand and Australia, the design process is democratic, including professional associations and employers (Kleinhenz & Ingvarson, 2007). In England, teacher standards are formulated by the Department of Education (2012). By involving different groups of professionals, this research aims to overcome the 'hierarchical structure' in which knowledge for teaching is generated at the university or a governmental body and then used in schools (Van Dijk & Kattmann, 2007; Wallace, 2012).

The study was undertaken in the Netherlands because The Netherlands lack inquiry-based science teaching standards although these standards are being discussed (Van Kuijck & van Keulen, 2010; Rohaan, Taconis & Jochems, 2010). The experts in the present Delphi study, work in the Dutch context: primary school children in the Netherlands are four to twelve years old; Dutch primary school teachers are generalists, who teach all subjects; and limited time is spent on science in Dutch primary (45 minutes out of a 25-hour lesson week) education (Martin, Mullis, & Foy, 2008).

3.2 Theoretical framework

3.2.1 Inquiry-based science education

Scientific inquiry generally refers to the diverse ways in which scientists study the natural world (Liang & Richardson, 2009). This view is also reflected in the widely cited description of the National Research Council: “a multifaceted activity that involves observations; posing questions, examining books and other resources of information to see what is already known; planning investigations; reviewing what is already known in the light of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations, and predictions; and communicating the results (NRC, 1996, p. 23). Inquiry-based education was born out of a blend of the works of Jean Piaget, Lev Vygotsky, and David Ausubel, with the philosophical nature of learning and teaching known as constructivism (Liang & Gabel, 2005). The constructivist approach emphasizes that phenomenology is constructed through active thinking, the organization of information, and the integration of existing knowledge. Teachers need specific inquiry-based science teaching competencies to support and facilitate student learning (Kirschner et al., 2006).

3.2.1.1 Subject Matter Knowledge (SMK)

SMK, also known as Content Knowledge (Shulman, 1986a; 1986b; 1992), encompasses the theories, principles, and concepts of a particular discipline that is to be learned and taught. SMK is the “amount and organization of knowledge *per se* in the mind of the teacher” (Shulman, 1986b, p. 13). SMK requires independent knowledge and understanding of facts and constructs, and the connections between facts and constructs of a discipline. Teachers must be aware that some ideas are more fundamental than others, some justify others, and some encompass others, as this enables teachers to know whether questions and hypotheses will lead to better understanding or confusion. In addition, teachers need knowledge about individual research skills (Akerson & Volrich, 2006), connected and applied. Teachers’ SMK strengths and weaknesses impact their classroom practices (Luera, Moyer & Everett, 2005). Compared to teachers with strong science SMK, teachers with weak SMK teach less science and choose paper-and-pencil exercises more often than inquiry-based science didactics (Kim & Tan, 2011). Fortunately, Akerson (2005) concluded that teachers developed their SMK through reading and talking with other teachers over time, allowing them to use less directive didactics.

Strong SMK is necessary but not sufficient for effective teaching: teachers also need knowledge that blends subject matter and pedagogical knowledge (Avraamidou & Zembal-Saul, 2010; Davis, 2006). Therefore, the transformation of SMK into PCK is a significant focus in teacher education.

3.2.1.2 Pedagogical Content Knowledge (PCK)

PCK was conceptualized by Shulman (1986b) as the knowledge of subject matter for teaching including: "the most powerful analogies, illustrations, examples, explanations, and demonstrations in a word, the ways of representing and formulating the subject that make it comprehensible for others" (p. 9). The key elements in Shulman's conception of PCK are (1) knowledge of representations of subject matter and (2) understanding of specific learning difficulties and pupils' conceptions. PCK is unique to teachers' professional understanding of blended content and pedagogy. Five components of PCK, drawn from the works of Grossman (1990) and Magnusson, Krajcik, & Borko (1999), were identified for science teaching: (1) knowledge of curriculum (2) knowledge of instructional strategies, (3) knowledge of assessment, (4) attitudes and beliefs about science teaching and (5) and attitudes and beliefs about pupils' understanding of science (Table 3.1). Park and Olivier (2007) reported the importance of teachers' understanding and practical implementation by taking into account contextual, cultural and social limitations in the learning environment. Davis (2003) concluded that, while pre-service teachers do have some knowledge of instructional strategies in an early stage of their studies, the other aspects of science PCK develop through extensive experience as a teacher.

3.2.1.3 Attitude

Attitude toward science and science education can be defined as the favorable or unfavorable feelings and beliefs about science as a learning and teaching subject. Attitude toward science and science teaching involves (1) the importance one attributes to science and to science teaching; (2) the experienced pleasure or anxiety; (3) the perceived nature of science; (4); teachers' sense of science teaching self-efficacy and (5) the attitude toward competence development. Teachers' self-efficacy is a specific aspect of science education attitudes and is seen as the belief that one is competent and capable as a teacher to perform in a certain manner to attain a certain set of goals. Teachers' sense of self-efficacy plays a major role in their classroom behavior, such as how they approach goals, tasks, and challenges (Bandura, 1997). It is related to teachers' motivation and efforts to develop their science teaching competencies, and it contributes to important pupil outcomes, such as pupils' self-efficacy beliefs, motivation and achievement (Tschannen-Moran, Woolfolk Hoy & Hoy, 1998; Liang & Richardson, 2009). In the American Science Teaching Standards (NRC, 1996), attitude does receive less attention than in international literature. While some researchers report no significant change of attitude over time as a result of practical experience with inquiry-based science teaching (Kang, 2007), others do (Bhattacharyya, Volk & Lumpe, 2009, Liang & Richardson, 2009) (Table3.1).

Table 3.1 Preliminary teachers' inquiry-based science teaching competence profile

SMK 1: Teachers' knowledge of facts and concepts related to living, technological and physical systems; earth and space systems; mathematical systems

1-1 Understanding of the meaning of isolated facts and concepts

1-2 Understanding of the relation between facts and concepts of:

- 1.2.1 different science sub-disciplines
- 1.2.2 the same science sub-discipline

1-3 Understanding of when and how to apply facts and concepts

SMK 2: Teachers' understanding of inquiry skills (Observe; pose questions and predictions; examine books and other resources of information to see what is already known; plan investigations; carry out investigations using tools to gather, analyze and interpret data; propose answers, explanations and predictions using data; communicate and justify results)

2-1 Understanding of the meaning of isolated research skills

2-2 Understanding of the relation between the research skills

2-3 Understanding of when and how to apply research skills

Science PCK 1: Pedagogical design capacity – Lesson preparation and adaptation of curriculum

1-1 Understanding and response to an individual pupil's interests, strengths, experiences and needs in order to teach meaningful content and context (taking into account prior knowledge; cognitive developmental stage; learning style; interest and language level related to age, gender, socio-economic, cultural and/or linguistic background; formal science lessons and experience)

1-2 Understanding and response to context: time, space, location, materials

1-3 Understanding and response to aims mentioned in standard document

- Ministry of education final curriculum goals for final year pupils (Kerndoelen)
- Detailed curriculum goals for each age group of primary school (Tussendoelen Stichting Leerplan Ontwikkeling)

Science PCK 2: Teachers' facilitation of scaffolded inquiry

2-1 Ability to ask pupils to make their prior ideas explicit

2-2 Ability to ask (divergent) questions about facts and concepts, and encourage and help pupils to apply this knowledge

2-3 Ability to ask questions about appropriate use of research skills, and encourage and help pupils to apply this knowledge

2-4 Ability to stimulate discourse, debate and discussion in small groups about research questions and predictions, answers and explanations

2-5 Ability to discuss and/or visualize pupils' thinking (including mistakes) to generate class discussion in order to enhance meta-cognitive awareness

Science PCK 3: Teachers' evaluation and assessment

3-1 Ability to connect new knowledge and understanding to prior knowledge
3-2 Ability to connect new knowledge and understanding to real life context
3-3 Ability to connect new knowledge and understanding to the overarching science concepts

Science PCK 4 and 5: Teachers' attitudes toward science education
4 Attitudes toward teaching science
5 Attitudes toward learners and learning science

Teachers' attitudes 1, 2 and 3
1- Attitudes toward science
- importance of science for society, pupils' daily life and environment, economy
- pleasure
- nature of science

2- Attitudes toward themselves as science teachers – self efficacy
3- Attitudes toward competence development of science and science teaching

3.2.2 Competence categories connected

Competencies are connected in complex ways. Teachers' competencies affect one another and improve, stabilize or weaken in the context of the workplace (Figure2 in Appendix). Researchers claim that teachers' high level of well-organized SMK has positive impact on their PCK and teaching for understanding (Lee, Maerten-Rivera, Buxton, Penfield, & Secada, 2009). Well-structured SMK also influences teachers' interest in science (Leonard, Boakes & Moore, 2009) and their confidence in teaching science (Bhattacharyya, et al, 2009). Additional self-efficacy contributes to teachers' PCK through enthusiasm, pupils' success, teaching performance (Tschannen-Moran, Woolfolk Hoy & Hoy, 1998; Liang & Richardson, 2009), and effective implementation of inquiry-based methods in practice (Luera & Otto, 2005). Curiosity toward science, as a way to express attitudes toward science, can be a foundation for an investigative approach to learning science (Leonard, et al., 2009) and teaching science (Eick & Stewart, 2010) and become part of teachers' PCK. Recently, several researchers have studied the relation of PCK (in terms of quantity and quality) to teacher practice (Loughran, Mullhall & Berry, 2008; Nilsson & Loughran, 2011) and to pupil learning (Hanuscin, Lee, Akerson, 2010; Rohaan, et al., 2010). They concluded that knowledge and beliefs about science teaching and learning guide a teacher's instructional decisions about the organization of activities, the content of pupil assignments, the use of textbooks, curricular materials, and the evaluation of pupil learning. They found that a well-developed PCK supports teachers to better align the content to be taught with pedagogy so that the content might be better understood by pupils. Abd-El-Khalick and Lederman (2001) concluded that there could be some connection between teachers' views on the nature of science and their conceptions of learning and teaching science. The relationship between teachers' Attitude, SMK, PCK and classroom practice is complex. Several variables mediate and moderate the translation of teachers' conceptions into practice, such as the pressure to cover content, classroom management and organizational principles; concern for pupil abilities and motivation; and institutional constraints (Abd-El-Khalick & Lederman, 2001). Figure 2.5 presents these complex links schematically.

3.3 Methods

The Delphi method is a process for investigating and developing agreement on subject matter where conclusive information is lacking. It is a group communication process, usually with controlled feedback, without face-to-face interaction among group members (Wiersma & Jurs, 2005). Respondents should be knowledgeable on the problem domain and remain mutually anonymous (Wiersma & Jurs, 2005; Bolger & Wright, 2011). Agreement and consistency are presumed to develop over the rounds and, in theory, the Delphi study is finished when a stopping criterion has been met. This section describes the research procedures used for this study.

3.3.1 Study design

In each Delphi round, respondents were asked to rate the items that contained the operational elements of inquiry-based science teaching competence on a five-point Likert scale (ranging from 1= very unimportant to 5= very important). Respondents were invited to clarify, to explain or to comment on their answers. After each round, the main researcher made a summary of the results including the comments and sent this to the respondents, together with the questions for the next round.

The maximum number of Delphi rounds was set at three. Many Delphi studies set a number of rounds in advance because the literature gives little guidance on when to stop. There is little information on the minimum level of agreement required and the agreement statistics to be used (Meijering, Kampen & Tobi, 2013). The choice for a new round and its content was based on the range of opinions and the comments of the respondents. To investigate whether respondents were consistent in their opinion, as a sign of seriousness, twenty-five items out of the first round reoccurred in the second round regardless of the (lack of) dispersion across respondents.

Means and standard deviations (SD) for each theme were used as proxy for the location and dispersion of the ratings (Tables 2 and 3). For an item to be classified as important, the mean needed to be equal to or higher than 2.5. An SD higher than 1.0 was interpreted as an indicator of poor convergence and a need for an additional round. Consistency or stability between two consecutive rounds was defined as a shift of one-third (33%) or less in respondents' ratings of one point on a scale of five. The experts were considered to agree on the importance of competence elements when the SD was lower than 1.0 and mean was higher than 2.5.

3.3.2 Respondents

Respondents were identified by two informants: a policymaker and a teacher trainer who also acts as a consultant in the area of primary science education. Each of the informants provided forty names. Respondents were sought to represent different expert groups: policymakers, researchers, implementation consultants and teacher educators, teacher coordinators in the field of primary science education. These expert groups share an interest in inquiry-based science education (competencies) at the primary level, acting as 'knowledge intermediaries' between science and community. Respondent groups were to reflect the heterogeneity of knowledge and opinions. Individual members of these groups were considered experts if they had a minimum of a bachelor's degree and five years of experience, and had published in a book or a peer-reviewed journal or presented at a conference. The size of each group of identified experts was reduced to 10-13 by identifying those mentioned twice, and by reducing the number of professionals with the same function and from the same organization to a maximum of two, while striving for diversity in gender and years of professional experience. These representatives were approached by the researcher, using e-mail and mentioning the informant.

Of the 60 experts approached, 33 (55%) responded in round one. Overall, participation declined per round (Table 3.2).

Table 3.2 Number of respondents representing five groups of experts

	Policy-Maker	Researcher	Teacher trainer	Consultant	Science Coordinator in primary school	N total	
Invited	12 / 20%	12/ 20%	13/ 22%	13/ 22%	10/ 17%	60	100%
First round	6	4	9	6	8	33	55%
Gender M/ F						20 /13	
Professional experience							
3-10 years						6	
10-15 years						6	
16-20 years						5	
>20 years						16	
Second round	1	3	7	2	4	17	28%
Third round	0	3	3	2	2	10	17%

3.3.3 Data collection

The first Delphi round contained questions on demographics and questions that dealt with the importance of three out of the twenty-two competence elements (Table 2 and Figure 4 in Appendix). The three competence elements chosen could be seen as conditionally for other competence elements. For example, understanding independent facts or constructs in isolation, is prerequisite for understanding connections between several facts or applying this knowledge in a context. Since each of the three competence elements contained five to eight sub-elements, over sixty questions were asked. This seemed to be the limit, as we were striving to achieve maximum response, and to prevent dropouts due to exhaustion. In order to avoid creating an unmanageably long question list, and thus to prevent respondents from quitting before answering all questions, we selected those three.

The results of round one were then summarized and fed back to the panel in round two. One newly included item in the second round scored lower than 2.5. This item was again included in the third round in order to confirm or deny this item's removal, from the competence list. An overview of items in each of the Delphi round can be found in Tables 2 and 3. Data collection took place between March 2010 and February 2011.

3.3.4 Data analysis

Results of the three Delphi rounds were summarized in descriptive statistics, words, and citations. The Wilcoxon matched pairs test was used to see if there were any statistically significant differences between the competence element ratings for novice and experienced teachers. Because of multiple testing, tests were considered significant at the 0.01 level.

3.4 Results

3.4.1 Competence importance for primary teacher groups

The expert ratings of the importance of the inquiry-based science teaching competence elements for primary teachers in the Netherlands can be found in Table 3.3. The panel reached agreement on the importance of proposed primary teachers' science SMK, and added one competence element. The panel members agreed on the importance of the proposed thirteen PCK elements. For both SMK and PCK, some competence elements were refined.

The importance of the competence elements of attitude toward science and science teaching was also agreed upon.

Table 3.3 Competence importance for teachers

Competence elements	Round* 1 Mean SD	2 Mean SD	3 Mean SD
SMK 1-1 Isolated facts and concepts	3.2 .7	3.2 .7	
SMK 1-2-1 Relation between facts and concepts of two sub-disciplines of science		2.9 .8	
SMK 1-2-2 Relation between facts and concepts of one sub-discipline of science			3.0 .8
SMK 1-2-3 Relation between facts and concepts of science and subjects other than sub-disciplines of science			3.1 .8
SMK 2-1 Isolated research skills	3.4 .5		
SMK 2-2 Relation between research skills			3.3 .8
SMK 2-3 Apply research skills		2.9 .6	
PCK 1.1 Design-Adaptation to individual pupils	3.5 .5	3.4 .6	
PCK 1.2 Design-Adaptation to context			3.4 .7
PCK 1.3 Design-Adaptation to curriculum			3.3 .9
PCK 2.1 Scaffolding- Inquire prior knowledge			3.4 .5

	Round*		
	1	2	3
Competence elements	**Mean SD**	**Mean SD**	**Mean SD**
PCK 2.2 Scaffolding-Ask questions about facts and concepts			3.6 .5
PCK 2.3 Scaffolding-Ask questions about use of research skills			3.4 .6
PCK 2.4 Scaffolding-Stimulate discourse			3.5 .5
PCK 2.5 Scaffolding-Discuss pupils' thinking			3.3 .7
PCK 3.1 Evaluation: Connect new knowledge to prior knowledge			3.4 .5
PCK 3.2 Evaluation: Connect new knowledge to real life context			3.7 .6
PCK 3.3 Evaluation: Connect new knowledge to science concepts			3.6 .7
PCK 5 Attitudes toward learners	3.0 1.0	3.2 1.2	
Attitude 1.1 Importance		3.1 .7	3.4 .9
Attitude 1.2 NOS			3.2 .6
Attitude 1.3 Pleasure		3.4 .7	3.5 .9

	Round*		
	1	2	3
Competence elements	**Mean SD**	**Mean SD**	**Mean SD**
Attitude 2 Self-efficacy		3.5 .6	3.3 .9
Attitude 3 Science teaching competence development		3.4 .6	3.3 .9

* Round 1 based on N=33, round 2 based on N=17, round 3 based on N=10

3.4.2 Competence importance for novice and experienced teachers

Respondents reported differences in the importance of required competencies for novice and experienced teachers on most SMK competence elements (Table3.4). Also with respect to PCK, differences were reported in the perceived importance. No statistically significant difference was reported in the reported importance of attitude toward nature of science.

Table 3.4 Competence importance for novice and experienced teachers

Group of teachers	**Novice**			**Experienced**		**P -value**	
Round	**1***	**2***	**3***	**1***	**2***	**3***	
Mean and Standard Deviation	**Mean** **SD**	**Mean** **SD**	**Mean** **SD**	**Mean** **SD**	**Mean** **SD**	**Mean** **SD**	
SMK 1-1 Isolated facts and concepts	3.0 .8	2.9 .7		3.3 .7	3.4 .7		.005**
SMK 1-2-2 Relation between facts and concepts of one sub-discipline of science			2.8 .8			3.3 .7	.04 *
SMK 2-1 Isolated research skills	3.2 .6			3.5 .5			.002**
SMK 2-2 Relation between research skills			3.1 .7			3.5 .8	.06
PCK 1.2 Design-Adaptation to context			3.7 .7			3.7 .7	1.0
PCK 1.3 Design-Adaptation to curriculum			3.0 .8			3.5 .6	.02*
PCK 2.1 Scaffolding-Inquire prior knowledge			3.2 .4			3.7 .5	. 046*
PCK 2.2 Scaffolding-Ask questions about facts and concepts			3.4 .5			3.7 .5	.16

Group of teachers	Novice			Experienced		P -value	
Round	**1***	**2***	**3***	**1***	**2***	**3***	
Mean and Standard Deviation	**Mean** **SD**	**Mean** **SD**	**Mean** **SD**	**Mean** **SD**	**Mean** **SD**	**Mean** **SD**	
PCK 2.3 Scaffolding-Ask questions about use of research skills			3.2 .5			3.6 .6	.058
PCK 2.4 Scaffolding-Stimulate discourse			3.2 .4			3.8 .4	.03*
PCK 2.5 Scaffolding-Discuss pupils' thinking			3.1 .8			3.4 .5	.18
PCK 3.1 Evaluation: Connect new knowledge to prior knowledge			3.2 .4			3.7 .5	.046*
PCK 3.2 Evaluation: Connect new knowledge to real life context			3.6 .7			3.9 .3	.18
PCK 3.3 Evaluation: Connect new knowledge to science concepts			3.3 .9			3.8 .4	.102
Attitude 1.2 NOS			3.2 .6			3.3 .7	.317

Round 1 based on N=33, round 2 based on N=17, round 3 based on N=10

* significance: $p \leq 0.05$

** significance: $p \leq 0{,}01$

3.4.3 Detailed results for SMK, PCK, and Attitude of teachers

3.4.3.1 SMK for all primary education science teachers

Respondents required a sixth-grade level for SMK of isolated facts and concepts on all subsystems of science (SMK 1.1). Reasons mentioned were that the knowledge was seen as a prerequisite for the ability to react to children's' misconceptions, to ask relevant questions and to feel confident in answering questions, and to recognize pupils' talents.

Competence elements on relations within and between science sub-disciplines were refined (see SMK 1.2.1 and SMK 1.2.2 in Figure 3 and Figure 4 in Appendix). The relation between earth and space systems and other systems was seen as not important. Relations within living systems were also seen as not important. A new competence element "Relation between facts and concepts of science and other subjects" was proposed in round 2 and partially confirmed in round 3. The respondents confirmed the importance of teachers' ability to relate science to history and language, but considered this as not important for handicrafts and drawing. SMK 1.2 was expanded accordingly (see Figures 3.5 and Table 3.4 in Appendix).

Of the SMK elements research skills, "isolated research skills" and "relation between research skills" (SMK 2.1 and SMK 2.2) were agreed on as important (Table2). The application of research skills (SMK 2.3) was considered not important. Respondents remarked that teachers ought to be able to evaluate pupils' research skills, but not necessarily be able to apply or demonstrate research skills flawlessly, especially manipulation.

3.4.3.2 PCK for all primary education science teachers

The experts suggested PCK refinements on the design of science lessons. All experts except for the consultants, agreed that the variables gender, social economic status and cultural background of pupils ought not result in design adaptations (PCK 1.1). One expert cited the fear of stereotyping as a reason. They did agree that differences in prior knowledge; cognitive developmental stage; learning style; interest and language level ought to lead to appropriate pedagogical action during class.

With respect to the design of lessons tailored to the national curriculum goals (PCK 1.3), the experts agreed that teachers need to know about both the general curriculum goals and the specific curriculum goals. These goals need not be memorized, but teachers should be able to consult them and adapt lesson design accordingly.

The importance of facilitation of scaffolded inquiry (PCK 2), is best illustrated by the respondent who added: “Asking good questions is possibly one of the most important skills. One needs to have adequate knowledge, meta-cognition, and transfer in order to understand what has been learned.”

3.4.3.3 Attitude for all primary education science teachers

The experts considered all attitude competence elements important. Nonetheless, importance of science (Attitude 1.1) was reduced from importance for society, economy and environment to importance for society and environment.

Table 3.5 Teachers’ inquiry-based science teaching competence profile

SMK 1: Teachers’ knowledge of facts and concepts related to living, technological and physical systems; earth and space systems; mathematical systems

1-1 Understanding of the meaning of isolated facts and concepts

1-2 Understanding of the relation between facts and concepts of:

- 1.2.1 different science sub-disciplines, except between earth and space systems and other systems
- 1.2.2 the same science sub-discipline, except within living systems
- 1.2.3 science sub-disciplines and other subjects

1-3 Understanding of when and how to apply facts and concepts

SMK 2: Teachers’ understanding of inquiry skills (Observe; pose questions and predictions; examine books and other resources of information to see what is already known; plan investigations; carry out investigations using tools to gather, analyze and interpret data; propose answers, explanations and predictions using data; communicate and justify results)

2-1 Understanding of the meaning of isolated research skills

2-2 Understanding of the relation between the research skills

2-3 Understanding of when and how to apply research skills, using a manual to support manipulation

Science PCK 1: Pedagogical design capacity – Lesson preparation and adaptation of curriculum

1-1 Understanding and response to an individual pupil’s interests, strengths, experiences and needs in order to teach meaningful content and context (taking into account prior knowledge; cognitive developmental stage; learning style; interest and language level)

1-2 Understanding and response to context: time, space, location, materials

1-3 Understanding and response to aims mentioned in standard document, with the standard document being available and accessible

- Ministry of education final curriculum goals for final year pupils (Kerndoelen)
- Detailed curriculum goals for each age group of primary school (Tussendoelen Stichting Leerplan Ontwikkeling)

Science PCK 2: Teachers' facilitation of scaffolded inquiry

2-1 Ability to ask pupils to make their prior ideas explicit

2-2 Ability to ask (divergent) questions about facts and concepts, and encourage and help pupils to apply this knowledge

2-3 Ability to ask questions about appropriate use of research skills, and encourage and help pupils to apply this knowledge

2-4 Ability to stimulate discourse, debate and discussion in small groups about research questions and predictions, answers and explanations

2-5 Ability to discuss and/or visualize pupils' thinking (including mistakes) to generate class discussion in order to enhance meta-cognitive awareness

Science PCK 3: Teachers' evaluation and assessment

3-1 Ability to connect new knowledge and understanding to prior knowledge

3-2 Ability to connect new knowledge and understanding to real life context

3-3 Ability to connect new knowledge and understanding to the overarching science concepts

Science PCK 4 and 5: Teachers' attitudes toward science education

4 Attitudes toward teaching science

5 Attitudes toward learners and learning science

Teachers' attitudes 1, 2 and 3

1- Attitudes toward science
   - importance of science for society, pupils' daily life and environment
   - pleasure
   - nature of science

2- Attitudes toward themselves as science teachers – self efficacy

3- Attitudes toward competence development of science and science teaching

3.4.4 SMK, PCK, and Attitude for novice versus experienced teacher

3.4.4.1 Details regarding SMK of novice and experienced teachers

Respondents agreed that the understanding of isolated facts and concepts (SMK 1.1), of the relation between facts and concepts of one sub discipline (SMK 1.2.2); of isolated research skills (SMK 2.1) and the ability to explain the relation between research skills (SMK 2.2) is not equally important for novice and experienced teachers. One respondent added to the latter one: "A curriculum developer should know and apply these relations, while a teacher should see to the understanding of her pupils, explain what is not clear, and stimulate pupils to apply their knowledge."

Table 3.6 Changes to the original elements of teachers' inquiry-based science teaching competence

SMK 1: Teachers' knowledge of facts and concepts related to living, technological and physical systems; earth and space systems; mathematical systems
1-2 Understanding of the relation between facts and concepts of:
Refined: 1.2.1 different science sub-disciplines, except between earth and space systems and other systems
Refined: 1.2.2 the same science sub-discipline, except within living systems
Added: 1.2.3 science sub-disciplines and other subjects

SMK 2: Teachers' understanding of inquiry skills
2-3 Understanding of when and how to apply research skills
Added: using a manual to support manipulation

Science PCK 1: Pedagogical design capacity – Lesson preparation and adaptation of curriculum
1-1 Understanding and response to an individual pupil's interests, strengths, experiences and needs in order to teach meaningful content and context (taking into account prior knowledge; cognitive developmental stage; learning style; interest and language level
Removed: related to age, gender, socio-economic, cultural and/or linguistic background; formal science lessons and experience)

1-3 Understanding and response to aims mentioned in standard document
Added: with the standard document being available and accessible

Teachers' attitudes
1- Attitudes toward science
Removed: importance of science for economy

3.4.4.2 Details regarding PCK of novice and experienced teachers

The rated importance of novice and experienced teachers' ability to adapt lessons to aims reported in documents differed (PCK 1.3).

Also the importance of the ability to ask pupils to make their prior knowledge explicit (PCK 2.1) and to stimulate discourse about research skills (PCK 2.4) differed between novice and experienced teachers.

The importance of experienced teachers´ ability to connect new knowledge to prior pupil knowledge (PCK 3.1) was rated of unequal importance for novice and experienced teachers. In contrast, no statistically difference was found for the importance of teachers´ ability to connect new knowledge to real life or to overall science concepts.

3.4.4.3 Details regarding Attitude of novice and experienced teacher

The Delphi panel experts expressed no significant difference in importance between novice and experienced teachers concerning the awareness of existing opinions, and their own, on the nature of science.

3.5 Conclusion and discussion

This Delphi study contributes to the identification of necessary competencies for inquiry-based science teaching: agreement on the core features of teacher competencies was reached for the Dutch setting, and differences and commonalities between these competences required for novice and experienced teachers could be identified. By involving different groups of professionals, this research aims to overcome the 'hierarchical structure' in which knowledge for teaching is generated at the university or a governmental body and then used in schools (Van Dijk & Kattmann, 2007; Wallace, 2012).

The US standards (NRC, 1996), international literature (Alake-Tuenter et al., 2012), and the respondents in this Delphi study view SMK and PCK as prerequisite for primary teachers of inquiry-based science. Elements of attitude receive more recognition in the international literature and the responses in the present study than in the U.S. standards.

According to the Dutch experts, facilitating science inquiry in primary classrooms is a complex enterprise, requiring many competencies of teachers. The Dutch experts may have been familiar with the work of Kirschner et al. (2006) in which evidence is provided for the assertion that teachers cannot assume pupils will have the same assumptions and thinking processes as a science professional. Experts were convinced that teachers' guidance is necessary during inquiry-based science lessons to ensure effectiveness and to prevent pupils acquiring misconceptions, or incomplete or disorganized knowledge. Experts agreed that teachers ought to use their well-developed SMK and PCK base to react to pupils' weaknesses with questions and instructions, in accordance with Luera, et al. (2005). Still, they expressed that teachers should be given the opportunity to enhance their SMK through science teaching experience, thus agreeing with Akerson (2005).

The reason for adding 'SMK integration with subjects other than the five science sub-disciplines' might be the relatively little time spent on science in Dutch primary classrooms (Martin et al., 2008). Involving history and language might enrich science lessons, preventing the teaching of fragmented and isolated facts (Appleton, 2003).

Respondents comply with the NRC (1996) definition of inquiry, involving planning investigations, and using tools to gather, analyze and interpret data. However, respondents indicated that teachers should not necessarily know how to manipulate and control an inquiry independently, and do not have to demonstrate all research skills flawlessly. As one of the respondents suggested, research skills can then be taught and learned by action and reflection, not by direct instruction. Another interpretation might be that teachers' books should themselves suggest several possible interventions.

Concerning PCK, respondents concurred that teachers should adapt lessons to their pupils, but did not reach agreement on designing lessons according to pupils' cultural and socio-economic background as Park and Oliver (2007) advocate. This does not mean, however, that causal factors are not important, or should not be better understood. Instead, respondents emphasized not the origin of pupils' differences, but the way these differences are expressed through different learning styles, interests, cognitive levels and prior knowledge, thus avoiding stereotyping.

The differences between the ratings of several SMK and PCK competence elements of novice and experienced teachers might be explained by the fact that experts realize primary teachers teach many subjects; science is one among many others taught in a week. TIMMS research (Martin, Mullis & Foy, 2008) concluded that primary science is taught an average of only 45 minutes per week in the Netherlands. According to Kim and Tan (2011), primary teachers are supposed to be subject generalists, requiring them to take into account SMK and PCK in many subject areas during the initial phase of their teaching. Subjects other than mathematics or languages might receive less attention in teacher training curricula. Experts might presume that teachers will develop professionally, mostly regarding PCK and SMK, by gaining more experience and by reflecting on these experiences, thus accepting that novice teachers might have a lower level than experienced teachers. In international research SMK and PCK are assumed to develop through practical experience, study, and teacher collaboration (Davis, 2003; Akerson, 2005).

The respondents concurred on adding several attitude elements not appearing in the American science teaching standards, but which do occur in international literature. A possible explanation is that research on attitude has gained increasing attention in recent years. Most respondents had likely read articles about research on attitudes toward science and science teaching, such as the works of Bandura (1997) and of Aavramidou and Zembal-Saul (2010). Experts might want to prevent a pervasive increase in negative attitudes toward science and an impoverishment of science in society, striving instead to promote advanced science literacy and more positive attitudes (NRC, 1996).

No significant differences were shown on the necessary attitude of novice and more experienced teachers. This is consistent with the findings by Kang (2007), suggesting that teaching experience does not necessarily change teachers' views on the nature of science and their epistemological understanding of pupils' learning. According to Liang and Richardson (2009), whenever teacher training fails to help novice teachers build confidence, these teachers might remain unfamiliar and uncomfortable with teaching inquiry-based science professionally.

3.5.1 Strengths and weaknesses

The Delphi study provides a well-established methodology for obtaining information from experts (Wiersma & Jurs, 2005; Bolger & Wright, 2011). Nonetheless, some general issues with response occurred. The response rate declined over rounds (as expected based on Bolger & Wright, 2011). Nonetheless, the heterogeneity of the Delphi respondent group was largely maintained. It should also be noted, that opinions as expressed in round one did not differ considerably from those in later rounds. Science coordinators in primary schools and teacher educators appeared to be more willing to explain their answers than other expert groups. We can only guess why policymakers did not volunteer any additional remarks and did not respond in the last round: they may have been too busy, less involved because the study will not impact their professional life, or have other opportunities to express their opinions and influence education. Bolger and Wright (2011), argued that decreased involvement and motivation might lead to poor quality of reasoning, or lack of comments and drop-out. Policymakers have opportunities to ventilate their opinions and to exert power that teachers and their trainers do not have. This study was one of the few opportunities for teacher trainers and teachers to share their opinions. The findings reported here provide a basis for other studies seeking to improve the relation between SMK, PCK and Attitude, or between competence elements.

3.5.2 Implications for future research and practice

Recommendations for future research are in line with Guerra-Ramos and colleagues (2010). They argue that much is to be gained by research that investigates teacher SMK, PCK, and attitudes toward science and science teaching and learning in situations closely connected to classroom practices. The critical issue is whether or not what is known (SMK and PCK) and believed (Attitude) is expressed while teaching. A question for future research is how teachers might be supported to develop knowledge, skills and attitudes that are relevant for a particular educational setting and how knowledge, skills, and attitudes support and contribute to each other. In the past, skills training of specific competencies trained independently, used to be the dominant model. It would be interesting to compare this model with a more integrated model of competence development, in which SMK, PCK and Attitudes are worked on simultaneously.

The findings of this Delphi study contribute to the professional development of teachers and teacher educators on the individual, organizational, and national (Dutch) level. Results from this study will be used to design assessment instruments to measure teachers' inquiry-based science teaching competencies, as proposed by Kelly and Staver (2005). The identified elements may assist teachers in analyzing and evaluating their actual competence. This will in turn help in setting up professional development inquiry-based science teaching programs for pre-service teachers. The competence profile might help teacher educators to reflect on the science curriculum in initial teacher training, implement competence elements not getting enough attention, and change the teaching approach for science courses. A competency list might also cause more transparency of expectations, reflected by professional licensing.

Dutch experts expressed the opinion that there is a difference in the importance of mastery of inquiry-based science teaching competence elements for novice and experienced teachers. This suggests that consistent support through ongoing, post-initial competence development is essential.

Supporting the development of teachers' attitude, SMK, and PCK for inquiry-based teaching is no simple task, but rather a complex activity. Ongoing professional development programs need to build on teachers' strengths and limitations, and should take into account the internal conflicts that teachers experience in their decision-making processes and classroom practices (Kim & Tan, 2010). Since the competence elements necessary to teach science successfully are so closely related, a teacher's strength or weakness in one may affect his or her mastery of others, and consequently also classroom practice and pupil performance and success. Skills training for teachers' SMK is not enough. There is a need to go beyond lecturing teachers on how to teach science and how to become science teachers (Kang, 2007; Mosely, Ramsey & Ruff, 2004).

There are several successful attempts to provide help to improve integrated science teaching competencies. An example is the New Zealand teacher support website (scienceonline.tki.org.nz/Nature-of-science).The present Dutch study contributed to this arena by providing an inquiry-based science teaching competence profile that distinguished between novice and experienced teachers.

Appendix 3.1 Labels, descriptions, number, examples and Cronbach's alpha of items

Label	Short label	Description	Number of items	Example of item	α
SMK 1.1	Isolated facts and concepts	Novice and experienced teachers' understanding of the meaning of isolated facts and concepts related to living, technological and physical, earth and space, and mathematical systems	5	How would you rate the importance of novice teachers' knowledge of isolated facts and concepts concerning physics?	N:.97 E:.96
SMK 1.2.1	Relation between facts and concepts of two sub-disciplines of science	Teachers' understanding of the relation between facts and concepts of different sub-disciplines of science (living, technological and physical, earth and space, and mathematical systems)	10	How would you rate the importance of teachers' knowledge of the relation between facts and concepts of the sub-systems physical and living systems?	T:.96
SMK 1.2.2	Relation between facts and concepts of one sub-discipline of science	Teachers' understanding of the relation between facts and concepts of one sub-discipline of science	5	How would you rate the importance of teachers' knowledge of the relations between aspects of living systems (such as respiration, circulation, digestion and or reproduction of humans, plants and animals)?	N:.98 E:.1.0
SMK 1.2.3	Relation between facts and concepts of science and subjects other than sub-disciplines of science	Teachers' understanding of the relation between facts and concepts of a science discipline (living, technological and physical, earth and space, and mathematical systems) and subjects, other than science	4	How would you rate the importance of teachers' knowledge of the relation between facts and concepts of science and language?	T:.91

Label	Short label	Description	Number of items	Example of item	α
SMK 2.1	Isolated research skills	Novice and experienced teachers' understanding of isolated research skills: observe; pose questions and predictions; plan and carry out investigations; use tools to gather, analyze and interpret data; propose answers, explanations and predictions using data; communicate and justify results	11	How would you rate the importance of novice teachers' knowledge and understanding of observing?	N:.92 E:.95
SMK 2.2	Relation between research skills	Novice and experienced teachers' understanding of relation between research skills: observe; pose questions and predictions; plan and carry out investigations; use tools to gather, analyze and interpret data; propose answers, explanations and predictions using data; communicate and justify results	2	How would you rate the importance of novice teachers' ability to explain to pupils the relation between research skills?	N.A.
SMK 2.3	Apply research skills	Teachers' understanding of when and how to apply research skills: observe; pose questions and predictions; plan and carry out investigations; use tools to gather, analyze and interpret data; propose answers, explanations and predictions using data; communicate and justify results	15	How would you rate the importance of teachers' ability to evaluate the research skills of children in an inquiry-based science lesson?	T:.92
Attitude 1.1	Importance	Teachers' understanding of the importance of science education for society, economy and pupils' life and environment	3	How would you rate the importance of teachers' awareness of the impact of science knowledge on society?	T:.68

Label	Short label	Description	Number of items	Example of item	α
Attitude 1.2	NOS	Teachers' awareness of the several existing opinions on the nature of science	2	How would you rate the importance of novice teachers' knowledge of different opinions about the nature of science, that is 'objective and related facts' versus 'ongoing, developing ideas'.	N.A.
Attitude 1.3	Pleasure	Teachers' pleasure while teaching science	1	How would you rate the importance of teachers' enjoyment in teaching science?	N.A.
Attitude 2	Self-efficacy	Teachers self-efficacy toward teaching science	1	How would you rate the importance of teachers having positive self-esteem concerning teaching science?	N.A.
Attitude 3	Science teaching competence development	Teachers' attitude toward science teaching competence development	1	How would you rate the importance of teachers' willingness to develop professionally in the area of science teaching?	N.A.

Label	Short label	Description	Number of items	Example of item	α
PCK 1.1	Design-Adaptation to individual pupils	Teachers' understanding and response to an individual pupil's interests, strengths, experiences and needs in order to teach meaningful content and context (taking into account prior knowledge; cognitive developmental stage; learning style; interest and language level, related to age, gender, socio-economic, cultural and/or linguistic background; formal science lessons and experience).	3	How would you rate the importance of teachers' ability to adapt lessons, taking into account pupils' intelligence?	T:.74
PCK 1.2	Design-Adaptation to context	Teachers' understanding of and response to context: time, space, location, materials	1	How would you rate the importance of teachers' ability to adapt lessons to context, such as available time, space or materials?	N.A.
PCK 1.3	Design-Adaptation to curriculum	Teachers' understanding of and response to aims reported in standard documents	4	How would you rate the importance of teachers' knowledge of content of the national curricular goals 'Orientation to yourself and the world (science)' written by the Ministry of Education?	N:.87 E:.70
PCK 2.1	Scaffolding-Inquire prior knowledge	Teachers' ability to ask pupils to make their prior ideas explicit	1	How would you rate the importance of teachers' ability to ask pupils to make their prior ideas explicit	N.A.

Label	Short label	Description	Number of items	Example of item	α
PCK 2.2	Scaffolding-Ask questions about facts and concepts	Teachers' ability to ask (divergent) questions about facts and concepts, and encourage and help pupils to apply this knowledge	1	How would you rate the importance of teachers' ability to ask (divergent) questions about facts and concepts, and encourage and help pupils to apply this knowledge?	N.A.
PCK 2.3	Scaffolding-Ask questions about use of research skills	Teachers' ability to ask questions about appropriate use of research skills, and encourage and help pupils to apply this knowledge	4	How would you rate the importance of teachers' ability to ask questions about appropriate use of research skills, and encourage and help pupils to apply this knowledge?	N:.90 E:.94
PCK 2.4	Scaffolding-Stimulate discourse	Teachers' ability to stimulate discourse, debate and discussion in small groups about research questions and predictions, answers, and explanations	1	How would you rate the importance of teachers' ability to ask questions about pupils' research questions?	N.A.
PCK 2.5	Scaffolding-Discuss pupils' thinking	Teachers' ability to discuss and/or visualize pupils' thinking (including mistakes) and to generate class discussion in order to enhance meta-cognitive awareness	1	How would you rate the importance of teachers' ability to discuss and/or visualize pupils' thinking (including mistakes) and to generate class discussion in order to enhance meta-cognitive awareness?	N.A.

Label	Short label	Description	Number of items	Example of item	α
PCK 3.1	Evaluation: Connect new knowledge to prior knowledge	Teachers' ability to connect new knowledge and understanding to prior knowledge	1	How would you rate the importance of teachers' ability to connect new knowledge and understanding to prior knowledge?	N.A.
PCK 3.2	Evaluation: Connect new knowledge to real life context	Teachers' ability to connect new knowledge and understanding to real life context	1	How would you rate the importance of teachers' ability to connect new knowledge and understanding to real life context?	N.A.
PCK 3.3	Evaluation: Connect new knowledge to science concepts	Teachers' ability to connect new knowledge and understanding to overarching science concepts	1	How would you rate the importance of teachers' ability to connect new knowledge and understanding to overarching science concepts?	N.A.
PCK 5	Attitudes toward learners	Teachers' attitudes toward learners and learning science	1	How would you rate the importance of teachers' willingness to aim for a realistic level of self-esteem for all children regarding science?	N.A.

T= Total group of teachers

N= Novice teachers

E= Experienced teachers

Chapter 4

Science teaching attitudes, self-efficacy, and SMK among first-year pre-service primary teachers

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Abstract

In the literature on science teaching, a relationship is observed between various teacher characteristics and science teaching. This study aimed to investigate the relationship between the Science Teaching Attitudes, S-SE Self-Efficacy (S-SE), Science Teaching Self-Efficacy (ST-SE), and SMK of pre-service teachers. Three teacher training institutes participated in the study. Based on the results from the first institute, informative hypotheses were formulated and then tested within the two other institutes. In total, 427 first-year pre-service teachers filled out a questionnaire designed to assess their Science Teaching Attitudes, S-SE and ST-SE. Scores on national tests were used as estimates of their SMK.

Results revealed that on average, pre-service teachers have positive attitudes towards science teaching. Their SMK of living and of earth and space systems is sufficient, while knowledge of physical, technological, and mathematical systems is lacking. ST-SE is positively associated with both S-SE and Science Teaching Attitudes. Generally, no relation was found between SMK and Science Teaching Attitudes, or with ST-SE. This suggests that increased SMK does not automatically result in more positive attitudes towards science teaching or to ST-SE (and vice versa). SMK, ST-SE and Science Teaching Attitudes each require attention during teacher training.

4.1 Introduction

Globally, teachers are required to prepare their pupils for a society in which science and technology have an increasing impact. Recently, attention has been focused on the improvement of science in primary and secondary education. Improving pre-service teachers' competence regarding attitudes towards science teaching (Johnston & Ahtee, 2006; Martin-Dunlop & Fraser, 2007) and their self-efficacy beliefs in teaching science (Bleicher, 2007; Liang & Richardson, 2009; Palmer, 2006; Yilmaz-Tuzun, 2008) have been of great concern. In our former literature study (Alake-Tuenter, Biemans, Tobi, Wals, Oosterheert, & Mulder, 2012), (Alake-Tuenter, Biemans, Tobi, & Mulder) and Delphi study, three competence domains were found to be collectively important for teacher effectiveness: SMK, Pedagogical Content Knowledge (PCK) and Science Teaching Attitudes. Pre-service first-year teachers' levels for these three domains, and the relation between them, were determined by questionnaire. In this article the results on SMK and Science

Teaching Attitude are reported; pre-service teachers' SMK and PCK will handled in our next article.

Over the last twenty years, there has been a trend of increased measurement of pre-service teachers' Science Teaching Attitude. Multiple factors are associated with attitudes. The understanding of the construct of Science Teaching Attitudes is still opaque. It is therefore important to first address the conceptions and definitions regarding Science Teaching Attitudes.

4.2 Theoretical framework

4.2.1 Science teaching attitudes

Scholars in the social and behavioral sciences, including the education and learning sciences, have conceptualized attitude as a complex, multidimensional construct (e.g. Ajzen, 2011; Osborne, Simons & Collins, 2003). This construct deals with an individual's prevailing tendency to respond with a positive or negative feeling to an object, people, institutions, events, ideas, and things (Bursal & Paznokas, 2006). Attitudes are relatively durable, are related to behavior, and can be learned and taught (Young, 1998).

Common definitions described attitude as including a cognitive, affective, and behavioral component (Johnston & Ahtee, 2006; Osborne, Simons & Collins, 2003; Palmer, 2001; Reid, 2006). The first of these components constitutes an individual's beliefs and perceptions regarding the knowledge about an object, whether accurate or not. In the context of this study, cognitive evaluation is seen as the value or importance a person assigns to science teaching for individual talent development, health, and society, and by the Nature of Science (NOS). The affective component is the emotional response that expresses an individual's preference and feeling towards the attitude object. Pleasure or anxiety occurs when confronted with objects, including science teaching (Bursal & Pasnokas, 2006). The behavioral component is a distinctive behavioral tendency of an individual, involving the action taken towards the object (Reid, 2006). It is expressed by the enactment in practice, and is involved in teaching, as well as the attendance or avoidance of competence development activities (Jang, 2004; Schibeci & Hickey, 2003).

4.2.2 Science self-efficacy and science teaching self-efficacy

Bandura defined self-efficacy as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (Bandura, 1997, p.3). Self-efficacy is a powerful predictor of behavior because these beliefs are ultimately self-referent in nature and directed toward specific tasks (Bandura, 1997; Palmer, 2006; Schoon & Boone, 1998; Weinburgh, 2007; Wenner, 1995). These beliefs are specific to particular sets of behaviors with two components: efficacy expectations and outcome expectations. Efficacy expectation represents the belief in one's capability of successful performance. Outcome expectation refers to the belief that performance will have certain outcomes. In the case of science, efficacy expectation refers to the pre-service teachers' beliefs about the extent of their own ability to perform science, while outcome expectation refers to the expectation that a test or assessment will be evaluated positively or negatively. In science teaching, efficacy expectation is defined as individuals' beliefs about their own ability to teach science, while outcome expectation refers to individuals' expectations that their own effective science teaching can influence student learning.

Teaching self-efficacy is context-specific: it varies according to the subject being taught, the pupils, and the setting (Tschannen-Moran & Woolfolk Hoy, 2007). The perception that successful past performance augments self-efficacy, or that failure diminishes it, may contribute to the probability that future performance will be proficient or inept (Bandura, 1997; Tschannen-Moran & Woolfolk Hoy, 2001). Howitt (2007) found that, in addition to evaluation of past performance, other factors also play a role in improving the Science Teaching Self-Efficacy of pre-service primary teachers: Pedagogical Content Knowledge, teacher educator, learning environment, reflection, and school placement.

Positive attitudes and self-efficacy should be shaped during pre-service teachers' initial education (Bleicher, 2007; Bursal & Paznokas, 2006). If teacher education fails to stimulate the development of positive ST-SE in pre-service teachers, they may feel incompetent at the start of their formal teaching career. However, the current number of carefully performed studies on the relation between Science Teaching Attitude, ST-SE, and SMK of pre-service primary teachers is limited.

The next section of this article contains a review of literature on the levels of Science Teaching Attitude, ST-SE, and SMK, and how these might affect science teaching practice. The possible relations between pre-service teachers' S-SE and ST-SE, their Science Teaching Attitude and their ST-SE, and their Science Teaching Attitude and their SMK are also discussed. The second section presents the methodology used for the empirical part of the present study. The third section presents the findings of the study. The final section includes discussion of the conclusions and implications for future research on positive-constructive attitudes of pre-service teachers.

4.2.3 Science teaching attitudes and science teaching practice

Educational researchers have shown that many pre-service and beginner teachers have problems with teaching science (Bursal & Paznokas, 2006). These teachers perceive science as a difficult subject and feel inadequately prepared to teach science (Tosun, 2000). Resistance to science and science teaching is common. Teachers tend to teach in the manner in which they were taught (Eiriksson, 1997; Palmer, 2001; Stuart & Thurlow, 2000). Since many pre-service teachers have not themselves been successful with science and have not had the opportunity to experience authentic scientific inquiry, they tend to use more direct didactical, rather than inquiry-based methods.

Teachers' attitudes play a critical role in their classroom practice, in the frequency, quality, and content of instruction. Primary school teachers with more positive attitudes toward science teaching tend to spend more time teaching science (Carleton, Fitch & Krockover, 2008; Wenner, 2001). They also utilize hands-on materials and inquiry-based instructional practices more often (Carleton, Fitch & Krockover, 2008).

4.2.4 Science teaching self-efficacy and science teaching practice

Several researchers in science education have examined pre-service teachers' ST-SE (Cannon & Scharmann, 1996; Cantrell et al., 2003; Enochs & Riggs, 1990; Haim, 2003; Huinker & Madison, 1997; King & Wiseman, 2001; Palmer, 2006; Plourde, 2002; Richardson & Liang, 2008; Tosun, 2000). These beliefs play a major role in how teachers approach goals, tasks, and challenges. Beliefs also influence the teaching strategies they use, and the amount of time they teach science (Martin, Mullis & Foy, 2008). Several studies have suggested that pre-service teachers' ST-SE is important in determining the quality of science taught to pupils (Schoeneberger & Russel, 1986; Weinburgh, 2007). Teachers who do not believe in their ability to teach science (low self-efficacy) are more likely to avoid science instruction than teachers with high self-efficacy (Bandura, 1997; Enochs, Scharmann & Riggs, 1995). Pre-service teachers with high ST-SE behave in a self-confident manner, and are more likely to master rather than avoid science teaching. Pre-service teachers with low ST-SE tend to be authoritarian and teacher-centered, and they tend to have a less clear understanding of the development levels of their pupils than those with high self-efficacy (Ajzen, 2002).

Lumpe and colleagues (2000) found that teachers with high ST-SE implemented inquiry-based activities, whereas teachers with low ST-SE transmitted knowledge through a fact-based curriculum in a directive manner. Pre-service teachers with a high ST-SE also seemed to invest more effort in setting goals and developing aspirations, to exhibit greater levels of planning and organizational behavior, to be more open to new ideas, and to be more willing to experiment with new methods that better meet the needs of pupils (Akinsola, 2008; Tschannen-Moran & Woolfolk Hoy, 2001).

Even though positive self-evaluation, including biases, are widely thought to be beneficial, there is a growing literature discussing their potential costs. Wheatley (2002), for example, asserts that teacher doubts can have valuable bearing on continued competence development and educational reform. Beside, in contexts requiring self-regulated learning, accurate or realistic evaluations of one's own competences are considered an important prerequisite for meaningful learning and effective goal setting (Narciss, Koerndle & Dresel, 2011).

4.2.5 Science self-efficacy and science teaching self-efficacy

In several studies, S-SE and ST-SE are mentioned in one breath, most often by indicating that both of them fall short. Spector, Burkett and Leard (2007) reported that all pre-service teachers learning science, and learning to teach science, might progress through the same stages, such as strong emotion, resistance, surrender, and acceptance. Gunning and Mensah (2010) assume that people who excel in school science enter hard science fields or teach secondary school science. They presume that most pre-service primary teachers have had negative experiences with science learning, or a lack thereof, and thus shy away from science and science teaching. However, both S-SE and ST-SE seem to be complex constructs, and influenced by many factors (Andersen, Dragsted, Evans & Sorensen, 2004; Howitt, 2007; Mulholland, Dorman & Odgers, 2004). Bursal and Paznokas (2006) recommend new studies to examine the relation between pre-service teachers' science anxiety and its role in teaching. This leads us to the question: how are pre-service teacher S-SE and ST-SE related?

4.2.6 Pre-service teachers' science teaching attitudes and science teaching self-efficacy

Pre-service teachers with high ST-SE exhibited greater pleasure and enthusiasm for teaching science (Czerniak & Lumpe, 1996), had greater commitment to teaching, and were more likely to stay in teaching (Akinsola, 2008; Tschannen-Moran & Woolfolk Hoy, 2001). Teachers who possessed positive ST-SE tended to show more commitment by engaging in competence development activities when faced with challenging situations (Schibeci &

Hickey, 2003). Thus, ST-SE may serve as a barrier or an accelerator for pre-service teacher science teaching. Smolleck and Mongan (2011) conclude that an area warranting further consideration is the notion of varying types of self-efficacy supporting or inhibiting a positive attitude towards teacher competence development. They also recommend researching the priority science is given by teachers in relation to self-efficacy. In this study the relation between Self-Efficacy and Science Teaching Attitudes (importance, pleasure, and tendency to participate in competence development activities) is investigated.

4.2.7 Subject Matter Knowledge

SMK, also known as Content Knowledge (Shulman, 1986a; 1986b; 1992) encompasses the theories, principles, and concepts of a particular discipline that is to be learned and taught. SMK is the "amount and organization of knowledge per se in the mind of the teacher" (Shulman, 1986b, p. 13). SMK requires knowledge of both substantive structure (facts and their organizing principles) and synthetic structure (legitimacy principles for the rules) of a subject domain. In the case of science, this means knowledge and understanding of various areas: physical, life, earth and space, technological, and mathematical systems (National Research Council, 1995) and of investigation skills (Akerson & Volrich, 2006). Teachers should be aware that some ideas are more fundamental than others, some are needed to justify others, and some compass others, enabling them to know whether questions and hypotheses will lead to better understanding or to confusion. Deep and complex understanding of science involves: 1) memorizing and understanding factual information and concepts; 2) understanding the relationships between those concepts; and 3) knowing when and how to apply them in context (Glen & Dotger, 2009). Teachers' strengths and weaknesses in SMK impact their classroom practice. Strong SMK is necessary but not sufficient for effective teaching. Teachers also need knowledge that blends subject matter and pedagogical knowledge (Davis, 2006).

4.2.8 Problem definition

Intuitively, one would expect a positive relationship between level of knowledge and ST-SE. Yet evidence for such a relationship is not consistent. Wenner, for example, found a negative relationship between science knowledge and attitudes toward teaching in his study of 1993, but the follow-up study of 1995 failed to support the initial results. Moseley and Utley (2006) found that a content-based science course had a positive effect on pre-service teachers' ST-SE. However, Howitt (2007) reported that SMK was perceived by pre-service teachers to have limited influence on their ST-SE. Luera and Otto (2005) concluded that USA students who took more than one revised, innovative content course, improved their science SMK and ST-SE significantly. Johnston and Ahtee (2006) compared British and Finnish pre-service teachers' attitudes, subject knowledge and pedagogical content knowledge in a physics activity. Their results indicated that the teaching of physics activities was rated unpopular, with negative attitudes towards physics teaching among the Finnish group. The attitudes of the British group, however, were more positive; this was attributed to been taught chemistry, biology, and physics at least to the age of sixteen. Bleicher (2007) and Yilmaz-Tuzun (2008) examined changes in personal ST-SE and science SMK of pre-service teachers. Both increased significantly during pre-service participation in a science teaching methods course. Their results suggest that there may be important connections between SMK and ST-SE of pre-service teachers. Rohaan (2009) studied the relation between Dutch pre-service teachers' technology SMK (as part of the five science systems) and their ST-SE. She found a positive relation between the two. To the best of our knowledge, the relation between SMK on all five science systems (living, earth and space, physical, technological, and mathematical systems) and attitudes towards science teaching has not been studied among pre-service primary student teachers in the Netherlands. The purpose of this study was to determine the relation between pre-service teachers' science SMK and their Science Teaching Attitude and ST-SE. This is internationally relevant because the Netherlands is one example of education at the bachelor's degree level, and of teaching all primary school subjects (as in New Zealand and the USA). The research results can be compared to other countries where the teaching degree is offered at the master's level (as in England, Finland, and Germany) and to pre-service teachers studying two or three subjects in depth (as in Australia, China, and Denmark).

The current study aimed to help clarify the relations (if any) between these constructs by using a sample of Dutch pre-service primary school teachers. The focus of research in the present study are science teaching attitude elements (importance, pleasure, and tendency to competence development), S-SE and ST-SE, and the SMK elements of pre-service teachers in their first year of study.

The research questions are:

1. What characterizes first-year pre-service teachers' Science Teaching Attitudes, Science Self-Efficacy (S-SE) and Science Teaching Self-Efficacy (ST-SE), and their science Subject Matter Knowledge (SMK)?
2. Is there an association between a) first-year pre-service teachers' Science Teaching Attitudes, (consisting of pleasure, importance, and competence development) and b) their Science Teaching Self-Efficacy beliefs (ST-SE)?
3. What is the relation between pre-service teachers' Science Self-Efficacy (S-SE) and Science Teaching Self-Efficacy (ST-SE)?
4. What is the relation between a) pre-service teachers' science Subject Matter Knowledge (SMK) b) their Science Teaching Attitudes (pleasure, importance, competence development) and c) their Science and Science Teaching Self-Efficacy (S-SE and ST-SE)?

4.3 Methods

4.3.1 Context of the study

Institutes

Each of the three Dutch institutes involved in this study is a mono-sector university of professional education that offers a four-year Bachelor's program in primary teaching. All students must meet the same entrance criterion: possession of a diploma from a five-year intermediate-level secondary school. Graduates from all three institutes are qualified to teach all primary education subjects except physical education, to children four to twelve years of age. The institutes are geographically spread and have a Catholic or protestant denomination.

Participants

Participants in the study are 427 first-year pre-service teachers at three different teacher training institutes in the Netherlands (Table 1). All of them are primary education majors. The majority of the students is female (Table 1).

4.3.2 *Data collection*

Primary science teaching instructors at three teacher training institutes were invited to participate in this research study. The instructors provided the researchers with their students´ results on the national CITO tests on mathematics, living, physics, technology, earth and space systems. The instructors allowed the first author to collect the data on attitudes towards science teaching by administering a questionnaire, in regular science class meetings, in January and February 2013. Those months, after half a year of study, were chosen to ensure that all of the participants were familiar with the vocabulary concerning inquiry-based science teaching. After having explained the purpose of the study and the benefits of participation to the pre-service teachers, the researcher administered the questionnaire in two classes, in the presence of the instructor. The instructors then introduced and administered the questionnaire to their remaining classes. Pre-service teachers voluntarily completed the questionnaire by paper and pencil. Although there was no time limit, completion of the questionnaire took approximately 30 minutes.

4.3.3 *Instrumentation*

Science attitudes were measured by means of part of the Oberon instrument also known as Dimensions of Attitude towards Science and Technology (DAST). The instrument was developed by Dutch researchers after an extensive review of literature and scales used in various educational contexts (Walma-Van der Molen, Wiegerinck & Rohaan, 2007). The original DAST has been stated to be a reliable, valid instrument useful in determining attitudes towards science teaching in primary schools (Rohaan, Taconis, & Jochems, 2010). For the present study, the length of the instrument was reduced while the content validity of the original instrument was retained. In line with previous work, we selected items of the DAST instrument on science teaching attitude to represent the three components: inquiry-based science teaching pleasure (5 items), importance (6 items), and tendency to develop science teaching competences (7 items). The 5-point Likert-type items showed the answer categories: strongly agree, agree, undecided, disagree, and strongly disagree.

To measure S-SE, 4 items of the science Student Teachers' Attitudes Towards Science instrument were used (STATS, Young, 1998). A selection of 8 ST-SE items was made: 5 from the Science Teaching Efficacy Belief Instrument (STEBI, Enochs & Riggs, 1990) and 3 from the DAST instrument. Selection was based on a broad concept of science teaching, including preparation, implementation, and evaluation of inquiry-based teaching, to motivate pupils and to support their understanding. The questionnaire ended with questions on demographics.

First, three independent science education lecturers gave written feedback on the items, in terms of selected topics and pupils' age mentioned in the ten cases, in relation to the national curriculum. They also reviewed the four answer options critically on the extent of being sufficiently distinctive. After some revisions, a team of three science education researchers discussed the selected items in terms of both wording and content validity, and agreed upon the final selection and formulation of the items. The questionnaire was pilot tested on 118 first-year pre-service teachers from one Dutch teacher training institute in January 2011 and then adapted and tested again on 124 first-year pre-service teachers in October 2012. As an indicator for internal consistency reliability, Guttman's Lambda 2 was used for each construct (Sijtsma, 2009). For importance, pleasure, tendency towards development of competencies, S-SE, and ST-SE, Lambda 2 was considered sufficient (Table 4.1). As the reliability of the Nature Of Science scales was considered too low (with λ_2=.48 for NOS1 and λ_2=.59 for NOS2), it was decided to disregard Nature of Science in this study.

Table 4.1 Lambda 2 of Attitudes and Self-Efficacy items of each institute

Institute	**Science Teaching Attitudes**			**Self-efficacy**	
	Pleasure	**Importance**	**Competence development**	**S-SE**	**ST-SE**
Pilot test (n = 133) 9 missing	.68	.59	.77		.77
1 (n = 133) 0 missing	.61	.58	.78	.78	.82
2 (n = 157) 3 missing	.76	.75	.81	.87	.83
3 (n = 137) 0 missing	.69	.69	.79	.87	.80

The SMK level for mathematics, living, physics and technology, earth and space systems, was assessed in national CITO tests. The mathematics test consists of 200 questions and is tailored in character: the questions offered are adapted to the performance on the previous questions. For the domain physics and technology there are 15 items; for living systems, 30 items; and for earth and space systems, 16 items were asked. SMK levels are expressed by the percentage of correct answers.

4.3.4 Data analysis

First, descriptive statistics were calculated. Then, two-tailed hypotheses were tested on the institute for which data was first completed (here referred to as institute 1). As appropriate, more informative one-tailed tests were formulated and tested on institutes 2 and 3. In this way, the availability of three participating institutes was optimally used: the risk of finding artifacts due to multiple testing without recognizing them as such is reduced, while variation between institutes is acknowledged. Please note that a multi-level analysis is inappropriate in cases such as this one, where the number of schools is too low (Snijders & Bosker, 2012).

Generally, the Pearson correlation coefficient was used to test for associations. Statistical tests were regarded significant with $p \leq 0.01$.

4.4 Results

On average, pre-service teachers agreed with the statement that science teaching is important, and they evaluated their experience of science teaching as pleasurable. However, they were neutral regarding their inclination to engage in competence development (Table 4.2).

Table 4.2 Means and standard deviations of Attitude components per institute

Science Teaching Attitudes						
Institute	**Pleasure (scale 1-5)**		**Importance (scale 1-5)**		**Competence Development (scale 1-5)**	
	X	**SD**	**X**	**SD**	**X**	**SD**
1 (n = 133) 0 missing	3.9	.50	3.9	.43	3.3	.54
2 (n = 157) 3 missing	3.7	.59	3.7	.53	3.0	.59
3 (n = 137) 0 missing	3.9	.56	3.9	.48	3.3	.57

On average, pre-service teachers scored “undecided” when they were asked the extent to which they agreed with positive expectations, expressing S-SE and ST-SE. The standard deviation of S-SE was high, which means that there is a large variation in how pre-service teachers esteemed their science competencies (Table 4.3).

Table 4.3 Means and standard deviations of Science Self-Efficacy (S-SE) and Science Teaching Self-Efficacy (ST-SE) per institute

Institute	**Self-efficacy (SE)**			
	Science –SE (Scale 1-5)		**Science Teaching-SE (Scale 1-5)**	
	X	**SD**	**X**	**SD**
1 (n = 133) 0 missing	2.9	.87	3.2	.49
2 (n = 157) 5 missing	2.7	1.09	3.1	.64
3 (n = 137) 9 missing	2.7	1.06	3.0	.51

Approximately half of all pre-service teachers passed the SMK test of living, physics and technology systems. Their mean score is below the pass mark of 67%. About two third of the respondent group passed the Earth and Space SMK test. The mean score of two out of three institutes is above the pass mark of 67%, while the mean score of the respondents of one institute is below the pass mark. Finally, less than half of the respondent group passed the mathematics test. The mean score of two out of three institutes is above the pass mark of 51.5%, while the mean score of one institute is below the pass mark (Table 4.4).

Table 4.4 SMK test results per institute

	SMK test results					
	Living, Physics, and Technology		**Earth and Space**		**Mathematics**	
Institute	**% Pass** **% missing**	**Mean score** **(n, SD)**	**% Pass** **% missing**	**Mean score** **(n, SD)**	**% Pass** **% missing**	**Mean score** **(n, SD)**
1 **N = 133**	50.4 18.0	65.0 (109, 17.5)	67.7 0	69.4 (133, 15.3)	57.1 10.5	56.1 (119, 12.6)
2 **N = 157**	41.9 1.9	64.2 (154, 9.5)	56.3 1.9	65.1 (154, 15.2)	15.6 47.5	49.6 (82,10.1)
3 **N = 137**	43.8 0	65.1 (137, 11.4)	65 0	68.4 (137, 15.2)	53.3 19	55.7 (111, 11.3)

NB. Missing values are mainly caused by pre-service teachers who did one or more of these test in a former academic year, in another institute.

Our second research question was: Is there an association between a) first-year pre-service teachers' Science Teaching Attitudes, (consisting of pleasure, importance, and competence development) and b) their Science Teaching Self-Efficacy beliefs (ST-SE)?

The results reveal that for institute 1, pre-service teachers' ST-SE was statistically significantly related to giving importance to science education, to experiencing pleasure in science teaching, and to tending towards competence development activities in science teaching. Because of this small positive, but significant relation between ST-SE and all Science Teaching Attitude elements (importance, pleasure and competence development), we tested for a positive association for institutes 2 and 3. Results for institutes 2 and 3 showed a consistent positive relation between ST-SE and competence development only (Table 4.5).

Table 4.5 Correlation between Science Teaching Self-Efficacy and Science Teaching Attitudes per institute

Institute	**Science Teaching Attitudes**		
	Pleasure	**Importance**	**Competence development**
ST-SE 1(n = 133) two-tailed 0 missing	.175*	.253*	.420*
ST-SE 2 (n = 157) one-tailed 5 missing	.383	.322*	.468*
ST-SE 3 (n = 137) one-tailed 9 missing	.306	.126	.328*

* significance: $p \leq 0.01$

The third question — is there an association between pre-service teachers' Science Self-Efficacy (S-SE) and Science Teaching Self-Efficacy (ST-SE)? — was answered affirmatively for institute so, a one-sided test was performed on institutes 2 and 3 (Table 4.6). The conclusion: there was a strong positive relation between pre-service teachers' S-SE and pre-service teachers' ST-SE.

Table 4.6 Correlation between S-SE and ST-SE per institute

Institute	**S-SE**
ST-SE 1 (n= 133) two-tailed, 0 missing	.698*
ST-SE 2 (n=157) one-tailed, 5 missing	.707*
ST-SE 3 (n= 133) one-tailed, 5 missing	.651*

* significance: $p \leq 0.01$

Research question 4 — "What is the relation between a) pre-service teachers' science Subject Matter Knowledge and b) their attitudes towards science teaching (pleasure, importance, and tendency to competence development activities) and their ST-SE is split in two (Tables 4.7 and 4.8).

First, no relation between SMK and science teaching attitudes could be found (Table 8). Secondly, in general no relation between SMK and ST-SE could be established, although the results for SMK of living systems were mixed (Table 9).

Table 4.7 Correlation between Science Teaching Attitudes and science SMK per institute

	Science SMK			
Institute **Science Teaching Attitudes**	**Living**	**Earth and space**	**Physics and technology**	**Mathematics**
Importance **1** **two-tailed** **(n=133)**	.046	-.065 0 missing	.032 24 missing	-.122 24 missing
Importance **2** **3**	N.A. N.A.	N.A. N.A.	N.A. N.A.	N.A. N.A.
Pleasure **1** **two tailed**	-.076 24 missing	-.143 0missing	-.083 24 missing	-.023 24 missing
Pleasure **2** **3**	N.A. N.A.	N.A. N.A.	N.A. N.A.	N.A. N.A.
Competence development **1** **two tailed**	.149 24 missing	-.092 0 missing	.028 24 missing	.004 24 missing
Competence development **2** **3**	N.A. N.A.	N.A. N.A.	N.A. N.A.	N.A. N.A.

* significance: $p \leq 0.01$

Table 4.8 Correlation between Science Teaching Self-Efficacy and science SMK per institute

Science SMK				
Institute **Science teaching Self-efficacy**	**Living**	**Earth and space**	**Physics and technology**	**Mathematics**
1 (n=133) **two tailed**	.289* 24 missing	.173 0 missing	.030 24 missing	.047 24 missing
2 one tailed (n=157)	.221* 6 missing	N.A.	N.A.	N.A.
3 one tailed (n=133)	.134 5 missing	N.A.	N.A.	N.A.

* significance: p ≤ 0.01

In general, we conclude there is no relation between institute 1 pre-service teachers' SMK and S-SE. However, pre-service teachers show a small positive relation between SMK of living systems and their S-SE. The hypothesis that there might be a positive relation between S-SE and SMK living systems is confirmed for the other two institutes (table 4.9).

Table 4.9 Correlation between Science Self-Efficacy and SMK per institute

Institute	**Science SMK**			
	Living	**Earth and space**	**Physics & technology**	**Mathematics**
S-SE **1 (n=137)** **two-tailed (n=133)**	.323* 24 missing	.033 0 missing	.102 24 missing	.040 24 missing
2 (n=157) **one-tailed**	.254* 6 missing	N.A.	N.A.	N.A.
3 (n=133) **one-tailed**	.264* 5 missing	N.A.	N.A.	N.A.

* significance: p ≤ 0.01

4.5 Conclusion and Discussion

Regarding the first research question, on average, Dutch pre-service teachers showed positive attitudes towards science teaching. They were neither positive nor negative towards engaging in competence development activities and their S-SE and ST-SE. Their SMK of all science systems was insufficient for one third to half of all pre-service teachers. This is in accordance with Appleton, who concluded in the context of New Zealand, that pre-service primary teachers science knowledge is not adequate. Regarding the second research question, this study demonstrated a positive association between ST-SE and science teaching attitude aspects. S-SE and ST-SE were positively correlated. In other words, pre-service teachers with higher Science Teaching Self-Efficacy tended to have a higher S-SE, show more pleasure in science teaching, find science teaching more important, and appear more willing to develop their science teaching competences, and vice versa. Our fourth research question dealt with the relation between self-efficacy and attitude aspects on the one hand and SMK on the other hand. No association was found for any of the five systems — living systems, earth and space systems, physics, technological, and mathematical systems — of which primary school science consists today. Only one of these, living systems was positively related to ST-SE in two out of the three institutes.

The attitude components “science teaching importance” and “science teaching pleasure”, can be seen as adequate. These results are promising, since teachers with more positive attitudes toward science teaching tend to spend more time teaching science (Carleton, Fitch & Krockover, 2008; Wenner, 2001). However, the attitude component “tendency to engage in competence development activities”, pre-service teachers’ S-SE and ST-SE, and their SMK of physical, technological, and earth and space systems could be improved — and require more attention in teacher training institutes and practical period placements. This is important indeed, since pre-service teachers with a higher sense of self-efficacy are more likely to engage in science teaching in general (Bandura, 1999), and are more willing to plan and implement lessons which offer experiences for the teaching and learning of science as inquiry (Carlton, Fitch and Krockover, 2008).

The positive association found between experienced pleasure in science teaching and ST-SE is in accordance with findings of Czerniak and Lumpe (1996). The positive relation found between ST-SE and tendency to develop one’s science teaching competence corresponds with the findings of Schibeci & Hickey (2003). These results mean that those who regard themselves as competent in science and science teaching (ST-S and ST-SE) more strongly express the intention to engage in competence development activities (and vice versa) than those who have a low science-teaching self-efficacy and less pleasure in teaching science. Teacher trainers have to find ways, in science competence development activities, to engage those who regard themselves as less competent, and who experience less pleasure in science and science teaching. The limited relationship found between SMK and ST-SE means that merely equipping first-year pre-service students with science knowledge is not enough. SMK, ST-SE, and Science Teaching Attitudes each need to be given attention during science lessons within the teacher training institute, as well as in practical placement experiences and reflections.

The ambiguous relationship between SMK living and ST-SE, and lack of relationships found between ST-SE and other SMK systems, might be due to several possible pre-service teachers' beliefs: 1) science perceived as synonymous with biology; 2) unrealistic estimation of their own SMK; 3) secondary school science SMK level not being required for teaching science in primary schools.

The misconception that science is mainly biology might be based on pre-service teachers' own learning experiences in primary school some five to ten years before (Palmer, 2001). So the presence (or absence) of SMK of other sub-disciplines may not have a relation with ST-SE.

Second, pre-service teachers might have an incorrect image of their own SMK of physics, and of technological systems and mathematics. In all institutes, a positive relation was shown between SMK of living systems and S-SE. Since students scored, on average, satisfactory on SMK living systems, this result means that most pre-service teachers regard their SMK as adequate; this, according to the CITO test, is indeed sufficient for the majority of them. No relation was found between SMK of physics and technology, earth and space, and mathematical systems with S-SE. Pre-service teachers might lack a realistic view of their own SMK knowledge of physics and technological systems, earth and space, and mathematical systems. No relation between SMK and S-SE means that some of them underestimate, while others overestimate their knowledge base. Third, pre-service teachers' expectation could be that a secondary-school level of science knowledge is not necessary for teaching at the primary school level. These experiences were solicited in order to measure subjects' Science Self-Efficacy.

4.5.1 Strength and weaknesses

This research involved three Dutch mono-sector teacher training institutes. In the Netherlands, there are 39 institutes offering fulltime program for teacher training, out of which 7 are mono sector institutes. Mono sector institutes have more similarities with primary schools, than multiple sector institutes have in terms of accessibility of facilities and lecturers with specific SMK and pedagogical content skills. So by the selection of three mono sector institutes the ecological validity of our research was increased.

In general, the quality of the selected scales and items seemed adequate, except for Nature of Science. Since Nature of Science may have impact on the "what and how" of pre-service teachers teaching science, it needs clearer operationalization and a validated measurement tool. Item answers were obtained on an ordinal scale but analyzed as if on an interval scale. This is not optimal from the statistics point of few, but common practice and we expect this of little influence.

With respect to data analysis, since three schools were involved in the research, multi-level analysis would have been inappropriate. Nonetheless, the available data was used in an elegant way. Hypotheses about the associations between Attitude and SE; ST-SE and S-SE; Attitude and SMK; SE and SMK were tested two-tailed in one institute, resulting in one-tailed hypothesis tests in the other institutes. This combination of hypotheses testing and the .01 significance level reduced the risk of statistical inference based on fallaciously capitalizing on chance.

4.5.2 Implications for primary teacher education

Teacher education is the timeliest period for providing opportunities for pre-service teachers to establish favorable science teaching self-efficacy and attitudes. Through our research, we might conclude that the majority of first-year pre-service teachers in the institutes involved in this study experience pleasure and regard science teaching as important. Their tendency to competence activities, science teaching self-efficacy, and science self-efficacy could be improved. Teacher education should devote continuous effort to positively influence attitudes towards science learning and teaching (NRC, 1996). Teacher education programs must be designed to bridge the gap between theory and practice.

The following suggestions, based on the literature, might enhance the self-efficacy of pre-service and experienced teachers towards the teaching of science in primary education. Teacher education programs should find ways of keeping attitudes positive towards science and science teaching. Ways to strive for these goals include early examination of self-efficacy and pre-initial science teaching courses; teacher-educator modeling behavior; reflections on practice; and by learning from best practices in other educational systems. Palmer (2001) concluded that student science experiences influence later expectations of science and science teaching (Palmer, 2001); these prior ideas require attention. Howitt (2006) found that teacher educator, learning environment, reflection, school placement and assessment are among influential factors for ST-SE and attitudes. This means that each factor should be addressed within the science curriculum in teacher training. First, early examination of pre-service teachers' confidence about learning science and teaching is crucial to ensuring that new teachers will succeed in their practice (Enochs & Riggs, 1990). Through summer school prior to attending teacher training classes, students might already be confronted with inquiry-based science in a comfortable atmosphere, drop some of their negative attitudes, and gain subject matter and pedagogical content knowledge. Second, teacher educators modeling, including enthusiasm for science, how to teach science, how to reflect upon learning and teaching experiences, and how to establish a meaningful learning environment, also exerts a major influence on the confidence of pre-service teachers (Howitt, 2006; Martin-Dunlop & Fraser, 2007). Exercising inquiry-based science in teaching training might help students to overcome anxiety about teaching the same way in primary schools. If pre-service teachers were engaged in scientific inquiry related to the real world in science content courses, students would have multiple opportunities to develop their understanding of science and scientific inquiry, and would therefore more likely develop more positive attitudes toward science, and become more confident and effective in teaching inquiry-based science to future pupils (Liang & Richardson, 2009).

Third, reflection on former science experiences and their practical placement might enable student teachers to become more aware of their own attitudes, what caused them, and that they can — or sometimes should — change. Last but not least, in a globalized and increasingly mobilized world, more attention can go towards learning from other educational systems, in order to avoid wasted effort.

In sum, teacher educators should design practical, integrated, and well-designed inquiry science courses into the training program that will help to increase science self-efficacy beliefs towards science teaching. A teacher educator should provide a supportive and positive environment in which students can link theory and practice (Howitt, 2006).

4.5.3 Implications for future research

The above has at least six implications for future research, including practice embedded observational research; mixed-method research; comparing teacher training institutes in other countries; research on other variables influencing self-efficacy, and collaboration between researchers on the topic of self-efficacy. First, in order to set the agenda for teacher training improvement, it could be useful to record observations of both pre-service teachers' practice and investigations regarding the quality of teaching, in relation to their science teaching attitudes, self-efficacy and SMK. Second, it would also be advantageous to follow participants through their teacher training and their future career as teacher in primary classrooms. This could be done with two aims. The first aim is to investigate how pre-service teachers' self-efficacy can be further improved, which might contribute to the amelioration of the low priority that inquiry science teaching is currently given within primary education. The second aim is to determine how self-efficacy, attitudes and SMK, and the relation between these constructs, changes over time. As pre-service teachers engage in field instruction, their attitudes and self-efficacy expand in their epistemological orientation (Smolleck & Mongan, 2011). Third, mixed-method research could be used to generate a hypothesis about the directions of the causal relations between S-SE and ScT-SE; and between self-efficacy, attitudes, and SMK. The relation between S-ST and ST-SE was highly significant. We expect that S-ST influences ST-SE, since there is a significant relation between the two, and S-ST is formed in secondary school, before ST-SE. The investigation of such a causal relationship requires additional, longitudinal research.

Fourth, future research might continuously investigate within multiple teacher training settings in several countries, since there are variations between and within national systems (Gray, 2012).

Fifth, further research is needed to penetrate other variables influencing the ST-SE of pre-service teachers. One of the variables might be pedagogical content knowledge of the pre-service teachers.

Finally, it would be beneficial to encourage collaboration among researchers with an interest in the preparation of teachers for inquiry-based science teaching. Often, blame is assigned to teacher training programs, the quality of the pre-service teacher, or the practical placement in primary schools. The benefits of actively striving to gain insight into all factors contributing to the development of pre-service teachers' science teaching should be explored by looking at successful models already in existence, as it is actually done in such networks as ProCoNet (Gray, 2012).

Chapter 5

The relationship between pre-service primary teachers' science Subject Matter Knowledge and Pedagogical Content Knowledge

This chapter has been submitted as:
Alake-Tuenter, E., Biemans, H.J.A., Tobi, H., Velthorst, G.J. & Mulder, M. (submitted). The relationship between pre-service primary teachers' Science Subject Matter knowledge and Pedagogical Content Knowledge.

Abstract

Teachers who have sufficient Subject Matter Knowledge (SMK) and up-to-date Pedagogical Content Knowledge (PCK) are the foundation of meaningful science education that is both effective and efficient. Although the SMK levels of pre-service teachers have been studied extensively, relatively little research has been reported regarding pre-service teachers' PCK and the relationship between their SMK and PCK. This research is clearly needed, as inquiry-based science teaching approaches vary in the extent to which they influence a pupil's motivation, knowledge, and research skills.

The purpose of this study was two-fold. First, we explored the reported preference of pre-service science teachers for science teaching approaches (STAs) as a result of PCK elements. Second, we investigated whether these reported preferred STAs are associated with their respective science SMK.

Three teacher training institutes participated in the study. In total, 427 first-year pre-service teachers completed a multiple-choice instrument designed to report their preferred STAs. SMK was measured using a series of validated national tests.

The results show that most pre-service teachers opt for structured or guided inquiry, whereas fewer teachers opt for confirmation inquiry, which is the most directive form of STA. Only one-fourth of all pre-service teachers preferred open inquiry as a teaching approach. No relationship was found between pre-service teachers' SMK and their preferred STA.

We conclude that teacher training curricula should involve theory about—and reflection on—science SMK and PCK, using the students' prior knowledge as the starting point. Pre-service teachers need a nuanced picture of teaching approaches in order to make a deliberate, informed choice, taking into account their pupils and context variables. Placing a disproportionate emphasis on inquiry-based science teaching in teacher training programs—without addressing the various forms—might result in pre-service teachers who tend to use open inquiry as their preferred science teaching approach, which includes an inherent risk of increasing pupils' misconceptions of constructs in science.

5.1 Introduction

In recent years, the science SMK of pre-service teachers has been studied fairly extensively, yielding the general international picture that pre-service teachers have insufficient science knowledge at the start of their studies (Weinburgh, 2007; Stein, Larrabee, & Barman, 2008). Pedagogical Content Knowledge (PCK) has also attracted considerable attention in science education research during the past two decades. Most science teaching studies focus on the PCK of either experienced teachers (Nilsson & Loughran, 2011) or pre-service teachers for secondary schools (for example, see Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu). However, little is known regarding the science PCK of pre-service teachers who are in the process of preparing themselves for employment in primary education (Loughran, Mullhall, & Berry, 2008; Nilsson, 2008).

According to Shulman, PCK includes "the most useful forms of representation of topics, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others. PCK also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons" (Shulman, 1986, p. 9). A teacher's PCK is the combined result of transforming experiences and applying several types of knowledge for teaching. Thus, each teacher's PCK is unique. Compared to teachers who have limited, fragmented knowledge, teachers who have differentiated, integrated knowledge will be better equipped to prepare and scaffold learning experiences—under specific conditions and constraints—in order to help diverse pupils develop research skills and obtain profound knowledge (Gess-Newsome & Lederman, 1999).

A teacher's PCK develops in the context of the classroom, the workplace, and society, in which specific teaching approaches prevail. Policy documents of the US National Research Council (NRC, 2013) and the Netherlands Institute for Curriculum Development (Van Graft & Kemmers, 2007) advocate an inquiry-based approach to science teaching. The criteria in these documents (NRC, 1996; 2013) specify that inquiry-based science teaching must proceed such that pupils: a) engage in scientifically oriented questions and explorations, b) place priority on evidence when addressing questions, c) formulate explanations based upon the investigation and evidence, d) connect these explanations to scientific knowledge, and e) communicate and justify the models and explanations. Thus, "Science" encompasses both process and product aspects, both of which are equally important.

"Inquiry instruction" can have several different interpretations, particularly when usage is not stated explicitly. The approach advocated by the NRC (1996; 2013) and the Dutch national curriculum standards (Van Graft & Kemmers, 2007) is one of "guided inquiry" rather than a directive, confirmation, or structured inquiry, or a minimally guided, self-directed, “discovery”, open inquiry (Buck et al., 2008). In guided inquiry, the teacher poses the question or problem to be investigated and then suggests the materials to be used. The pupils—working individually, in pairs, or in groups—then design and perform a procedure for the investigation; the procedure is collaborative and is guided by the teacher. The pupils then draw conclusions and explanations from the data collected (Buck, et al., 2008; Colburn, 2000; Banchi & Bell, 2008; Zion & Mendelivice, 2012). The teacher acts as a facilitator in the problem-solving process and may give the pupils prompts and probing questions in order to help the pupils decipher the question or problem being posed; the teacher may also suggest subtle responses that direct the pupils to formulate their own procedures and explanations.

The most developmentally appropriate approach is not necessarily a simple function of age and/or grade, but will be largely contingent upon prior learning opportunities (Duschl, Schweingruber & Shouse Duschl, 2007). However, guided inquiry approaches have proven to be more motivating, and the pupils’ science content knowledge, science process skills, and scientific reasoning skills all seem to improve more rapidly when using guided inquiry compared to using structured inquiry (Bunterm et al., 2014). Moreover, some researchers consider guided inquiry approaches—which place an emphasis on scaffolding primary pupils’ learning process—to be more effective and efficient than open inquiry approaches (Butts et al., 1994; Davis & Petish, 2005). Guided inquiry can help prevent pupils from developing these alternative conceptions and non-scientific ideas (Butts et al., 1994; Davis & Petish, 2005). Scaffolding a primary school pupil’s engagement in an inquiry process over which he/she has increasing responsibility and control might help the pupil develop an understanding of science as a way of knowing, and it may stimulate the pupil’s capacity as an independent inquirer (Metz, 2004). Thus, in many situations, guided inquiry can be considered the most effective approach.

Teacher training institutes, as well as pre-service teachers, are stimulated to use these inquiry-based approaches. However, experienced teachers who have relatively low science SMK tend to use more direct, structured teaching approaches in order to avoid being confronted with questions that they cannot answer. On the other hand, teachers who have sufficient science SMK tend to use more guided or open inquiry–based approaches (Davis & Petish, 2005; Kim & Tan, 2011). However, to the best of our knowledge, this issue has not been studied with respect to pre-service primary teachers. Cobern et al. (2014) argue that this issue is an avenue for further research to address whether a pre-service teacher’s degree of SMK is related to his/her preferred science teaching approach (which is the case with experienced teachers). Thus, research is needed to study the relationship between pre-service teachers' science SMK and their preferred science teaching approach.

The aim of this study was to increase the body of knowledge regarding the relationship between pre-service teachers' science SMK and their preferred science teaching approach. We addressed the following research questions:

1. How can the reported preferred Science Teaching Approaches of pre-service primary teachers be characterized?
2. Is there a relationship between reported preferred science teaching approaches and the science SMK of these pre-service teachers?

5.2 Theoretical framework

5.2.1 Pedagogical Content Knowledge and Science Teaching Approach

Several researchers (Avraamidou & Zembal-Saul, 2010; Davis, 2006; Shulman, 1986; 1987) have argued that merely having knowledge of subject matter and general pedagogical strategies—although necessary—is not sufficient for good teachers. To be successful, teachers must confront both issues (i.e., content and pedagogy) simultaneously by embodying "the aspects of content most germane to its teachability" (Shulman, 1986, p. 9). Shulman (1986; 1987) proposed the term Pedagogical Content Knowledge (PCK) to draw attention to the elucidation of teachers' understanding of the relationship between SMK and the instruction that teachers provide to their pupils.

The conceptualization of PCK is not universally accepted (Kind, 2009; Park & Oliver, 2008). However, despite differences (for example, see Alake-Tuenter et al., 2012), commonalities also exist. For example, there is consensus regarding two essential elements of PCK, namely: 1) pupils' specific learning difficulties, and 2) knowledge regarding how the subject is represented in order to overcome these difficulties. The present study is based on our previously proposed science PCK model, which was based on an international literature review and a Delphi study (Alake-Tuenter, Biemans, Tobi, Wals, Oosterheert, & Mulder, 2012; see the Figure in Appendix 1).

Recently, several researchers studied the relationship between PCK (in terms of quantity and quality) and teaching (Loughran et al., 2008; Nilsson & Loughran, 2011). The authors concluded that the interaction between two components of PCK—specifically, the scaffolded instruction and the attitude towards teaching—results in preferred approaches to teaching science. Teachers generally apply PCK depending on the context, the content to be taught, the context in which the content is taught, and the way in which the teacher reflects on his/her experiences (Davis, 2004; Nilsson, 2008).

Science teaching approaches include confirmation inquiry, structured inquiry, guided inquiry, and open inquiry (Banchi & Bell, 2008; Bruck et al., 2008; Cobern et al. 2014; see also Table 5.1). Teachers have conscious—or subconscious—preferences for one part of the instructional spectrum or another.

Table 5.1 Science teaching approaches (STAs)

Confirmation Inquiry	The teacher presents a question or problem and a science concept or principle directly, and then explains it. The explanation includes an example or demonstration in which the teacher decides on the procedure and materials. The teacher analyzes the results and communicates the results and conclusion. No pupil activities are used, but the teacher answers and/or clarifies the pupils' questions.
Structured Inquiry	This is essentially the same as confirmation inquiry, but this STA is followed by a pupil activity that is based on the presented science (e.g., a practical verification of a law). Pupils might have a say in the materials that will be used.
Guided Inquiry	The topics and research questions presented by the teacher are approached by the pupils, who explore a phenomenon or idea. The pupils decide on the design or procedure and the materials to be used. The pupils analyze their results and draw conclusions from those results, with the teacher guiding them to the desired concept or principle that arises from the activity. The teacher may provide a further explanation and may give examples for consolidation. Questions are addressed through discussion.
Open Inquiry	The pupils receive minimum guidance from the teacher, and they are free to explore their own research questions, phenomenon, and/or idea in any way they wish, using any method they wish. The pupils analyze their results, draw their own conclusions, and communicate those conclusions. The teacher facilitates the process but does not interfere. The process itself is generally considered to be the most important aspect, and the pupils present their findings.

Source: Cobern et al. (2014)

In essence, the aspects of the four inquiry-based STAs differ in the extent to which the learning process is regulated by the teacher or pupils (Table5.2).

Table 5.2 The features of the four inquiry-based STAs

	Formulate problem/ question	**Plan and perform investigations**	**Analyze results**	**Draw conclusions (formulate explanations; connect explanations to scientific knowledge)**	**Communicate results**
Confirmation	T	T	T	T	T
Structured	T	T	P+T	P+T	P+T
Guided	T	P+T	P	P	P
Open	P	P	P	P	P

T= teacher-regulated activity
P= pupil-regulated activity

5.2.2 Subject Matter Knowledge

Subject Matter Knowledge (SMK) or Content Knowledge refers to the “amount and organization of knowledge per se in the mind of the teacher” (Shulman, 1986, p. 13). Similarly, Zeidler (2002) described SMK as a person’s quantity, quality, and organization of information, conceptualizations, and underlying constructs in a given field. A deep and complex understanding of science involves: 1) memorizing and understanding factual information and concepts; 2) understanding the relationships between those concepts; and 3) knowing when and how to apply the concepts in the appropriate context (Glen & Dotger, 2009). With respect to the domain of science education, this means that pre-service teachers must have both knowledge and understanding of many systems, including physical, life, Earth and space, technological, and mathematical systems (NRC, 1995). Gess-Newsome (1999) went even further than Shulman, suggesting that in the case of science, a teacher’s SMK should also include scientific literacy, participation in scientific discourse, and an understanding of the structure of the very nature of science as a discipline. In addition to knowing facts and organizing principles for the domain, pre-service teachers also need to have knowledge of investigation skills, knowledge of the relationship between those skills, and knowledge of how to apply the skills (Akerson & Volrich, 2006). These competence elements are summarized in Appendix 2.

Research indicates that in general, primary school teachers have relatively limited science SMK (Appleton, 2003; 2006). Compared to teachers with limited science SMK, teachers who possess an adequate level of SMK have a deeper understanding of isolated concepts, and they possess more knowledge of related concepts and use methods to connect one concept with another (Lederman et al., 1994). Experienced teachers with a low level of science SMK tend to use direct teaching approaches, whereas teachers with adequate science SMK tend to use approaches that are more inquiry-based (Davis & Petish, 2005; Kim & Tan, 2011).

5.3 Methods

5.3.1 Context of the study

The three Dutch teacher training institutes in this study are mono-sector universities that provide a four-year Bachelor's program in primary teaching. All incoming students must possess a diploma from a five-year intermediate-level secondary school. Graduates of the three institutes are qualified to teach all primary education subjects—except physical education—to children from 4-12 years of age. The three institutes are distributed geographically throughout the Netherlands and are Catholic or Protestant universities.

5.3.2 Data collection

The primary science teaching instructors at the three teacher training institutes provided the researchers with their students´ results on the national SMK tests on mathematics; physics, technology, and living systems; and Earth and space systems. With the instructors' permission, the researcher collected data regarding PCK by administering a questionnaire during the regular science class meetings in January and February 2013. These specific months were chosen because after half a year of study, all of the pre-service teachers were familiar with the vocabulary regarding inquiry-based science teaching. After explaining the purpose of the study and the benefits of participating, the researcher administered the questionnaire in two classes in the presence of the instructor. The instructors then introduced and administered the questionnaire to the students in their remaining classes. The pre-service teachers voluntarily completed the questionnaire using paper and pencil. Although there was no time limit, the questionnaire was generally completed within approximately 20 minutes.

The study included 427 first-year pre-service teachers with a major in primary education at the three abovementioned institutes. The majority of the students are female.

5.3.3 Instruments

The Pedagogy of Science Inquiry Teaching Test (POSITT; Schuster et al., 2007; Cobern et al., 2014) was adapted and abridged to assess the preferred STA.

We selected seven items from the 28 items in the two original POSITT instruments. The following criteria were used for item selection: the item must represent all five science systems; the item must cover topics that appear in curricula used to teach 6-8-year-old students and 9-12-year-old students; the item must provide diversity and recognition of the content and appropriateness to the learning objectives of the Dutch system of primary education. The topics for the technological and mathematical systems included examples taken from existing lesson series, and the four possible teaching approaches (Table 5.1 and Table 5.2) were used as response options. We added two items regarding technological systems and one item regarding mathematical systems to the existing items. Thus, all systems are represented equally. The resulting "POSITT-NL-short" instrument consisted of ten items. Five of these items covered topics from the national Dutch curriculum goals that are taught to 6-8-year-old students, and five items covered topics that are taught to 9-12-year-old students. Each item required either an evaluation of a described science teaching approach or an intended way of intervening in a primary science education context. The four response options reflected the spectrum of science teaching approaches depicted in Table 5.1. The complete POSITT-NL-short instrument is provided in Appendix 5.1.

The SMK levels for mathematics; living, physics, and technology; and Earth and space systems were assessed in three national CITO tests, which are Netherlands-based exams that measure and monitor students' knowledge. The mathematics test consisted of a maximum of 200 questions delivered in a dynamic response-tailored test; the number and complexity of the questions were adapted based on the student's performance on previous questions. The living, physics, and technology system test consisted of 45 items, and the Earth and space systems test consisted of 16 items. All SMK test results were expressed as the percentage of answers that were correct.

5.3.4 Data analysis

First, the percentage of pre-service teachers who passed the SMK tests was calculated. The pass mark for living, physics and technology systems test, and the pass mark for earth and space SMK test were 67 %, while the pass mark of mathematics was 51.5%. The percentage of each preferred STA was calculated. Preferred STA scores were calculated as the sum of the preferred options; thus, for each of the four STAs, a respondent could have a score ranging from 0 to 10, and all four STA scores must add up to exactly 10. Finally, as a measure of the extent to which one prefers pupil-regulated inquiry-based approaches, the STAs were collapsed to differentiate between low (confirmation inquiry and structured inquiry) or high (guided inquiry and open inquiry) scores regarding pupil-regulated inquiry as the preferred STA. The respondents who opted 0-4 times for a pupil-regulated STA were categorized as low for preferring pupil-regulated inquiry, and the respondents who opted 6-10 times for a pupil-regulated STA were categorized as high. In order to minimize the consequences of misclassification, the respondents with a pupil-regulated STA score of 5 were not included in either category.

The associations between SMK and STA were investigated using several approaches. First, non-parametric correlation coefficients (Spearman's rank and Kendall's Tau) were estimated for SMK test score and pupil-regulated inquiry as preferred STA score. Second, Chi-square analysis was used to analyze pass/fail on SMK tests and low/high on pupil-regulated inquiry as preferred STA. Tests with $p \leq 0.01$ were considered to be statistically significant.

5.4 Results

The percentage of pre-service teachers in this study who passed the SMK tests ranged from 15.6% to 67.7% (Table 5.3).

Table 5.3 SMK test results (percent pass, missing cases, percentage correct scores on test results) by institute, by knowledge system

	SMK test results					
	Living, Physics, and Technology		Earth and Space		Mathematics	
Institute	% Pass % missing	Mean score (n, SD)	% Pass % missing	Mean score (n, SD)	% Pass % missing	Mean score (n, SD)
1 N=133	50.4 18.0	65.0 (109, 17.5)	67.7 0	69.4 (133, 15.3)	57.1 10.5	56.1 (119, 12.6)
2 N=157	41.9 1.9	64.2 (154, 9.5)	56.3 1.9	65.1 (154, 15.2)	15.6 47.5	49.6 (82,10.1)
3 N=137	43.8 0	65.1 (137, 11.4)	65 0	68.4 (137, 15.2)	53.3 19	55.7 (111, 11.3)

On average, the pre-service teachers reported that their preferred STA's were either structured inquiry or guided inquiry approaches. These approaches were chosen significantly more often than confirmation inquiry in Institutes 1 and 2. In each institute, 13-16% of all first-year pre-service teachers chose confirmation inquiry, and 22-27% chose open inquiry (Table5.4). In all three institutes, open inquiry was chosen significantly more often than confirmation inquiry.

Table 5.4 POSITT-NL-short results (percentage STA, medians and low/high scores on pupil pupil-regulated inquiry score preferred by pre-service teachers) by institute

	% preferred STA over items and respondents				Pupil-regulated inquiry score		
	Teacher-regulated inquiry		Pupil-regulated inquiry			% respondents (n)	
Institute	Confirmation	Structured	Guided	Open	Median (min, max)	Low	High
1 (N = 130)	13%	31%	33%	24%	5 (1,10)	36.7 (36)	63.3 (62)
2 (N = 148)	16%	36%	27%	22%	5 (0,9)	53.4 (62)	46.4 (54)
3 (N = 130)	13%	29%	30%	27%	6 (2,10)	31.3 (31)	68.7 (68)

NB. Total do not equal 100% due to rounding errors

We found no correlation between SMK and pupil-regulated inquiry-based STA score (all correlation estimates had an absolute value that was less than 0.21 and all p-values were >0.01). We also found no evidence of an association between SMK and low or high with respect to pupil-regulated STA scores (all Chi-square tests yielded a p-value >0.01).

5.5 Conclusion and discussion

In this contribution the following research questions were posed: *1) How can the reported preferred Science Teaching Approaches of first-year pre-service primary teachers be characterized? and 2) Is there a relationship between reported preferred science teaching approaches and the science SMK of these pre-service teachers?* In this discussion we will address the major discussion issues. As regards the first question, the majority of teachers reported that they preferred an active direct inquiry or guided inquiry STA. In terms of impacting a primary pupil's science SMK, research skills, and attitude, most researchers consider guided inquiry to be the most effective approach (Butts et al., 1994). In a few cases, the pre-service teachers opted for the science teaching approach that was the most directive. However, all three institutes in our study reported that at least 22% of their pre-service teachers preferred an open inquiry–based STA. In total, more pre-service teachers reported to prefer pupil regulated inquiry than teacher regulated inquiry. Regarding our second research question, the pre-service primary teacher's STA preference was not correlated with the level of SMK. In contrast, experienced teachers do exhibit such a correlation. For example, experienced teachers with insufficient SMK tend to favor more directive science teaching approaches, whereas experienced teachers with standards-compliant SMK tend to favor more inquiry-based teaching approaches (Davis & Petish, 2005; Kim & Tan, 2011). Several factors might account for this difference between pre-service teachers and experienced teachers. First, inquiry-based science teaching receives considerable attention in teacher training curricula and current policy documents (SLO, 2007). Even if a pre-service teacher's SMK does not meet the national standards, inquiry-based teaching might still be chosen, as pre-service teachers have been told it is a better approach in terms of stimulating motivation and curiosity among their pupils. Second, compared to experienced teachers with insufficient SMK, pre-service teachers with insufficient SMK might be less insecure and more open-minded to trying these teaching methods, as they will have had relatively few experiences failing at teaching science. This presumption is consistent with the outcomes of our previous study, in which pre-service teachers with low SMK did not differ with respect to their self-efficacy towards science teaching, compared with teachers with high SMK (Alake-Tuenter et al., 2013).

This result has both a positive aspect and a negative aspect. The positive aspect is that pre-service teachers who experience inquiry-based science teaching might be convinced that pupils—and possibly the teachers themselves—gain a higher appreciation of science when inquiry-based methods are used compared to when more directive learning methods are used. Moreover, the questions that pupils might ask the pre-service teacher might stimulate the teachers to actively increase their science content knowledge in order to overcome the shortfall in their SMK. Furthermore, teachers who gain experience using inquiry-based teaching in a safe setting (for example, in a practical placement school under the guidance of a nurturing mentor) will be motivated to further develop their organizational, pedagogical, and didactic competences. On the other hand, one negative aspect is that the use of inquiry-based science teaching approaches—particularly open inquiry–based approaches—by pre-service teachers with inadequate SMK might actually reinforce pupils' misconceptions.

5.5.1 Strengths and weaknesses

The complexity of pre-service teachers' PCK—and the fact that PCK is not directly observable—has driven researchers to use a variety of different methods to probe, analyze, and report science PCK. The research method used here was a prompt-based study, which has several advantages. First, the items are essentially familiar "problems" to pre-service teachers involving various pedagogical approaches to address a given teaching situation. Pre-service teachers can recall situations without the need to verbalize the situation, as is the case in common research methods as interviews, open-ended questionnaires, portfolios, etc., all of which might be difficult in the first year of teacher training. Working through these problems with pre-service teachers serves as a scaffold for supporting the novice teachers' current lack of schemas. Second, unlike a survey, the cases are based upon actual classroom occurrences and are therefore more relevant to real-world situations. Third, compared to *in situ* studies that investigate how pre-service teachers teach science in a classroom or laboratory setting, completing the instrument is not as time-consuming for pre-service teachers. Similarly, collecting and analyzing data using a questionnaire is less-labor intensive for the researchers than collecting data using *in situ* studies. Finally, the POSITT instrument was adapted to the Dutch situation and was abridged for use in this study. However, this might have affected the validity and reliability of the instrument.

In this study, the POSITT-NL-short was only used once. In future studies, the instrument might be used longitudinally in order to analyze how pre-service teachers develop their PCK, to provide a formative evaluation and to serve as a professional development tool for pre-service teachers, and/or to help pre-service teachers develop a practical understanding of the general principles that they are learning.

5.5.2 Implications for future research and educational practice

To gain further insight into the way in which pre-service teachers and in-service teachers develop their science teaching competences, and to determine whether the relationship between competence categories changes over time, longitudinal research is clearly needed. Such research might provide a better understanding of the process through which one becomes an expert in the field of science teaching. For example, this process might be gradual, continuous, and never-ending; on the other hand, certain experiences in a teacher's career might play a critical role by driving a sudden change in the teacher's beliefs, attitudes, knowledge, and/or practices. Such research might also add to the growing discussion regarding epistemological issues surrounding the nature of PCK. Gess-Newsome (1999) drew two models of PCK: an integrative model and a transformative model. In the integrative model, PCK does not exist as a stand-alone, independent category. The teacher's knowledge is regarded as an intersection between subject matter, pedagogy, and context. During the teaching process, all three of these knowledge areas are integrated as needed in order to create a meaningful and effective learning environment for the pupils. From such a perspective, the domains of knowledge can be developed independently and then integrated at a later stage. In the transformative model, PCK is an independent category of knowledge. In this model, PKC results from merging and transforming knowledge regarding subject matter, pedagogy, and context into a new form of knowledge that is greater than the sum of its constituent parts. In both models, reflection emerges as an important element for pre-service teachers in becoming experts in their field, and reflection is central to their ability to accept more responsibility for their actions (Loughran, 2002).

Kind (2009) suggests that in the very early stages of becoming a teacher, the development of one component of teacher knowledge—for example, SMK—can lead to significant mental adaptation of PCK for classroom use. This notion fits within the transformative model. However, SMK might be more difficult to distinguish as a separate component within the teacher's knowledge base when the teacher is more experienced (and therefore more effective), thus representing an integrative perspective. Therefore, both the integrative and transformative PCK models likely have a place in education, and the choice of model may depend upon the teacher's phase in his/her professional development.

Longitudinal research in the context of both teacher training colleges and primary schools might also provide insight into the specific characteristics and components of teacher education programs that help or hinder the teacher's ability to develop inquiry-based science PCK and SMK, as well as the subsequent implementation of inquiry-based science education in practice. Such research might answer the following questions: *What is the optimal set of experiences that will both inspire and enable teachers to be effective in inquiry-based science teaching, and how can primary teachers develop science-related competencies in addition to—or in combination with—the many other competencies that are required for teaching other subjects?* In the past, the dominant model involved teachers being trained in specific competencies independently. It would therefore be interesting to compare this model with a more integrated model of competence development in which SMK, PCK, and attitudes are developed simultaneously. Such a comparison would address the question of how pre-service teachers might be supported in their quest to develop knowledge, skills, and attitudes that are relevant for their particular education setting, and how knowledge, skills, and attitudes support each other.

Our results suggest that science SMK is not correlated with the science teaching approach that a first-year pre-service teacher prefers. This conclusion suggests that gaining SMK alone is no sufficient to learn, master, and apply inquiry-based science teaching competencies in practice and will not necessarily lead to a deliberately chosen science teaching approach. Therefore, we must develop teacher education programs that are designed to bridge the gap between theory and practice. Modeling teacher educators—including their enthusiasm for science, how to teach science, how to reflect upon learning and teaching experiences, and how to establish a meaningful learning environment—can exert a major influence on pre-service teachers' confidence (Howitt, 2006; Martin-Dunlop & Fraser, 2007). However, instructional approaches that merely advocate inquiry-based teaching by giving theoretical arguments—without providing direct experience—seem to be insufficient and contrary to inquiry-based learning (Britner & Finson, 2005).

Pre-service teachers should also clearly understand the various types of inquiry-based teaching. Open inquiry–based teaching differs from guided inquiry–based teaching with respect to the circumstances in which the approaches might be applied successfully, as well as the impact that each approach might have on the pupil's learning process. Open inquiry–based learning can be a motivating starting point for a lesson series for pupils. However, offering open inquiry–based learning is not sufficient (Metz, 2010). Guided inquiry, and questioning or refuting misconceptions, is needed in order to prevent pupils from reinforcing their existing misconceptions. Placing a disproportionate emphasis on inquiry-based science teaching in teacher training programs—without clarifying the difference between open-inquiry and guided-inquiry based approaches—could result in a disproportionate number of pre-service teachers who tend to use open inquiry as their preferred science teaching approach, particularly in the case of pre-service teachers who lack adequate SMK, which carries an inherent risk of increasing pupils' misconceptions of constructs in science.

To learn how to implement the inquiry-based method, pre-service teachers require mentoring and support during their internship (Moseleyet al., 2004), as well as during their induction period as a starting teacher (Avraamidou & Zembal-Saul, 2010). Establishing strong partnerships between teacher training institutions and primary schools might help teacher trainers achieve this goal.

Appendix 5.1 POSITT-Nl short

1. Organismen reageren op hun omgeving
   Juffrouw Nienke wil haar leerlingen uit groep 4 leren dat levende organismen reageren op hun omgeving. De leerlingen hebben een onderzoek gedaan hoe aardwormen reageren op hun omgeving. Daarna hebben ze in kleine groepen vragen besproken over het onderzoek. Juffrouw Nienke wil de les nu afsluiten.

Welke van onderstaande mogelijkheden zou jij gebruiken om de les af te sluiten?

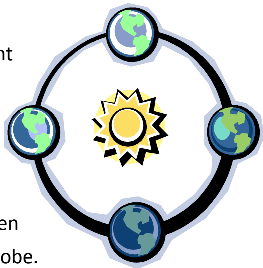
A. De leerlingen stimuleren om een algemene conclusie te trekken, gebaseerd op de gegevens die ze hebben verzameld met hun onderzoek, met als doel ze meer begrip bij te brengen.

B. De leerlingen uitleggen dat organismen reageren op hun omgeving, en aan de leerlingen vragen met gegevens van hun onderzoek te komen die dat aantonen.

C. Leerlingen eerst hun conclusies laten rapporteren, dit laten relateren aan de gegevens die ze uit observaties hebben verkregen.

D. De leerlingen uitleggen dat organismen reageren op hun omgeving, dit als leerkracht relateren aan de gegevens die ze uit observaties hebben verkregen.

2. Draaiing van de aarde
   Juffrouw Mirte wil haar groep 7 leren dat de draaiing van de aarde dag en nacht veroorzaakt. Ze begint door met een zaklamp (de zon) op de draaiende globe (de aarde) te schijnen. Ze vraagt aan haar leerlingen de aandacht te richten op een rode stip die ze op de globe heeft gemaakt, en vraagt een aantal keren waar de stip is, ten opzichte van het licht. Juffrouw Mirte versterkt het leren van de leerlingen door uit te leggen hoe dag en nacht gerelateerd zijn aan het draaien van de aarde, terwijl ze dit nog een keer demonstreert met de zaklamp en de globe.



Als je er over na denkt hoe jij deze les zou geven, wat zou jij er aan veranderen?

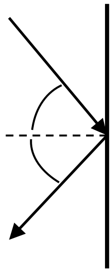
A. Ik zou de les zijn begonnen met het uitleggen hoe dag en nacht verband houden met de draaiing van de aarde. Daarna zouden de leerlingen kunnen voorspellen of de rode stip in het licht of in het donker zou komen te staan tijdens de demonstratie die er op volgt.

B. Ik zou de leerlingen eerst nauwkeurig laten waarnemen wat er gebeurt met de rode stip, terwijl ik de globe draai. Daarna zou ik de leerlingen zelf tekeningen laten maken van hun observaties. De les eindigt met het bespreken van hun observaties.

C. Ik zou de les beginnen met het uitleggen hoe dag en nacht en de draaiing van de aarde met elkaar in verband staan, waarbij ik de zaklamp en de globe zou gebruiken voor demonstratie, steeds vertellend welk deel van een etmaal het nu is.

D. Ik zou de les hetzelfde geven als Juffrouw Mirte.

3. Licht weerkaatsing
   Meester Benno geeft zijn groep 7 les over de wet van lichtweerkaatsing: wanneer een lichtbundel tegen een spiegelend oppervlak komt, weerspiegelt het met dezelfde hoek als waar het mee op het oppervlak is aangekomen. Benno moet nog besluiten hoe hij deze les aan gaat pakken.



Hoe zou jij de les geven? Kies het antwoord dat het meest lijkt op jouw aanpak.

A. Ik zou de wet van weerkaatsing op het bord schrijven en het illustreren door middel van een tekening. Vervolgens zou ik ze een echt voorbeeld geven, door een lichtbundel, spiegel en een gradenboog of geodriehoek te gebruiken. Daarna bespreken we alle vragen die de leerlingen hebben.

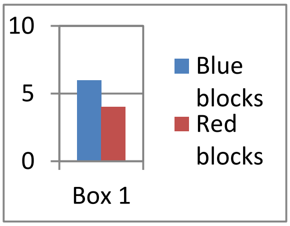
B. Ik zou de leerlingen vragen zoveel mogelijk uit te zoeken over het gedrag van licht rond spiegels, door hen zelfstandig experimentjes te laten doen met een assortiment aan materiaal, zoals lichtbronnen, spiegels en gradenbogen of geodriehoeken. Daarna rapporteren de leerlingen wat zij hebben gevonden.

C. Ik zou eerst een vraag stellen over weerkaatsing die de leerlingen beantwoorden door te gaan onderzoeken. De leerlingen kunnen onderzoeken door lichtbronnen, spiegels en gradenbogen of geodriehoeken te gebruiken. Ik zou de les eindigen door hen een samenvatting van de wet van weerkaatsing te geven.

D. Ik zou de wet van weerkaatsing op het bord schrijven en illustreren door middel van een tekening. Daarna zou ik de leerlingen de wet laten toepassen door het gebruik van lichtbronnen, spiegels and gradenbogen of driehoeken. We bespreken hun bevindingen.

4. Staafdiagrammen

Juf Moniek leert haar kinderen in groep 4 hoe ze een eenvoudige staafdiagram kunnen maken. Ze geeft de kinderen een voorbeeld van een staafdiagram die ze al getekend heeft waarbij ze rode en blauwe blokken in een doos met elkaar vergelijkt.



Hoe zou jij de les geven? Kies het antwoord dat het meest lijkt op jouw aanpak.

A. Tel de rode en blauwe blokken hardop voor de leerlingen en laat hen zien hoe de staafdiagram het aantal rode en blauwe blokken representeert. Ik zou ook een aantal groene en gele blokken klaarleggen waarmee de leerlingen aan het werk kunnen. Ik zou de leerlingen de groene en gele blokken laten tellen en dan hun eigen diagram laten maken, waarbij ze mijn voorbeeld volgen van de rode en blauwe blokken.

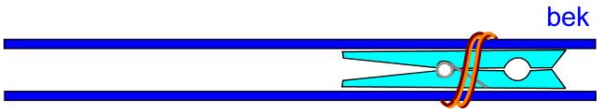
B. Ik zou het voorbeeld van mijn staafdiagram nog niet geven. Ik zou eerder blokken uitdelen en aan de leerlingen vragen tekeningen te maken van het aantal blokken dat ze zien van elke kleur. Na het klassengesprek, zou ik mijn tekening (het voorbeeld van de staafdiagram) rond geven en de leerlingen laten bespreken hoe dit plaatje ook laat zien hoeveel blokken er van elke kleur zijn.

C. Tel de rode en blauwe blokken hardop voor de leerlingen en laat hen zien hoe de staafdiagram het aantal rode en blauwe blokken representeert. Ik zou ook een aantal gele en groene blokken klaarleggen. Als we de groene en gele blokken geteld hebben, zou ik de leerlingen laten zien hoe je van de groene en gele blokken een staafdiagram kunt maken.

D. Geef de leerlingen rode en blauwe blokken en vraag hen of ze uit kunnen vinden wat de staafdiagrammen vertellen over de blokken. Na het bespreken van hun ideeën zou ik hen laten demonstreren wat zij denken door henzelf staafdiagrammen te laten maken waarbij ze groene en gele blokken gebruiken, die ik al klaar gelegd heb om door te geven.

5. Hefbomen

Meester Andries wil de kinderen uit groep 4 laten kennis maken met hefbomen en hun draaipunten. Hij laat de kinderen in een circuitvorm de werking van een wasknijper, wip, schaar en hefboom bij een modelspoorbaan ervaren, aan de hand van gerichte opdrachten op een werkblad. Als iedereen daarmee klaar is laat Andries de volgende schematische afbeelding op het digibord zien en demonstreert daarbij ook twee voorbeelden:



Vogel 1

Vogel 2

Hij zegt tegen de kinderen: “Zo dadelijk maak je jouw eigen vreemde vogel. Pak daarvoor een wasknijper, elastiekjes en twee stokjes. Maak met je schoudermaatje plaatje a en b na. Ga dan samen met je schoudermaatje kijken wat het verschil is tussen de bek van vreemde vogel 1 en vreemde vogel 2. Kruis het op het werkblad aan. Dat bespreken we met de klas. Daarna mag je de vogel versieren.

De kinderen pakken de materialen en maken de twee bekken. Zij kruisen op een werkblad aan

“Van welke vogel kan de bek het verst open? Vogel 1/vogel 2

Andries zegt dan: “Kies de bek van de vogel die het verste open kan. Versier die met bijvoorbeeld een gekleurde snavel, zijn ogen en veren”.

Andries bespreekt de les met de kinderen na. Hij doet dat door enkele Vreemde Vogels en hun bek te laten zien. Hij vraagt hen waarin de Vreemde Vogels en de voorwerpen uit het circuit overeen komen. De kinderen reageren op elkaar en Andries vult de kinderen aan, waarbij hij de woorden ‘hefboom’ en ‘draaipunt’ gebruikt.

Als jij deze les een week later bij de parallelgroep zou mogen geven, hoe zou jij het dan aanpakken?

A. Ik zou de les precies zo geven als Andries

B. Ik zou de kinderen direct vanaf het begin van de les met wasknijpers en andere hefbomen, zoals pincetten, scharen en een wip laten experimenteren, zonder gerichte opdrachten op een werkblad te geven. Daarna kunnen ze de Vreemde Vogel maken.

C. Ik zou eerst een filmpje laten zien over hefbomen in het dagelijks leven (zoals bruggen, een koevoet van inbrekers, een wip en wasknijpers). Daarin worden de woorden ‘hefboom’ en ‘draaipunt’ ook gebruikt en de werking van een hefboom uitgelegd. Daarna zou ik de kinderen in een circuitvorm, de werking van een wasknijper, wip, schaar en hefboom bij een modelspoorbaan laten ervaren, aan de hand van gerichte opdrachten op een werkblad. Daarna maken ze de Vreemde Vogel. Ik bespreek het werkblad en de Vreemde Vogels met de kinderen na.

D. Ik zou eerst een filmpje laten zien over hefbomen in het dagelijks leven (zoals bruggen, een koevoet van inbrekers, een wip en wasknijpers). Daarin worden de woorden ‘hefboom’ en ‘draaipunt’ ook gebruikt en de werking van een hefboom uitgelegd. Ik zou hen daarna enkele hefbomen demonstreren en een werkblad laten invullen over de werking van hefbomen in het dagelijks leven.

6. Fotosynthese

1	2	3	4	5	6

Juf Hadassa heeft haar groep 7 een les gegeven over fotosynthese, en meer specifiek dat de aanmaak van bladgroenkorrels door licht in gang wordt gezet. Ze heeft een voorbeeld neergezet om dit te illustreren. Ze heeft snel groeiende kiemplantjes neergezet op plekken waar ze een verschillende hoeveelheid licht krijgen. De leerlingen observeren de groei van de kiemplantjes verschillende dagen achter elkaar en schatten de hoeveelheid bladgroenkorrels in door een kleurenkaart te gebruiken bij het vastleggen van de bladkleur. Ze leggen de gegevens vast in hun schrift en op een groepstabel. Op de laatste dag beoordeelt juf Hadassa de invloed van licht op de aanmaak van bladgroenkorrels, toegelicht met de onderzoeksactiviteit.

Als je er over na denkt hoe jij deze les zou geven, welke van onderstaande mogelijkheden vind je het beste?

A. Dit is een goede lesopzet, omdat juffrouw Hadassa start met het uitleggen van de belangrijkste begrippen die ze de leerlingen aan wil leren, gevolgd door een activiteit door leerlingen waarin wordt bevestigd dat de aanmaak van bladgroenkorrels door licht in gang wordt gezet.
B. Juf Hadassa begint goed door met een uitleg te starten over de begrippen die ze de kinderen aan wil leren. Het is echter niet duidelijk of de activiteit nodig is, vooral niet omdat het zoveel tijd vraagt.
C. Juf Haddassa is te georganiseerd en voorschrijvend. Het zou beter zijn voor de leerlingen als zij zelf mogen besluiten hoe ze plantjes en licht neerzetten, kijken wat er gebeurt en dat ze er zelf achter komen hoe ze de aanmaak van bladgroenkorrels kunnen vergelijken.
D. Het instructie gedeelte zou beter zijn als de leerlingen eerst de observaties van de planten doen, zodat ze zien dat de aanmaak van bladgroenkorrels door licht in gang wordt gezet. Daarna kan juf Hadassa het proces verder uitleggen.

7. Regen en waterstromen

Juf Femke wil haar groep 4 les gaan geven over waterstromen en de manieren waarop water op aarde voorkomt. Zo wil ze dat de leerlingen leren dat als regen op de aarde neer komt, het water naar beneden stroomt door slootjes, rivieren, meren en oceanen, of in de grond verdwijnt.

Hoe zou jij juf Femke adviseren de les te geven? Kies het antwoord dat het meest lijkt op jouw aanpak.

A. De leerlingen maken van verschillende grondsoorten heuvels en valleien en laten er water overheen vloeien. Vertel ze voorafgaand niet wat jij als leerkracht wilt dat ze onderzoeken, of waarop ze hun aandacht moeten richten. Laat hen rapporteren wat ze zagen dat gebeurde en vraag hen hoe dit vergelijkbaar is met iets op aarde.
B. Projecteer een diagram waarin wordt getoond dat water als regen op aarde neer komt. Ook laat het zien dat regen naar beneden stroomt, en slootjes, rivieren, meren en oceanen vormt, en een deel de grond in gaat. Bespreek elk aspect terwijl je naar de diagram wijst, en ga ondertussen in op vragen van leerlingen.
C. Vertel leerlingen dat regen die neervalt slootjes, rivieren, meren en oceanen vormt, en dat een deel de grond in gaat. Demonstreer dit met een model: een grote, ondiepe, doorzichtige doos waarin grond als heuvels en dalen neergelegd is. De leerlingen kijken als de leerkracht water over de grond spuit, alsof het regen is. Daarna doen de leerlingen dit zelf, schrijven op wat ze zien en relateren dit aan wat er op aarde gebeurt.
D. Geef elk tafelgroepje een doorzichtige doos en laat de groepen een landschap van heuvels en valleien maken. Laat hen bedenken wat er gebeurt als ze water over het landschap spuiten, alsof het regent. Laat het hen dan uitproberen, hun observaties rapporteren en relateren aan wat er op aarde gebeurt.

8. Magnetische aantrekking

Meester Hans begint met zijn groep 4 aan een lessenserie over magnetisme. Zijn doel is dat zij leren over magnetische aantrekkingskracht. Hij geeft aan elk groepje leerlingen een magneet en een dienblad met daarop een paperclip, een munt, een ijzeren spijker, een schaar, een pen, enkele sleutels, een knikker, een potlood, aluminium folie, een beetje zand, en leerlingen kunnen zelf enkele voorwerpen toevoegen.

Meester Hans introduceert de term ‘magnetische aantrekking’ en demonstreert hoe een aantal objecten getest kan worden met een magneet. Groepjes leerlingen wordt dan gevraagd de voorwerpen te sorteren op het dienblad, afhankelijk van of zij wel of niet aan worden getrokken door de magneet.

Als je er over nadenkt hoe jij de les zou geven, hoe zou je de les van meester Hans evalueren?

A. In plaats van met begrippen te beginnen, zou meester Hans beter zijn begonnen met de leerlingen zelf de verschillende voorwerpen te laten onderzoeken en hun ideeën erover met hen bespreken.

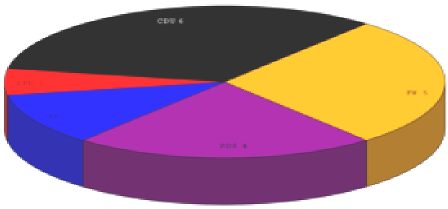
B. Dit is een goede les omdat meester Hans direct begint met de belangrijkste begrippen te introduceren. Hij zou, na te hebben gedemonstreerd hoe je een voorwerp met een magneet kan testen, ook kunnen laten zien wat met andere voorwerpen gebeurt en deze dan sorteren.

C. Meester Hans zou de leerlingen vrij moeten laten onderzoeken met magneten en voorwerpen, zonder de terminologie aan de orde te stellen. Daarna zou hij ze hun ideeën hierover kunnen laten bespreken en dit delen met de klas. De enige bijdrage die hij moet doen is de term magnetische aantrekking introduceren.

D. Dit is een goede les omdat meester Hans direct begint met de belangrijkste begrippen te introduceren, en dit laat volgen door de leerling een onderzoekje te laten doen, waarbij ze de voorwerpen zelf testen en sorteren.

9. Cirkeldiagram

Juf Anne heeft met de kinderen van groep 7 een week lang bijgehouden, in welke mate ze lichamelijk actief zijn geweest. Per dag hebben ze ingevuld hoeveel minuten ze intensief hebben bewogen, matig hebben bewogen, hebben gezeten of geslapen. Juf Anne wil de leerlingen nu leren hoe je daarvan een cirkeldiagram kunt maken.



Hoe zou jij dat aanpakken?

A. Ik zou de leerlingen vertellen dat 24 uur in een dag gezien moet worden als 100 % en dus als de hele cirkel. Ik zou hen op het digibord laten zien hoe je aan kunt geven dat je 8 uur geslapen heb. Ik gebruik verder voorbeelden als 1 uur intensief sporten, 6 uur zitten in de klas Ik vraag hen steeds: hoeveel procent is dat van het geheel? Dan demonstreer ik hen hoe dat ingekleurd kan worden. Ze nemen dit over in hun schrift.

B. Ik zou de leerlingen een ingekleurde cirkel laten zien op het digibord: bijna de helft groen, een smalle streep rood, een kwart geel en een kwart oranje. Ik vraag hen: “Welke kleur komt het meest voor? En welke het minst? Als elke kleur een activiteit voorstelt, wat denk je dat rood betekent voor een kind uit jullie klas? En groen? Hoeveel tijd slaapt dit kind ongeveer? En hoeveel uur sport dit kind ongeveer op een dag? Hoe zou je dus 12 uur in kunnen kleuren? En 2? Doe dat eens voor een dag dat je veel hebt gesport. Vergelijk het met je buurman- of vrouw”. We bespreken het op het einde klassikaal na.

C. Ik zou de leerlingen elk een cirkel geven, verschillende kleuren potloden en een schaar. Ik zou hen vragen met behulp van de cirkel aan een klasgenoot te laten zien hoe een dag waarop de leerling actief is geweest, er uit zag. Daarbij zou een deel van de cirkel steeds symbool moeten staan voor een activiteit. De leerlingen laten dit in tweetallen aan elkaar zien en geven elkaar feedback. Daarna vertelt een aantal leerlingen aan de hele klas hoe ze het hebben opgelost en reagerend e leerlingen op elkaar.

D. Ik zou de leerlingen vertellen dat 24 uur in een dag gezien moet worden als 100 % en dus als de hele cirkel. Ik zou hen op het digibord laten zien hoe je aan kunt geven dat je 8 uur geslapen heb. Ik gebruik verder voorbeelden als 1 uur intensief sporten, 6 uur zitten in de klas Ik vraag hen steeds: hoeveel procent is dat van het geheel? Daarna kleuren ze aan de hand van hun meegebrachte gegevens een lege cirkel in. Die bespreken we daarna klassikaal aan de hand van enkele voorbeelden.

10 Een knikkerbaan maken

De leerlingen van groep 7 werken over constructies. In deze les is het voorbeeld een knikkerbaan, gemaakt van papieren stroken. Meester Patricks bedoeling is, dat de kinderen leren welke vormen zorgen voor stevige constructies.

Hoe zou je deze les aanpakken?

A. Ik laat de kinderen naar het digibord kijken waarop foto's van stevige constructies, zoals bruggen en de Eiffeltoren geprojecteerd zijn. Ik vraag hen wat hen opvalt. De kinderen reageren op mijn vraag en op elkaar. De kinderen experimenteren met papieren stroken om deze constructie voor elkaar te krijgen. Dit laten ze aan elkaar zien. Daarna maken ze van driehoekvormige goten een knikkerbaan in tweetallen en proberen met knikkers uit welke baan het stevigst is. We bespreken hun bevindingen na.

B. Ik laat de kinderen naar het digibord kijken waarop foto's van stevige constructies, zoals bruggen en de Eiffeltoren geprojecteerd zijn. Ik wijs hen erop, dat stevige constructies vaak een driehoekige vorm aannemen en benoem dat. Ik laat hen zien hoe je stevige goten kunt maken, geef hen een stapsgewijs werkblad met plaatjes hoe je een knikkerbaan kunt maken en laat hen dat in tweetallen nadoen. We testen op het einde van de les of alle banen stevig zijn door er knikkers over te laten rollen. Ik vraag de kinderen wat heeft gezorgd voor stevigheid.

C. Ik laat de kinderen naar het digibord kijken waarop foto's van stevige constructies, zoals bruggen en de Eiffeltoren geprojecteerd zijn. Ik wijs hen erop, dat stevige constructies vaak een driehoekige vorm aannemen en benoem dat. Vervolgens demonstreer ik verschillende knikkerbanen voor de klas, en noem daarbij waarom het wel of niet stevig is. De kinderen vullen daarna hun werkblad in, waarin bij plaatjes wordt gevraagd of het een stevige of minder stevige constructie is. Dit werkblad bespreken we na.

D. Ik geef de kinderen papieren stroken en vraag hen ermee te experimenteren. Na enkele minuten geef ik de opdracht: "Maak een knikkerbaan die stevig is". De kinderen kunnen daarbij verschillend papier gebruiken, knikkers van verschillende grootte, steentjes, aluminiumfolie en perspex ballen. Aan het einde van de les vraag ik bij wie de opdracht goed gelukt is en waardoor dit kwam.

Chapter 6

General conclusions and discussion

6.1 Introduction

This final chapter summarizes the combined results obtained from the studies described in the previous chapters. Given that the results of each study have been discussed in their respective chapters, this chapter goes one step further by framing the primary findings in a broader perspective. Two questions are leading: *Which inquiry-based science teaching competencies are required in order to teach inquiry-based science in primary schools?* and *Is there a relationship between the various inquiry-based science teaching competence components?*

Here, it was reviewed how the four studies in this thesis have answered these questions, and the primary findings of these studies were re-stated. Then the outcomes were reviewed in light of the literature, connections were drawn between the studies, and the studies' strengths and limitations was discussed, as well as potential directions for future research. Finally, in the last section, practical implications for educational practice were suggested.

6.2 Primary findings

Inquiry-based science teaching is considered an important innovation in education. However, which competencies are required in order to teach inquiry-based science in primary schools, and how these competencies are related to one another, has remained unclear. In the first two studies of this thesis (a literature study and a Delphi study), the question regarding which competencies pre-service teachers need were answered. The third and fourth studies answered the question regarding how various components of science teaching competences are interrelated.

6.2.1 Required inquiry-based science teaching competencies: a literature review

The United States has used national science teaching standards since 1996. These standards are the end-product of an interactive process that involved several groups of stakeholders, thus reflecting a broad consensus that was reached nearly 20 years ago regarding the elements of science teaching competence. These standards are referenced in many articles published in international journals (for example, Avraamidou & Zembal-Saul, 2010; Howes, Lim, & Campos, 2009; Lin, Hong & Cheng; Liang & Richardson, 2009; Park Rogers, 2009; Varma, Volkmann, & Hanuscin, 2009). Here, it was examined whether these standards are still consistent with contemporary scientific thinking. Specifically, the aim was to investigate whether additions or changes should be introduced to the standards based on research findings that were published from 2004 through 2011. Such information might be helpful in the future for establishing directives in Europe. As discussed above, the US previously differed from Europe with respect to the main conceptualization of competence and competencies. On one hand, fragmenting tasks in the US resulted in a list of atomized work descriptions and isolated competencies; on the other hand, Europe viewed describing competence, the integrative character of performance-oriented capabilities, and adaptation to specific context as important.

Chapter 2 reviewed and compared the recent international scientific literature and the American National Science Education Standards with respect to the elements of teacher competencies that are considered to be necessary for teaching inquiry-based science. Accordingly, the first research questions were as follows: *What elements of competencies required by primary school teachers who teach inquiry-based science are mentioned, discussed, and researched in recent literature?* and *To what extent are the American National Science Education Standards (which were introduced nearly 20 years ago) consistent with the elements of competencies found in recent literature?* To address these questions, we performed a comprehensive literature review using the ERIC (Education Resource Information Center) and Google Scholar databases. Fifty-seven peer-reviewed science journal articles published from 2004 through 2011 were identified using key word combinations. An analysis of these articles resulted in the identification and classification of 23 elements of competencies that are needed by primary school teachers who teach inquiry-based science. These elements were then compared with the American National Science Education Standards. The analysis revealed both similarities and differences between the reviewed literature and the American National Science Education Standards. For example, the reviewed literature was similar to the American Standards with respect to SMK. In both nations, science SMK was perceived to involve physical science, life science, Earth and space science, technology, and mathematics systems. Both the literature review and the American Standards mention and explain the science content component and the required research skills. These skills were further subdivided into the following “levels of mastering”’: isolated, connected, and applied within a context. Both the articles and the American Standards emphasized the importance of establishing a broad range of competencies with respect to the teacher’s Pedagogical Content Knowledge (PCK).

Pedagogical design and preparation, the facilitation of scaffolded inquiry, evaluation, and assessment all cover the same aspects. However, whereas the teachers’ attitudes towards science teaching and science learning are not discussed in the American teaching standards, these aspects of science PCK surfaced repeatedly in our literature review. The teachers' self-efficacy and attitudes towards science are also lacking in the American Standards, whereas our literature review indicated that factors can impact upon other science competence components, as well as science teaching. Therefore it was recommended to add these elements to the American Standards, as they can have a direct impact on teaching practices. Finally, reciprocal relationships between the competence components were found. For example, an experienced teacher's high level of well-connected SMK will affect that teacher's interest in science (Leonard et al., 2009), his/her self-efficacy beliefs (Bhattacharyya et al., 2009; Van Zee et al., 2005), and his/her science-related pedagogical and didactic skills (Lee et al., 2009). Adequate SMK and higher self-efficacy beliefs contribute to a teacher's motivation and commitment to his/her pupils, and they enable the teacher to implement inquiry-based methods more easily and more effectively in practice (Kim & Tan, 2011; Lee et al., 2009; Luera & Otto, 2005). However, the American Standards are presented in a summative manner. Therefore it was recommended that the National Research Council (NRC) should present these competencies in an integrated and holistic manner.

6.2.2 Required inquiry–based science teaching competencies: a Delphi study

The findings of the literature study served as a starting point for our next study, which was a Delphi study. Different groups of Dutch professionals participated in the Delphi study, including teachers who are science coordinators in their schools, as well as researchers, developers, teacher trainers, and policymakers in the area of primary science. By using this approach, it was attempted to overcome the "hierarchical structure" in which knowledge for teaching is generated at the university or government body level and then imposed upon the schools (Van Dijk & Kattmann, 2007; Wallace, 2012). The primary purpose of this study was to validate the previously identified competencies (see Chapter 2) in the context of the Netherlands—where such standards were lacking—and to distinguish between the importance of mastering these competencies for novice teachers versus experienced teachers. The following two research questions were formulated in accordance with the research objective: *To what extent do Dutch experts agree or disagree with the importance of inquiry-based science teaching competence elements as derived from the literature and the American National Science Teaching Standards (NRC, 1996)?* and *According to experts, are there any differences between the importance of competencies for novice teacher versus experienced teachers?"*

A panel of 33 experts was consulted in the Delphi study regarding the importance of 23 identified competencies. The panel reached agreement regarding the importance of proposed primary teachers' science SMK; they also added one additional competency element, and they refined other elements. The additional competency was "knowing and understanding the relationship between facts and concepts of science and subjects other than sub-disciplines of science". The elements that were refined included the understanding of relationships within a science system, particularly within living systems, which respondents did not consider to be important to primary school teachers. Another change included "understanding the relationships between science systems". In general, the panel accepted this as an important competency, but they made an exception for Earth and space systems in relation to other systems. The application of research skills was considered to be unimportant. Respondents noted that teachers should be able to evaluate their pupils' research skills, but they should not necessarily be able to apply or demonstrate research skills—particularly manipulation—flawlessly. The panel also agreed upon the importance of the 13 proposed PCK elements. However, they recommended refining PCK for the competencies regarding the design of science lessons. First, they stated that teachers should not consider demographic factors such as gender and socio-economic status when preparing the lessons, as this could lead to stereotyping. Instead, they proposed that teachers should consider the pupils' prior knowledge, learning styles, and interest. Second, the panel proposed that teachers should be familiar with curriculum goals, as well as how to find and apply these goals; however, the teachers do not necessarily need to know these goals by heart. The panel also agreed upon the importance of all of the competence elements regarding attitudes towards science and science teaching. Nevertheless, in their view the competency element "the importance of science" had to be reduced from the importance for society, economy, and environment to the importance for society and environment.

Agreement was also reached with respect to differences and commonalities between the competencies that are necessary for both novice teachers and experienced teachers. With respect to SMK and PCK, mastering nearly all competencies was considered to be more important for experienced teachers than for novice teachers. Thus, with respect to SMK and PCK in general, novice teachers are expected to develop these competencies throughout their teaching career. This was not the case for "ability to connect new knowledge to either real life or overall science concepts"; thus, teachers must master these competencies early in their career. In addition, experts did not differentiate between novice teachers and expert teachers with respect to the importance of an awareness of existing opinions—and their own opinions—regarding the nature of science. Experts might not expect this competency to develop easily over the years. This is consistent with Hubbard & Abell (2005), who argued that beliefs can persist even when they logically should not. Because most teachers invest emotionally and intellectually in their beliefs, they seek to maintain those beliefs unless they are adequately challenged. Because each new experience is filtered through the lens of the teacher's prior beliefs, teachers may take conflicting evidence and use it to support their beliefs. Thus, the problem that teacher educators face is to challenge firmly held beliefs that are often in conflict with published best practices.

6.2.3 Science teaching attitudes, self-efficacy, and SMK among first-year pre-service primary teachers

Interest has been growing with respect to improving pre-service teachers' attitudes towards science teaching (Johnston & Ahtee, 2006; Martin-Dunlop & Fraser, 2007) and with respect to the teachers' self-efficacy beliefs in teaching science (Bleicher, 2007; Liang & Richardson, 2009; Palmer, 2006; Yilmaz-Tuzun, 2008). To date, however, the relationship between SMK of all five science systems (living, Earth and space, physical, technological, and mathematics systems) and attitudes towards science teaching has not been studied among pre-service primary student teachers. The aim of this study was therefore to help clarify the relationship (if any exists at all) between SMK, science teaching attitude, and self-efficacy using a cohort of Dutch pre-service primary school teachers.

The following research questions were addressed:

1. What characterizes first-year pre-service teachers' Science Teaching Attitudes, Science Self-Efficacy (S-SE), Science Teaching Self-Efficacy (ST-SE), and the teachers' science Subject Matter Knowledge (SMK)?
2. Is there an association between a) first-year pre-service teachers' Science Teaching Attitudes (consisting of pleasure, importance, and competence development) and b) their ST-SE?
3. What is the relationship between pre-service teachers' Science Self-Efficacy (S-SE) and ST-SE?
4. What is the relationship between a) pre-service teachers' SMK, b) their Science Teaching Attitudes (pleasure, importance, and competence development), and c) their S-SE and ST-SE?

On average, the Dutch pre-service teachers who participated in this study reported having a positive attitude towards science teaching. The teachers were neither positive nor negative with respect to engaging in competence development activities and their S-SE and ST-SE. This finding is in contrast with the findings of other researchers with respect to experienced teachers, who perceive science as a difficult subject and feel inadequately prepared to teach science (Tosun, 2000). This finding is also in contrast with the report by Gunning and Mensah (2010), who concluded that most pre-service primary teachers have had negative experiences with science learning—or a lack thereof—and thus shy away from science and science teaching. On one hand, this can be seen as a positive result, as pre-service teachers who have a more positive attitude and science teaching self-efficacy tend to invest more heavily in setting goals and developing aspirations in order to: *i*) exhibit greater levels of planning and organizational behavior, *ii*) be more receptive to new ideas, and *iii*) be more willing to experiment with new methods that may better meet the needs of their pupils (Akinsola, 2008; Tschannen-Moran & Woolfolk Hoy, 2001). On the other hand, pre-service teachers' doubts can have a strong bearing on their continued competence development and on education reform. Moreover, in contexts that require self-regulated learning, accurately and/or realistically evaluating one's own competences is considered an important prerequisite for meaningful learning and effective goal-setting (Narciss, Koerndle, & Dresel, 2011).

The majority of first-year pre-service teachers in our study reported having adequate SMK of living systems and mathematics systems; in contrast, they reported inadequate knowledge of the physical and technological system and the Earth and space system. A positive association was found between ST-SE and aspects of Science Teaching Attitude. S-SE and ST-SE were also positively correlated; in other words, pre-service teachers with higher ST-SE tend to have higher S-SE, derive more pleasure from science teaching, find science teaching to be more important, and appear more willing to develop their science teaching competences. Finally, no association was found between SMK and Science Teaching Attitude or ST-SE. This is consistent with Howitt (2007), who reported that pre-service teachers feel that SMK has little influence on their ST-SE.

6.2.4 The relationship between pre-service primary teachers' science Subject Matter Knowledge (SMK) and Pedagogical Content Knowledge (PCK)

The literature study (Chapter 2) suggested that experienced teachers with low science SMK tend to use more direct teaching approaches in order to avoid being confronted with pupils' questions they cannot answer. On the other hand, teachers with adequate science SMK tend to use more inquiry-based strategies (Davis & Petish, 2005; Kim & Tan, 2011). However, this relationship has not been studied with respect to pre-service teachers. The following question therefore remained: *Is the level of pre-service primary teachers' SMK related to preferred science teaching approaches, as was found among experienced teachers?* Thus, research was needed to investigate the relationship between pre-service teachers' science SMK and their preferred science teaching approaches (STAs), as a component of PCK. Therefore, the aim of this study was to contribute to the body of knowledge regarding the relationship between pre-service teachers' science SMK and science PCK. The following research questions were addressed: How can the reported preferred Science Teaching Approaches (STAs) of pre-service primary teachers be characterized? And is there a relationship between reported preferred science teaching approaches and the science SMK of these pre-service teachers?

The active direct approach and the guided inquiry approach were the most commonly preferred STAs reported by the pre-service teachers in the present study. In terms of impacting pupils' science content knowledge, their research skills, and their attitude towards science, the guided inquiry is considered by some researchers to be the most effective approach (Bunterm et al., 2014; Kirschner, Schweller, & Clark, 2006). In a few cases, pre-service teachers opted for confirmation inquiry, which is the most directive STA. In all three participating institutes, at least 22% of the pre-service teachers indicated a preference for open inquiry–based STAs.

One cannot speak in terms of the "best" STA *per se*. Indeed, the specific approach used should be adapted to match the pupils' prior experiences and knowledge. However, pupils are better motivated during guided and open inquiry lessons compared to confirmation and structured approaches. Moreover, pupils' content knowledge and research skills develop faster with guided inquiry lessons than structured inquiry situations (Bunterm et al., 2014). However, the likelihood of strengthening pupils' misconceptions and misapplications of research skills is lower in the case of structured or guided inquiry compared to open inquiry (Davis & Petish, 2005). This is because misconceptions can be identified and addressed through a process of asking questions and then listening, which is an important component of the structured inquiry and guided inquiry approaches. Thus, it might be concluded that of the two most-preferred STAs, only guided inquiry can be considered the most effective approach in many situations. Open inquiry—which is the STA that was chosen by approximately twenty percent of teachers—is less desirable in cases in which the pupils lack in-depth experience and knowledge of scientific inquiry.

Unlike with experienced teachers, no association between the level of SMK and the preferred STA among pre-service teachers was observed. This lack of association means that pre-service teachers with inadequate SMK might also prefer inquiry-based approaches, unlike experienced teachers who have inadequate SMK. Compared to experienced teachers with inadequate SMK reported on in the literature, first-year pre-service teachers seem to be more open to trying these teaching methods, as they have had relatively few failures associated with teaching science. This could be explained by de results of our former studies, which showed that pre-service teachers with low SMK and pre-service teachers with high SMK do not differ with respect to their self-efficacy towards science teaching (Alake-Tuenter et al., 2013).

6.3 Research findings in an integrative perspective

In this section, the main findings of the studies in this thesis are discussed. The following two questions are leading: *Which inquiry-based science teaching competencies do teachers need in order to use inquiry-based science teaching methods in primary schools?* and *What is the relationship between the inquiry science teaching competence components?*

6.3.1 Required inquiry-based science teaching competencies

A clear understanding of what inquiry-based science entails is essential in order to answer the question of which inquiry-based science teaching competencies are required. All the studies were based on the six essential features of classroom inquiry that apply across grade levels and which were mentioned by the US National Research Council (NRC, 1996; 2000), as these features fit nicely with the understanding of inquiry-based learning by the Dutch National Institute for Curriculum Development (SLO, 2007) and many international researchers (Avraamidou & Zembal-Saul, 2010; Cuevas et al., 2005; Dietz & Davis, 2006; Lin et al., 2009; Howes et al., 2009; Ling & Richardson, 2009; Lin et al., 2009; Park Rogers, 2009; Varma et al., 2009; Smolleck et al., 2006). Specifically, pupils: *i*) address scientifically oriented questions; *ii*) plan and perform studies to gather evidence; *iii*) give priority to evidence when responding to questions; *iv*) formulate explanations for the evidence; *v*) connect those explanations to scientific knowledge; and *vi*) communicate and justify their explanations. In our literature study (described in Chapter 2), the following five levels of inquiry-based science were listed, considering the level of the pupils' independence associated with each aforementioned feature of classroom inquiry: confirmation inquiry, structured inquiry, guided inquiry, student-directed inquiry, and open inquiry. These levels were based on Bonstetter (1998) as discussed by Liang & Richardson (2009). These five levels were reduced to four levels in our PCK study (Chapter 5), as more recent theories do not mention pupil-directed inquiry as a distinct level of inquiry; rather, student-directed inquiry is considered to be a variation of open inquiry, as these two levels do not differ in their fundamental aspects (for example, see Banchi & Bell, 2008; Bruck et al., 2008; Cobern, et al., 2010; Cobern, et al., 2014).

Many researchers (Butts et al., 1994) and policymakers (NRC, 1996; SLO, 2007) view guided inquiry approaches that emphasize scaffolding primary pupils' learning processes as being more effective and efficient than open inquiry approaches. Using guided inquiry approaches, teachers facilitate the primary school pupils' engagement in inquiry, over which the pupils have increasing responsibility and control. This approach might help the pupils develop their understanding of science as a way of knowing, and it may enhance their capacity as independent inquirers (Metz, 2004). In this way, a complex interplay between maturation, experience, and instruction can create opportunities for the pupils to learn (Duschl et al., 2007).

In this thesis, the competencies that are required for inquiry-based teaching were searched for, and a competence profile was developed. According to Du Chatenier et al. (2010), such a profile can be described as an overview of the essential elements of professional competence that are required for performing a job effectively. In Chapters 1 and 2, the concept of "competence" was defined from the perspective of a professional situation. Within this tradition, the concept of "competence" is defined as follows: "Competence is the integrated performance-oriented capability of a person or an organization to reach specific achievement. These capabilities consist of clusters of knowledge structures and cognitive, interactive, affective and (where necessary) psychomotor skills, and attitudes and values, which are conditional for carrying out tasks, solving problems and effectively functioning in a certain profession, organization, position and role" (Mulder, 2001, p. 76).

Although some educationalists believe that SMK is part of PCK (see Chapters 1 and 5), our Delphi study (Chapter 3) and our empirical studies (Chapters 4 and 5) indicated the existence of three distinct clusters of competencies—SMK, PCK, and attitude—with 24 underlying components and/or elements (Table6.1).

Table 6.1 Inquiry-based science teaching competencies list with three clusters and 24 elements

SMK 1: Teachers' knowledge of facts and concepts related to living, technological, and physical systems; Earth and space systems; and mathematics systems

1.1 Understanding the meaning of isolated facts and concepts
1.2 Understanding the relationship between facts and concepts of:
  1.2.1 Different science sub-disciplines, except between Earth and space systems and other systems
  1.2.2 The same science sub-discipline, except within living systems
  1.2.3 Science sub-disciplines and other subjects
1.3 Understanding when—and how—to apply facts and concepts

SMK 2: Teachers' understanding of inquiry skills (Observe; pose questions and predictions; examine books and other sources of information to identify what is already known; plan studies; perform studies using tools to gather, analyze, and interpret data; propose answers, explanations, and predictions using data; communicate and justify results)

2.1 Understanding the meaning of isolated research skills
2.2 Understanding the relationship between the research skills
2.3 Understanding when—and how—to apply research skills, using a manual to support manipulation

Science PCK 1: Pedagogical design capacity: Lesson preparation and adaptation of the curriculum

1.1 Understanding and responding to an individual pupil's interests, strengths, experiences and needs in order to teach meaningful content and context (taking into account prior knowledge, cognitive developmental stage, learning style, interest, and language level)
1.2 Understanding and responding to context (time, space, location, materials, etc.)
1.3 Understanding and responding to aims mentioned in a standard document, with the standard document available and accessible
  1.3.1 Ministry of Education final curriculum goals for final-year pupils (kerndoelen, or core goals)
  1.3.2 Detailed curriculum goals for each primary school age group (Tussendoelen Stichting Leerplan Ontwikkeling)

Science PCK 2: Teachers' facilitation of scaffolded inquiry

2.1 Ability to ask pupils to state their prior ideas explicitly
2.2 Ability to ask (divergent) questions regarding facts and concepts, and encouraging and helping pupils apply this knowledge
2.3 Ability to ask questions regarding the appropriate use of research skills, and encouraging and helping pupils apply this knowledge
2.4 Ability to stimulate discourse, debate, and discussion in small groups regarding research questions and predictions, as well as answers and explanations
2.5 Ability to discuss and/or visualize pupils' thought processes (including mistakes) in order to stimulate class discussion and enhance meta-cognitive awareness

Science PCK 3: Teachers' evaluation and assessment

3.1 Ability to connect new knowledge and understanding with prior knowledge
3.2 Ability to connect new knowledge and understanding with real-life situations

3.3 Ability to connect new knowledge and understanding with overarching science concepts

Science PCK 4 and Science PCK 5: Teachers' attitudes towards science education

4. Attitudes towards teaching science
5. Attitudes towards learners and learning science

Teachers' attitudes 1, 2 and 3

1. Attitudes towards science
   1.1 Importance of science for society, the pupils' daily life, and environment
   1.2 Pleasure
   1.3 Nature of science
2. Teachers' attitudes towards themselves as science teachers (i.e., self-efficacy)
3. Attitudes towards competence development of science and science teaching

The three components and twenty-four identified elements may help pre-service and experienced teachers assess their actual competence. This will in turn help establish professional development inquiry-based science teaching programs for pre-service and experienced teachers. The competence profile might help teacher educators *i*) reflect upon the existing science curriculum in initial teacher training, *ii*) implement competence elements that do not receive sufficient attention, and *iii*) change the teaching approach for science courses. Creating a competency list might also increase the transparency of expectations, which will be reflected by professional licensing; this will be true particularly in the future, when rubrics will be added to the existing list.

In our Delphi study (see Chapter 3), differences emerged between the percieved importance of the competencies that are needed by novice teaches versus experienced teachers. These differences indicate that experts presume that several SMK and PCK competencies can still develop as a result of teaching experience, whereas attitude is seen as a more stable aspect of teaching competence. However, research is needed in order to gain more insight into the development of three science teaching competence components over time. Another objective for future research is to determine the circumstances under which teachers develop the knowledge, skills, and attitudes that are relevant for a particular educational setting, and to determine how knowledge, skills, and attitudes support and contribute to each other.

6.3.2 The relationship between the inquiry-based science teaching competence components of first-year pre-service teachers

Comparing research into the relationship between competence components of experienced teachers with the results of our own study reveals some striking similarities and differences. One similarity between experienced and pre-service teachers was the positive relationship between ST-SE and several attitude elements, including the preparedness of engaging in competence development activities.

Most of the relationships between competence components identified in studies of experienced teachers were not evident among pre-service teachers in the present thesis. Experienced teachers with adequate SMK and high ST-SE tend to use more inquiry-based activities, whereas teachers with inadequate SMK and low ST-SE tend to be teacher-centered, transmitting their knowledge through a fact-based curriculum using a directive approach (Lumpe et al., 2000). Pre-service teachers' SMK in relation to their preferred STA were studied. Although this does not necessarily reflect actual behavior, it was expected to observe the same relations; however, the researchers did not. Rather, it was found that pre-service teachers with inadequate SMK also opt for guided inquiry and open inquiry approaches. This finding may suggest that unlike experienced teachers, the primary competence components of pre-service teachers are not integrated and develop independently of each other. The following question still remains: *When—and under which conditions—do these competence components develop, and are certain interventions required in order to integrate the components?*

While applying confirmation, structured, or guided inquiry approaches, pre-service teachers would provide their pupils with the problem or research question. These three approaches allow the teachers to prepare themselves by gaining knowledge regarding the specific topic before the lesson, thus helping compensate for their knowledge deficits. By reading about the topic beforehand, teachers might also gain insight into their pupils' most common science misconceptions (for example, see Duit, 2009); however, this is not possible in the case of open inquiry, as the pupils create their own research questions, and the teacher does not know the topics in advance. In the case of open inquiry, pre-service teachers can use only their own prior knowledge in the teaching process, and that knowledge might be inadequate. In other words, the likelihood of a pre-service teacher with inadequate SMK augmenting his/her pupils' misconceptions is higher in open inquiry situations than in confirmation, structured, and guided inquiry approaches.

In the third study (see Chapter 4), no association between pre-service teachers' SMK and either their attitude towards teaching science or their ST-SE was found. Thus, simply equipping first-year pre-service students with science knowledge seems not sufficient. In the same study, pre-service teachers with high S-SE had higher ST-SE, expected to derive more pleasure from science teaching, found science teaching to be more important, and were more willing to develop their science teaching competences. These results suggest that teachers who regard themselves as competent in science and science teaching (S-SE and ST-SE, respectively) are more likely to engage in competence development activities (and vice versa) than teachers who have a low ST-SE and derive less pleasure from teaching science. The case of pre-service teachers with low ST-SE can be seen as problematic, as their interrelated negative attitudes and resulting behaviors might become self-fulfilling prophecies—in other words, their negative attitude towards competence development may actually result in less active behavior towards professional development activities, less professional growth, and even lower ST-SE. Thus, teacher trainers must find science competence development activities that specifically engage teachers who regard themselves as being less competent and who derive less pleasure from science and science teaching. A logical starting point might be to teach science in combination with other subjects, or studying pupils' misconceptions and attempting to refute those misconceptions. To gain insight into the relationships between SMK and attitude and between SMK and PCK, SMK tests and question lists were used in studies 3 and 4. These data enabled us to draw conclusions regarding the level of teachers' SMK and their reported preferred STAs, but not regarding their actual behavior in practice. It can be concluded that Dutch pre-service teachers show relatively few associations between SMK and attitude, and they have no association between SMK and their preferred STA. However, SMK might be correlated with the STAs that teachers actually apply in practice. Analyzing observations might reveal connections between SMK, attitudes, and behavior in the classroom. Thus, our recommendation for future research is to study these relationships in practice, in the classroom.

6.4 Strengths and weaknesses

In this section, some of the strengths and weaknesses inherent to the research methods used in this thesis are discussed. One clear strength of this literature study is that recent articles published in international journals were systematically searched for and analyzed. This minimized the risk of including articles that were based on an outdated concept of inquiry-based education (for example, hands-on science). Thus, the likelihood that teacher competencies that are based on outdated science concepts such as fragmented and isolated aspects of behavior would be identified, was reduced. On the other hand, one limitation is that several interesting and potentially relevant publications regarding science teaching competencies were published after 2011, including the new American Science Teaching Standards (2013) and a more refined concept of teachers' perceived self-control, published by Van Aalderen-Smeets & Walma Van der Molen (2013). Another potential weakness of our literature study is that all articles were weighted equally. In addition, either the size or the type of studies that were included in our analysis were not limited, through which the highest possible number of competencies were identified. Future studies should make distinctions between the importance given to the outcomes of empirical versus conceptual articles.

A second strength is that the literature review and Delphi study yielded a useful competence profile, which might be helpful in preparing and/or revising curricula for teacher training programs. The profile might also serve as a starting point for the self-assessment and professional development of individual teachers and school teams.

A strength of Delphi studies in general is the possibility to include a variety of experts, including experts who might not usually disseminate their expertise to others (Wiersma & Jurs, 2005; Bolger & Wright, 2011). Thus, the hierarchical structure of research and policy institutes were overcome by developing competence profiles for those actors who must implement and apply the profiles in the context of teacher training colleges and/or primary schools. However, some general issues with the responses occurred, and these issues can be seen as a weakness. For example, the response rate declined over successive rounds, although this was to be expected (Bolger & Wright, 2011). Nonetheless, the heterogeneity of the Delphi panel members was relatively stable, and the opinions expressed in round one did not change considerably in later rounds.

Studies 3 and 4 involved three Dutch mono-sector teacher training institutes. Compared to multiple-sector institutes, mono-sector institutes are more similar to primary schools in terms of accessibility of facilities and lecturers with specific SMK and pedagogical content skills. Therefore, one strength of selecting three mono-sector institutes is that the ecological validity of our research was strengthened. However, these results cannot easily be generalized to all teacher training institutes. The differences in scores among the three institutes highlight the fact that the institutes likely vary in population and prior knowledge.

Another strength of our study is that the data regarding SMK of pre-service teachers were obtained using a validated SMK test. Thus, it was possible to use standards that apply to our own cohort as well as to the entire population of first-year primary teacher training students in the Netherlands. The two other instruments, which measured science teaching attitude and preferred science teaching strategies, were also based on validated questionnaires. These questionnaires were adapted to fit both our theoretical framework and the Dutch primary curriculum. In general, the quality of the selected scales and items was reliable, except for the concept of Nature of Science. Because Nature of Science, which contains epistemological beliefs of teachers regarding science, might influence how science is taught in primary schools, this concept needs clearer operationalization and a validated measurement tool. Such a tool might provide a more complete picture of teachers' competence.

With respect to data analysis, because three institutes were involved in the studies, a multi-level analysis would not have been appropriate. Therefore, the available data using a different approach were analyzed. Specifically, hypotheses regarding the associations between Attitude and SMK and between PCK and SMK using two-tailed testing in one institute were tested. This resulted in one-tailed hypothesis testing in the other two institutes. The combination of sequential hypothesis testing and the 0.01 significance level reduced the risk of statistical inference based on erroneously capitalizing on random chance.

6.5 Suggestions for future research

The studies performed during this thesis open new important questions that future research should address. With respect to the required science teaching competencies, several new questions arose. For example, research is needed to gain further insight into the development of each of the three science teaching competence components over time. To provide additional insight into the way in which pre-service teachers and experienced teachers develop their science teaching competence, and to determine whether the relationship between competence categories changes over time, longitudinal research is needed. Such research might help us understand better the process by which one becomes an expert in science teaching. For example, is it a gradual, continuous, ongoing process, or do specific critical experiences in a teacher's career drive sudden changes in the teacher's beliefs, attitude, knowledge, and/or practices?

Another question to be addressed in future research is to determine under which circumstances teachers develop the SMK, PCK, and attitudes that are relevant to a given educational setting. Future research might investigate these circumstances and/or conditions in multiple teacher training settings in several countries, as variations exist both between and within national systems (Gray, 2012). For example, the level of teacher training programs differs among countries: some countries offer Bachelor's-level programs, whereas other countries provide pre-service teachers with Master's-level programs. Moreover, some countries prepare their pre-service primary teachers to teach only two or three specific subjects, whereas other countries (for example, the Netherlands) prepare teachers to teach virtually all subjects. The responsibility that teacher training institutes and primary schools have in terms of professional development for pre-service teachers also varies among countries, and these differences can cause dissimilarities in pre-service science SMK, PCK, and attitudes. Longitudinal research into the context of both teacher training colleges and the practice of primary schools might help highlight specific characteristics and components of teacher education programs that can help or hinder the development of inquiry-based science PCK, SMK, positive attitude, and science self-efficacy. Longitudinal research might also yield evidence to suggest how these components integrate with one another, how they are used to implement inquiry-based science education in practice, and how they impact pupils' results. This research might answer several open questions, including: *What is the optimal set of experiences that will both inspire and enable teachers to be effective in inquiry-based science teaching?* and *How can primary teachers develop science-related competencies in addition to—or in combination with—the many other competencies that are necessary for teaching other subjects?* In the past, the dominant model was isolated skills training of specific competencies. It would therefore be interesting to compare this dominant model with a more integrated model of competence development in which SMK, PCK, and attitudes are studied simultaneously. Such a comparison will address the question of how pre-service teachers might be supported in their development of the knowledge, skills, and attitudes that are relevant to a given educational setting, and how knowledge, skills, and attitudes support and contribute to each other.

It would be interesting to examine whether relationships similar to those found in the literature study or in the empirical studies in this thesis also exist between SMK, attitude, and actual behavior. In our literature study, we found evidence to support the assumption that science SMK, PCK, and attitudes are interrelated for experienced teachers. However, we found relatively few such relationships in our empirical studies of pre-service teachers. An SMK test and a question list to study pre-service teachers' attitudes were used, and the teachers' preferred STA's, but not their actual behavior were reported. The recommendation for future research is that these relationships should be studied in the classroom. This recommendation is consistent with Guerra-Ramos et al. (2010), who argue that much can be gained by performing research that investigates teachers' science SMK, PCK, and attitudes, as well as science teaching and learning in situations closely related to classroom practices. The critical issue at hand is whether or not what is *known* (i.e., SMK and PCK) and *believed* (i.e., attitude) is actually expressed while teaching.

Performing longitudinal mixed-methods research —including observations, question lists to probe their attitudes, knowledge tests, a large number of respondents, and the use of multi-level analyses—will directly contribute to the development and testing of hypotheses regarding the nature of the causal relationships between Science Self-Efficacy and Science Teaching Self-Efficacy, as well as between self-efficacy, attitudes, and SMK for each school and for the entire cohort. Practice-embedded observational research might be useful for recording both the teaching context and actual teacher interventions. Subsequently, the pre-service teachers' science teaching attitudes, self-efficacy, and SMK can be related to their actual teaching practices. This research might also be useful for obtaining a better understanding of how a pre-service teacher's perceived control develops (either positively or negatively) due to the teacher's subjective beliefs and feelings regarding internal and external obstacles that might impede the ability to teach science in primary school (Van Aalderen-Smeets & Walma van der Molen, 2013). In this study, an internal factor derived by measuring pre-service teachers' self-efficacy was included. However, the perceived dependency (i.e., the beliefs and feelings that one has regarding the influence of external factors on their teaching), and this might be a useful addition in order to understand better pre-service teachers' expectations and behavior towards science teaching in a specific context was not examined.

Longitudinal research might also add fuel to the discussion regarding epistemological issues surrounding the nature of PCK. Gess-Newsome (1999) drew two models of PCK: an integrative model and a transformative model. In the integrative model, PCK does not exist as a stand-alone category. Teacher knowledge is regarded as an intersection of subject matter, pedagogy, and context. While teaching, all three knowledge areas are integrated as needed in order to create a meaningful and effective learning situation for the pupils. From such a perspective, the domains of knowledge can be developed independently and can be integrated in a later stage. In the transformative model, PCK is an independent category of knowledge. PCK results from merging and transforming knowledge of subject matter, pedagogy, and context to create a new form of knowledge that is more powerful than the sum of its constituent parts; this is particularly true when applied in practice. In both models, reflection emerges as an important element for pre-service teachers in developing expertise in their practice; moreover, reflection is central to teachers accepting more responsibility for their actions (Loughran, 2002).

Appleton (2005) advocates that integrative and transformative PCK may be used at different times by the same teacher, depending on classroom experiences. However, Kind (2009) suggests that in the very early stages of becoming a teacher, the development of one component of teacher knowledge (for example, SMK) can lead to the significant mental adaptation of PCK for classroom use. This notion fits within the transformative model. However, SMK might be more difficult to distinguish as a separate component within a teacher's knowledge base when he/she is more experienced and/or effective, thus representing an integrative perspective. Therefore, both transformative and integrative PCK models might have their place in the curriculum, depending on the teacher's phase in his/her professional development. The question remains whether empirical evidence can be used to support the existence of each model. If so, does each model fit within certain categories of teachers, or are the models applicable only in a specific developmental stage within each teacher's career?

Finally, researchers should be encouraged to collaborate with a common interest in preparing teachers for inquiry-based science teaching. Oftentimes, blame is assigned to the teacher training programs, the quality of the pre-service teacher, and/or the practical placement in primary schools. Actively striving to gain insight into all factors that contribute to the development of pre-service teachers' science teaching should include looking at the successful models that are already in existence, similar to the approach used by networks such as Project Coordinators Network Education (Gray, 2012). These networks actively promote collaborations between stakeholders at all levels (including teachers, teacher educators, school authorities, and industry) in order to support the widespread use of inquiry-based learning in schools around the world. The knowledge obtained is then collated through research and exchanged between projects by publishing articles that describe features of national systems and by evaluating the results of teachers' professional activities.

6.6 Implications for educational practice

Current society requires its citizens to be scientifically literate and to be able to independently research phenomena in daily life. Also this society needs skilled professionals in the fields of education, science and research. Children do not make final choices for one occupational domain during their primary years. However they do rule out certain occupational domains. To prevent children from excluding science and research as a possible future domain, they need teachers who are able to teach science enthusiastically and on a sufficient level. High-quality teachers with up-to-date knowledge and skills and a positive attitude are the foundation of a successful formal science education system. Thus, the development of systems that ensure the recruitment, retention, and continuous professional development of such teachers must take high priority in Europe (Osborne & Dillon, 2008). A certain degree of standardization might contribute to that aim. However, we need to consciously move on the continuum between defining and controlling extreme idiosyncratic competencies on the one hand and giving teachers full responsibility for their own professional development and competence on the other hand. Protocolling certain tasks, routines and standardizing levels of a minimum of competence development contribute to efficient and qualitative good education.

In the Netherlands, a debate is currently ongoing regarding the level of teacher training institutes, pre-service teachers, and teachers in the field of primary education (for example, see http://www.nwo.nl/en/research-and-results/cases/dutch-students-perform-well-but-rarely-excel.html).

National SMK tests to assess Dutch language, mathematics, science, and history were recently introduced for all first-year and third-year teacher training students in order to ensure that students have an adequate level knowledge in these subjects. Students who do not meet the minimum required level of knowledge are asked to leave the teacher training program. As stated above, SMK is a necessary—but not sufficient—condition for being a good teacher. Placing too much emphasis on improving science SMK during initial and post-graduate teacher training might have a negative effect on the attention that is given to developing pre-service teachers' PCK and attitude. In order to successfully develop SMK, PCK, and attitude simultaneously, a recommendation is to select students who have a larger *a priori* knowledge base when they are admitted to the program. This can be achieved in several ways. First, admitting only applicants who competed six years of pre-academic secondary education will help ensure that incoming students have high cognitive abilities and a high degree of prior knowledge. Most teacher training institutes in the Netherlands have gained experience with such students during the past five years, and the initial experiences of the pre-service teachers themselves, the teacher educators, and their mentors seem to be positive in terms of their competences gained during their studies and their preparedness to teach pupils in a global, continuously changing society. Second, requiring students to attend at least one science subject through to their last year of secondary school will increase their SMK. Finally, the SMK test that is currently administered in the first year could be administered before the summer prior to the first academic year.

If the test reveals that a student's knowledge level is inadequate, summer courses could help the student achieve the necessary level.

Science SMK seems to have little relation with pre-service teachers' attitudes towards science or their preferred STA. This conclusion suggests that gaining SMK in initial or post-graduate courses is not sufficient to learn, master, and then apply inquiry-based science teaching competencies in practice, nor will it necessarily lead to a more positive attitude, more positive self-efficacy, or a deliberately chosen science teaching strategy. Moreover, instructional approaches that merely advocate inquiry-based teaching (by giving theoretical arguments for inquiry-based teaching without providing direct experience) seem to be both insufficient and contrary to inquiry-based learning (Britner & Finson, 2005). Exposing students to effective science inquiry models in student teaching programs might help overcome this problem, but it may not be sufficient to change the attitudes of pre-service teachers and/or experienced teachers. If pre-service teachers and experienced teachers in post-graduate science teaching courses merely copy "activities that work" (Appleton, 2003), they may end up teaching a fragmented curriculum in which activities might be considered isolated experiments with a predictable outcome. For the best outcome, the learning activities should be embedded in the pupils' daily environment. We must therefore develop teacher education programs that are designed to bridge the gap between theory and practice. Modeling teacher educators—including enthusiasm for science, how to teach science, how to reflect upon learning and teaching experiences, and how to establish a meaningful learning environment—exerts a major influence on the confidence of pre-service teachers (Howitt, 2006; Martin-Dunlop & Fraser, 2007).

Both pre-service teachers and experienced teachers should understand clearly the various types of inquiry-based teaching. In order to prevent the consolidation of pupils' misconceptions, guided inquiry should be used, and those misconceptions should be questioned or refuted. Placing a disproportionate emphasis on inquiry-based science teaching in teacher training programs—without clarifying the difference between open inquiry and guided inquiry–based teaching—might result in teachers who opt for open inquiry as their preferred science teaching strategy, including the inherent risk of augmenting pupils' misconceptions of constructs in science. When teachers are cognizant of these different inquiry approaches, and their inherent advantages and disadvantages, they might then be able to deliberately opt for one approach, depending on the context and the pupils.

Several didactic strategies in teacher training might be valuable for achieving a higher level of SMK, more consciously selected STA, and more positive attitudes towards competence development and integration of SMK and PCK. One such strategy is to encourage both pre-service teachers and experienced teachers to study specific science topics in order to broaden their SMK. Teachers should also study the most common misconceptions among pupils in this area, as well as didactic approaches to tackle those misconceptions. These strategies are based—at least in part—on theory (for example, see Taber, 2002; Barker, 2004; Duit, 2009). Pre-service teachers can also reflect upon and collect misconceptions when teaching these themes, bringing their results back to their teacher training classes and studying and discussing those misconceptions with their peers and teacher educators, thereby determining how to best confront pupils with their misconceptions. Teacher educators can also introduce several misconceptions together with proven strategies to understand what pupils are thinking either prior to—or in response to—instruction. These strategies include various forms of "real type" feedback, which can involve electronic survey systems (Martyn, 2007), “just in time teaching" (in which pupils are asked various questions prior to the class, and the pre-service teacher uses the responses to adapt his or her teaching to the pupils' prior knowledge and misconceptions) (Rozycki, 1999), and diagnostic concept inventory instruments (Taber, 2002). Concept inventories can be particularly helpful for identifying pupils’ preconceptions by bringing the preconceptions to a conscious level, thereby allowing the pupils to confront them, using results obtained from their inquiries. Using this strategy, pre-service teachers can become familiar with their pupils' initial and developing misconceptions, and they can adapt their lessons accordingly (Bransford et al., 2000; Garvin-Doxas & Klymkowsky, 2008). These misconceptions—as well as the teaching strategies that pre-service teachers can use to change them—can then be shared and reflected upon in collaborative teacher training. Reflecting on former science experiences and their practical placement might enable pre-service teachers to become more aware of their own attitudes, what caused those attitudes, and whether those attitudes can—or even should—change. Moreover, providing opportunities to reflect upon the conceptions of inquiry within curriculum materials, as well as within educational practice in order to add ideas to their repertoires might help increase PCK. By integrating these ideas with others, teachers might further develop their own identities as teachers (Dietz & Davis, 2009; Park Rogers, 2009). Furthermore, discussions and/or assignments that stimulate reflection among pre-service elementary school teachers might also give teacher educators insight into the knowledge that pre-service elementary teachers have regarding inquiry-based science teaching, what they think about inquiry-based science teaching, and the challenges that they face in practice. This explicit, reflective approach could help teacher educators adapt the lessons of teacher training programs to meet the needs of their students.

Encouraging pre-service teachers to map natural objects and infrastructure in the neighborhood of the school might provide them with better insight into their pupils' daily lives. Thus, teachers can adapt the content of their science lessons to the context (i.e., their pupil's interests and prior knowledge base). Moreover, teacher educators should provide pre-service teachers with the opportunity to examine, elaborate, and integrate new knowledge and beliefs regarding teaching and learning into their existing set of knowledge and beliefs. To learn how to implement the inquiry method, pre-service teachers require both mentoring and support during their internship (Moseley et al., 2004), as well as an induction period as a beginning teacher (Avraamidou & Zembal-Saul, 2010). Establishing strong partnerships between teacher training institutes and primary schools might help educators achieve this important goal. In such a context, SMK, PCK, and a positive attitude can grow simultaneously and strengthen one another.

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Summary

In recent years, improving primary science education has received considerable attention. In particular, researchers and policymakers advocate the use of inquiry-based science teaching and learning, believing that pupils learn best through direct personal experience and by incorporating new information into their existing knowledge base. Therefore, corresponding educational paradigms have shifted from merely reproducing knowledge to asking scientifically oriented questions and searching for evidence when responding to those questions. This approach is considered to be the starting point for motivating pupils to apply research skills, construct meaning, and acquire scientific knowledge. Teachers' competencies are essential for increasing pupils' learning and for stimulating their interest in science. Research has indicated that primary school teachers find it difficult to become effective inquiry-based science teachers because they often lack key knowledge regarding how science inquiry works and—in particular—how to implement inquiry-based teaching in their classrooms (Lee, Hart, Cuevas & Enders, 2004; Van Zee et al., 2005; McDonald, 2009). In the absence of these key competencies, qualitatively poor or insufficient guidance and insufficient feedback could be received during the discovery process. High-quality teacher education that yields competent teachers is the foundation of any system of formal education. However, the Netherlands lacks a recent formal agreement between professionals regarding the competencies that teachers need in order to teach inquiry-based primary science.

In light of this issue, this thesis has two key aims. The first aim is to clarify which competencies are needed in order to teach inquiry-based primary science. The second aim is to determine how various components of science-teaching competence are related. The first aim was achieved by performing a literature study and a Delphi study, and the second aim was achieved by performing empirical studies using a knowledge test, a list of attitude questions, and a case-based questionnaire designed to assess Pedagogical Content Knowledge (PCK).

Chapter 1 describes the context of the study, the problem statement, the purpose of the research, and the core concepts of this thesis. Given the lack of an overview of research in inquiry-based competencies for teaching science, Chapter 2 addresses the following question: *What elements of competencies required by primary school teachers who teach*

inquiry-based science are mentioned, discussed and researched in recent literature? The literature review used specific inclusion criteria, and a total of 57 articles were selected for analysis. The analysis led to the identification and classification of 3 competence components and 23 elements of competencies that are needed by primary school teachers who teach inquiry-based science.

We then compared the outcomes of the analysis with the American National Science Education Standards, as these standards are referenced in international articles. The aim of this comparison was to investigate whether the standards should be supplemented or changed based upon the research findings that were published from 2004 through 2011. Because this analysis might be helpful in stating future directives in the context of Europe, the second research question was as follows: *To what extent are the original American National Science Education Standards (which were introduced 15 years ago) consistent with elements of competencies found in recent literature?* We concluded that most teaching-related American National Science Education Standards are similar to the elements of teacher competencies that are found in the articles reviewed. Moreover, the articles and the American standards emphasized the importance of research skills and competencies in the teachers' Subject Matter Knowledge (SMK). Our research indicates that the American standards do not mention whether teachers' attitudes towards themselves as science teachers, nor do they mention the teachers' attitudes towards science, science teaching, or science learning. We suggest that these elements should be added, as they can have an impact on teaching practices. Adding these elements might also encourage educators to focus on these aspects, and it might help primary school teachers reflect upon their attitudes and gain insight into the aspects that help or hinder their professional development.

In Chapter 3, we used a Delphi study to investigate to what extent 33 experts agreed regarding the importance of the 23 competencies that were identified in the second chapter. Accordingly, we asked the following research question: *To what extent do Dutch experts agree or disagree with the importance of using the inquiry-based science-teaching competence elements that were derived from the literature and the American National Science Education Standards (NRC, 1996)?* In addition, the Dutch experts distinguished between the importance of novices mastering these competencies versus the importance of experienced teachers mastering these competencies. Therefore, Chapter 3 also addressed the following second research question: *According to experts, are there any* *differences between the importance of competencies of novice versus experienced teachers?* The panel reached consensus regarding the importance of the proposed SMK for primary teachers, and the panel added one additional competence element. The panel of experts also agreed on the importance of the proposed 13 Pedagogical Content Knowledge (PCK) elements. In addition, some of the competence elements regarding both SMK and PCK were refined. The panel also agreed on the importance of the competence elements of attitudes with respect to science and teaching science. The respondents reported differences between the importance of required competencies for novice teachers and experienced teachers regarding most SMK competence elements. In addition, with respect to PCK, differences were reported in the perceived importance between novice teachers and experienced teachers. On the other hand, no statistically significant difference was reported with respect to the importance of attitudes regarding the nature of science. The experts proposed that teachers should be given sufficient opportunities to integrate competences regarding science knowledge, attitudes, and teaching skills throughout their careers. Based upon the analysis, we propose a competence profile. In addition, Chapter 3 synthesizes the findings and suggests areas that still need further research.

Based on the results of the Delphi study in Chapter 3, the aim of fourth chapter was to investigate the relationship between the Science Teaching Attitudes, Science Self-Efficacy (S-SE), Science Teaching Self-Efficacy (ST-SE), and Subject Matter Knowledge (SMK) of pre-service teachers. This study addressed the following research questions:

1. What characterizes first-year pre-service teachers' Science Teaching Attitudes, S-SE, ST-SE, and SMK?
2. Is there an association between
    a) first-year pre-service teachers' Science Teaching Attitudes (consisting of pleasure, importance, and competence development) and
    b) their ST-SE beliefs?
3. What is the relationship between pre-service teachers' S-SE and ST-SE?
4. What is the relationship between
    a) pre-service teachers' science SMK,
    b) their Science Teaching Attitudes (pleasure, importance, and competence development), and
    c) their S-SE and ST-SE?

Three institutes that train teachers participated in this study. Based on the results obtained from the first institute, informative hypotheses were formulated and then tested at the two other institutes. In total, 430 first-year pre-service teachers completed a questionnaire that was designed to assess their Science Teaching Attitudes, S-SE, and ST-SE. The scores obtained from national tests were used to estimate the teachers' SMK.

The results revealed that on average, pre-service teachers have a positive attitude towards science teaching. Regarding SMK, not up to two-third of pre-service teachers had passed the SMK tests (Table 3). ST-SE was positively associated with both S-SE and Science Teaching Attitudes, particularly with respect to pleasure in—and the valued importance of—science teaching and competence development. These results indicate that teachers who consider themselves to be competent in science and science teaching (S-SE and ST-SE) express a stronger intention to engage in competence development activities—and vice versa—compared to teachers who have low ST-SE and derive less pleasure from teaching science. Teacher trainers must find science competence development activities to engage pre-service teachers who consider themselves to be less competent, and to engage teachers who derive less pleasure from science and science teaching. No correlation was found between S-SE and SMK with respect to physics and technology, earth and space, or mathematical systems. Indeed, pre-service teachers may lack a realistic view of their own SMK regarding these systems. A lack of correlation between SMK and S-SE means that some pre-service teachers underestimate their knowledge base, whereas other teachers overestimate their knowledge base. In general, no correlation was found between SMK and Science Teaching -Attitudes, or ST-SE. This finding suggests that increased SMK does not automatically result in a more positive attitude towards science teaching or ST-SE (and vice versa). SMK, ST-SE, and Science Teaching -Attitudes all require attention during teacher training.

Although the SMK levels of pre-service teachers have been studied extensively, relatively little research has been reported regarding the PCK of pre-service teachers and the relationship between the teachers' SMK and PCK. Therefore, in ourfifth chapter, we addressed the following research questions:

1. How can the reported preferred Science Teaching Approaches of pre-service primary teachers be characterized?
2. Is there a relationship between reported preferred science teaching approaches and the science SMK of these pre-service teachers?

This study included the same three teacher training institutes and the same first-year pre-service teachers as chapter 4. The results showed that pre-service teachers more frequently opt for structured or guided inquiry; in contrast, teachers are less likely to opt for confirmation inquiry, which is the most directive form of STA. Only in one-fourth of all cases pre-service teachers preferred open inquiry as their teaching approach. No correlation was found between pre-service teachers' SMK and their preferred STA's. We therefore conclude that teacher training curricula should include theory regarding—and reflection upon—science SMK and PCK, using the pupil's prior knowledge as a starting point. Pre-service teachers require a nuanced overview of teaching approaches in order to make deliberate and informed choices, taking into account their pupils and various contexts. Placing a disproportionate emphasis on inquiry-based science teaching in teacher training programs—without addressing the various forms—could result in pre-service teachers who tend to use open inquiry as their preferred science teaching approach, which includes the inherent risk of increasing pupils' misconceptions of constructs in science.

Chapter 6 summarizes the combined results of the studies and also reflects upon the aims of this thesis. The results suggest that having SMK is necessary—but is not sufficient—for being a good teacher. During initial and post-graduate teacher training, placing too much emphasis on improving science SMK might negatively affect the attention towards—and the development of—pre-service teachers' PCK and attitudes. We therefore recommend selecting students who have a high level of prior knowledge at the time of intake. To improve SMK, a more consciously chosen science teaching approach might be beneficial. Such an approach will result in positive attitudes regarding competence development and the integration of SMK and PCK, as well as several didactic strategies in teacher training. One such possible strategy is to stimulate pre-service and experienced teachers to study specific science topics in order to obtain broader SMK. Combining the most common misconceptions regarding pupils and didactic approaches in this area will help eliminate these misconceptions. Applying this knowledge in practice—and reflecting on teachers' experiences—might strengthen all three components of science teaching competence. Thus, teachers need both mentoring and support during their internship in order to learn how to implement the inquiry method in their pre-service (Moseley, Ramsey & Ruff, 2004) and induction periods as starting teachers (Avraamidou & Zembal-Saul, 2010). In addition, establishing strong partnerships between teacher training institutions and primary schools will likely contribute to achieving this goal.

Finally, the results of this thesis suggest that additional research must be performed in order to determine how science teaching competencies develop over time. Another outstanding topic to be investigated in future research is the circumstances under which teachers develop the knowledge, PCK, and attitudes that are relevant to a particular educational setting. It would therefore be beneficial to encourage collaborations among researchers who share an interest in preparing teachers for inquiry-based science teaching. All too often, blame is assigned to the teacher training program, the quality of the pre-service teacher, and/or the practical placement in primary schools. The benefits of actively striving to gain insight into all factors that contribute to the development of science teaching among pre-service teachers should be explored by examining the successful models that are currently in place.

Samenvatting

De laatste jaren heeft het verbeteren van wetenschap onderwijs in de basisschool veel aandacht gekregen. Onderzoekers en beleidsmakers pleiten voor de didactiek van onderzoekend leren, er van uitgaande dat leerlingen het beste leren door persoonlijke ervaringen en door integratie van nieuwe informatie in hun voorkennis. Daarom zijn onderwijskundige paradigma's verschoven van de nadruk op reproduceren van kennis naar het stellen van wetenschappelijk georiënteerde vragen en het zoeken naar bewijs bij het beantwoorden van die vragen. Deze aanpak wordt verondersteld het startpunt te zijn van het motiveren van leerlingen voor het toepassen van onderzoek vaardigheden, het construeren van betekenis en het opdoen van wetenschappelijke kennis. De competenties van een leerkracht zijn essentieel voor het verbeteren van leerprocessen bij leerlingen en voor het stimuleren van hun interesse in wetenschap. Onderzoek heeft laten zien dat basisschool leerkrachten het moeilijk vinden onderzoekend leren effectief vorm te geven, omdat ze belangrijke kennis met betrekking tot het doen van onderzoek en hoe onderzoekend leren te implementeren in hun klaslokaal, missen (Lee, Hart, Cuevas & Enders, 2004; Van Zee et al., 2005; McDonald, 2009). Bij afwezigheid van deze competenties kan tijdens het onderzoek leerproces kwalitatief slechte of onvoldoende begeleiding en feedback worden ontvangen. Goede lerarenopleidingen die competente leerkrachten afleveren, vormen de basis van elk kwalitatief goed formeel onderwijssysteem. In Nederland mist echter een actuele, formele overeenkomst tussen professionals betreffende competenties die basisschoolleerkrachten nodig hebben om vorm te geven aan onderzoekend leren bij wetenschap.

Dit proefschrift heeft aansluitend bij deze constatering twee doelen. Het eerste doel betreft het in kaart brengen welke competenties nodig zijn bij wetenschap onderwijzen volgens de didactiek van het onderzoekend leren. Het tweede doel is het vaststellen hoe verschillende competentiecomponenten, nodig om les te geven in wetenschap volgens de didactiek van onderzoekend leren, tot elkaar gerelateerd zijn. Het eerste doel werd behaald door het uitvoeren van literatuuronderzoek en het doen van een Delphi studie; het tweede door het uitvoeren van empirische studies waarbij gebruik werd gemaakt van een kennistest, een attitude vragenlijst en een case-based assessment instrument ontworpen om de Pedagogical Content Knowledge (PCK) van leerkrachten vast te stellen.

Hoofdstuk 1 beschrijft de context van de studie, de probleemstelling, de onderzoeksdoelen, en de belangrijkste concepten van deze thesis. Omdat een samenvattend overzicht van onderzoek in competenties nodig om met behulp van onderzoekend leren te onderwijzen mist, gaat hoofdstuk 2 in op de vraag: “ Welke competentie elementen die basisschool leerkrachten nodig hebben als zij wetenschap volgens de didactiek van onderzoekend leren onderwijzen, worden genoemd, bediscussieerd en onderzocht in recente literatuur?” In het literatuuronderzoek zijn specifieke inclusie criteria gehanteerd en 57 artikelen werden aldus geselecteerd voor analyse. De analyse heeft geleid tot de identificatie en classificatie van 3 competentie componenten en 23 elementen van competenties welke basisschoolleerkrachten nodig hebben als zij wetenschap volgens de didactiek van onderzoekend leren onderwijzen.

We hebben de uitkomsten van de analyse vergeleken met de Amerikaanse ‘National Science Education Standards’ omdat veelvuldig naar deze standaarden wordt verwezen in internationale artikelen. Het doel van deze vergelijking was te onderzoeken of deze standaarden aangevuld of veranderd zouden moeten worden, gebaseerd op onderzoeksresultaten welke zijn gepubliceerd tussen 2004 en 2011. Omdat deze analyse bij kan dragen aan toekomstige standaarden voor de Europese context, was de tweede onderzoeksvraag: “In welke mate zijn de originele Amerikaanse National Science Standards (welke 15 jaar geleden werden geïntroduceerd) consistent met in de recente literatuur gevonden competentie elementen*?* We concludeerden dat de meeste Amerikaanse National Science Education Standards vergelijkbaar zijn met competentie elementen welke werden gevonden in de onderzochte artikelen. De artikelen en de Amerikaanse standaarden benadrukten het belang van onderzoek vaardigheden en vakinhoudelijke kennis (SMK). Ons onderzoek liet zien dat de Amerikaanse standaarden de attitude ten aanzien van zichzelf als leerkracht in wetenschap, attitude ten aanzien van wetenschap en attitude ten aanzien van het lesgeven in en competentie ontwikkeling ten aanzien van wetenschap niet noemen. We stellen voor deze elementen toe te voegen, omdat ze een invloed kunnen hebben op de onderwijspraktijk. Het toevoegen van deze elementen zou docenten van lerarenopleidingen kunnen stimuleren ook op deze aspecten te focussen, en het kan basisschoolleerkrachten tot hulp zijn bij het reflecteren op hun houding en inzicht geven in aspecten die hun professionele ontwikkeling stimuleren dan wel afremmen.

In hoofdstuk 3 hebben we de Delphi methode gebruikt om te onderzoeken in welke mate 33 experts overeen kwamen met betrekking tot het belang dat zij hechten aan de 23 competenties die eerder werden geïdentificeerd in het tweede hoofdstuk. Overeenkomstig daarmee was onze onderzoeksvraag: *In welke mate komen Nederlandse experts overeen of verschillen ze ten aanzien van het belang dat zij hechten aan het gebruik van leerkracht competenties op het gebied van wetenschap onderwijzen volgens de didactiek van* *onderzoekend leren, welke ontleend zijn aan literatuur en de Amerikaanse Natianal Science Education Standards* (NRC, 1996)? Aanvullend hebben de Nederlandse experts het verschil aangegeven tussen het belang dat zij hechten aan de beheersing van de competenties door startende en door meer ervaren leerkrachten. In hoofdstuk 3 staat dan ook een tweede onderzoeksvraag centraal: *Zijn er volgens experts verschillen tussen het belang van competenties van startende en meer ervaren leerkrachten?* Het panel heeft consensus bereikt wat betreft het belang van de voorgestelde vereiste vakinhoudelijke kennis (SMK) van basisschoolleerkrachten. Ze hebben een element toegevoegd. Het expertpanel was ook eens over het belang van de 13 Pedagogical Content Knowledge (PCK) elementen. Sommige aspecten van de voorkennis en PCK werden verfijnd. Het panel bereikte ook overeenstemming wat betreft het belang van attitude elementen met betrekking tot wetenschap en het onderwijzen van wetenschap bij basisschoolleerkrachten. De respondenten gaven verschillen aan tussen het belang van de vereiste competenties voor startende en ervaren leerkrachten betreffende aspecten van voorkennis. Ook gaven zij een verschil aan tussen het belang van PCK voor startende en ervaren leerkrachten. In tegenstelling daarmee werd geen statistisch significant verschil gevonden tussen het belang van de gepercipieerde aard van wetenschap tussen startende en ervaren leerkrachten. De experts opperden dat leerkrachten voldoende mogelijkheden moeten krijgen hun competenties betreffende vakkennis, attitudes en pedagogisch didactische vaardigheden ten aanzien van wetenschap gedurende hun loopbaan te integreren. Op basis van de analyse stellen we een competentie profiel voor. Hoofdstuk 3 vat de resultaten samen en suggereert gebieden waarop meer onderzoek nodig is.

Gebaseerd op de resultaten van de Delphi studie in hoofdstuk 3, is het doel van hoofdstuk 4 de relatie tussen de attitudes ten aanzien van wetenschap onderwijzen; de self-efficacy ten aanzien van wetenschap en wetenschap onderwijzen (S-SE en ST-SE); en voorkennis (SMK) van aanstaande leerkrachten te onderzoeken.

De studie gaat in op de volgende vragen:

5. Wat kenmerkt de attitude van eerstejaars aanstaande leerkrachten ten aan zien van wetenschap onderwijzen, de S-SE, ST-SE, en SMK?
6. Is er een relatie tussen
   a) de attitude ten aanzien van wetenschap onderwijzen van eerstejaars aanstaande leerkrachten (bestaande uit plezier, belang, en competentie ontwikkeling) en
   b) hun ST-SE?
7. Wat is de relatie tussen de S-SE en ST-SE van eerstejaars aanstaande leerkrachten?
8. Wat is de relatie tussen

a) de voorkennis (SMK) van eerstejaars aanstaande leerkrachten,
b) hun attitude ten aanzien van wetenschap onderwijzen (plezier, belang en competentie ontwikkeling) en
c) hun S-SE en ST-SE?

Drie PABO's hebben geparticipeerd in de studie. Gebaseerd op de resultaten verkregen in het eerste instituut zijn hypothesen geformuleerd en getest in de twee andere instituten. In totaal hebben 430 eerstejaars aanstaande leerkrachten een vragenlijst gericht op het in kaart brengen van attitudes ten aanzien van wetenschap en wetenschap onderwijzen, S-SE en ST-SE, ingevuld. De scores verkregen door middel van nationale toetsen zijn gebruikt om de het niveau van voorkennis van aanstaande leerkrachten te beoordelen. De resultaten lieten zien dat eerstejaars aanstaande leerkrachten gemiddeld genomen een positieve attitude hebben ten aanzien van het lesgeven in wetenschap. Wat betreft vakinhoudelijke kennis heeft minder dan twee derde de kennistoetsen behaald (zie tabel 4.3). ST-SE was positief geassocieerd met zowel S-SE als de attitude ten aanzien van wetenschap onderwijzen, zowel het plezier in en het belang van wetenschap onderwijzen als competentie ontwikkeling op het gebied van wetenschap onderwijzen.

Deze resultaten laten zien dat leerkrachten die zichzelf bekwaam achten in wetenschap en in wetenschap onderwijzen (S-SE en ST-SE) uitdrukking geven aan een sterkere intentie zich in te zetten voor activiteiten met betrekking tot competentie ontwikkeling - en vice versa-, in vergelijking met leerkrachten met een lage ST-SE en die minder plezier hebben in wetenschap onderwijzen. Docenten aan lerarenopleidingen moeten daarom op zoek naar aansprekende leeractiviteiten voor aanstaande leerkrachten die zichzelf als minder competent zien, en die weinig plezier beleven aan wetenschap onderwijzen, zodat ook zij zich inzetten voor wetenschap.

Er werd geen correlatie gevonden tussen S-SE en SMK op het gebied van natuurkundige en fysische systemen, aarde en ruimte systemen of mathematische systemen. Eerstejaars aanstaande leerkrachten missen mogelijk een realistische kijk op hun eigen vakinhoudelijke kennis ten aanzien van deze systemen. Als er geen correlatie tussen SMK en S-SE is, betekent dit dat sommige aanstaande leerkrachten hun vakinhoudelijke kennis onderschatten, terwijl anderen hun kennis overschatten. Er werd algemeen genomen geen correlatie gevonden tussen SMK en attitudes ten aanzien van wetenschap onderwijzen. Deze uitkomsten suggereren dat toename van vakinhoudelijke kennis niet automatisch resulteert in een positievere houding ten aanzien van wetenschap onderwijzen of een positieve ST-SE (en vice versa). SMK, ST-SE en attitudes ten aanzien van wetenschap onderwijzen hebben elk aandacht nodig in de lerarenopleiding.

Hoewel het niveau van vakinhoudelijke kennis van aanstaande leerkrachten uitvoerig bestudeerd is, is er relatief weinig onderzoek gedaan naar PCK van aanstaande leerkrachten en naar de relatie tussen de voorkennis en PCK van leerkrachten. Daarom gaan we in het vijfde hoofdstuk in op de volgende onderzoeksvragen:

3. Hoe kan de gerapporteerde, geprefereerde onderwijsaanpak (STA) van aanstaande leerkrachten worden gekarakteriseerd?
4. Is er een relatie tussen de gerapporteerde, geprefereerde onderwijsaanpak (STA) en vakinhoudelijke kennis van wetenschap van aanstaande leerkrachten?

In deze studie hebben dezelfde drie lerarenopleidingen en dezelfde aanstaande leerkrachten geparticipeerd als in hoofdstuk 4. De resultaten laten zien dat aanstaande leerkrachten vaker kiezen voor gestructureerd of begeleid onderzoekend leren. Daarentegen kiezen aanstaande leerkrachten minder vaak voor confirmatief onderzoekend leren, welke de meest directieve onderwijsaanpak (STA) is. In een op de vier gevallen verkiezen de respondenten open onderzoekend leren als hun onderwijsaanpak. Er werd geen correlatie gevonden tussen de vakinhoudelijke kennis van aanstaande leerkrachten en hun geprefereerde onderwijsaanpak. Daarom concluderen we dat de curricula van lerarenopleidingen theorie over en reflectie ten aanzien van vakinhoudelijke kennis en PCK zouden moeten omvatten, waarbij de voorkennis van basisschoolleerlingen als startpunt wordt genomen. Aanstaande leerkrachten zouden een genuanceerd overzicht moeten hebben van onderwijsaanpakken om in staat te zijn een bewuste en beargumenteerde keuze te maken, waarbij ze hun leerlingen en de specifieke context in ogenschouw nemen. Een onevenredige nadruk op onderzoekend wetenschapsonderwijs in lerarenopleidingen- zonder de verschillende vormen te behandelen- kan er toe leiden dat aanstaande leerkrachten de neiging hebben open onderzoekend leren te verkiezen boven andere vormen, wat het inherente risico van het versterken van misconcepten bij leerlingen tot gevolg zou kunnen hebben.

Hoofdstuk 6 vat de resultaten van de verschillende studies samen, in relatie tot elkaar en reflecteert op de doelen van dit proefschrift. De resultaten suggereren dat het hebben van voldoende voorkennis een noodzakelijke, maar geen voldoende voorwaarde, voor een goede leerkracht vormt. Gedurende de initiële en post-initiële opleiding kan het teveel benadrukken van het verbeteren van vakinhoudelijke kennis de aandacht voor en de ontwikkeling van PCK en attitudes negatief beïnvloeden. We bevelen daarom aan bij de intake studenten te selecteren die een hoog niveau van vakinhoudelijke kennis bezitten. Een bewust gekozen onderwijsleerstrategie kan daarbij bevorderlijk zijn voor de ontwikkeling van vakinhoudelijke kennis. Zo’n aanpak kan in de lerarenopleiding resulteren in positievere attitudes ten aanzien van competentie ontwikkeling en de integratie van vakinhoudelijke kennis en PCK, als ook in de toename van gekende didactische strategieën. Een mogelijke strategie om dit te bereiken is het stimuleren van aanstaande leerkrachten en meer ervaren leerkrachten tot het bestuderen van specifieke onderwerpen uit de wetenschap en zo toe te nemen in vakinhoudelijke kennis. Het combineren van de meest voorkomende misconcepten van leerlingen en didactische aanpakken binnen dat onderwerp zal kunnen bijdragen aan het voorkomen of aanpakken van die misconcepten. Het toepassen van die kennis in de praktijk en het reflecteren op praktijkervaringen zou elk van de drie competentie componenten ten aanzien van het onderwijzen van wetenschap, kunnen versterken. Leerkrachten hebben begeleiding nodig van een mentor, tijdens de initiële opleiding in stage (Moseley, Ramsey & Ruff, 2004) en in de inductie periode als startende leerkracht (Avraamidou & Zembal-Saul, 2010) om te leren hoe ze onderzoekend leren in de praktijk kunnen implementeren. Verder kunnen een goede samenwerking tussen de lerarenopleiding en tussen opleidingsscholen bijdragen aan het bereiken van dit doel.

Tenslotte suggereren de resultaten van dit proefschrift dat toekomstig onderzoek nodig is om vast te stellen hoe competenties op het gebied van wetenschap onderwijzen zich over langere tijd ontwikkelen. Een ander openstaand onderwerp voor toekomstig onderzoek betreffen de omstandigheden waaronder leerkrachten kennis, PCK en attitudes die belangrijk zijn voor een specifieke context, ontwikkelen. Samenwerking tussen verschillende onderzoekers die interesse hebben in het voorbereiden van aanstaande leerkrachten op het geven van wetenschap onderwijs, zou daaraan bij kunnen dragen, Te vaak wordt nu met een beschuldigende vinger gewezen naar de lerarenopleiding, of naar het niveau van de aanstaande leerkracht, of naar de kwaliteit van stagescholen. Het voordeel van actief streven naar inzicht verwerven in alle factoren die bijdragen aan de ontwikkeling van competenties van aanstaande leerkrachten om wetenschap te onderwijzen moet verder worden verkend door reeds bestaande, succesvolle modellen gestructureerd op hun succes te toetsen.

Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
Writing research proposal	WASS	2007-2008	6
Participating in Research Meetings at ECS	ECS	2007-2014	3
Presentation: "Inquiry-based science teaching competence of pre-service primary teachers"	AERA Toronto, Canada	2012	1
Presentation: "Inquiry-based science teaching competence of pre-service primary teachers"	European Teacher Education Network, Lisbon, Portugal	2012	1
Presentation: "Attitude van PABO studenten tav. Wetenschap en Techniek onderwijzen"	Onderwijs Research Dagen Wageningen	2012	1
Presentation and/or participation Kennis Centrum Wetenschap en Techniek	KWT-G	2010, 2012, 2014	2
B) General research related competences			
English Scientific Writing	Wageningen University and Research centre-Language centre	1999	1,5
Research Methodology: From topic to proposal	WASS	2010	4
Competence Theory and Practice	ICO/WASS	2012	4
Lecturing Module A: General Introduction to Education Sciences	Open University	2010-2014	2
Lecturing Module B: Learning and Development	Open University	2010-2013	2
C) Career related competences/personal development			
Chair of National Research Project "Professional Identity and Professional development of teachers: the role of school leaders"	Hogeschool Iselinge, De Kempel, Marnix, KPZ, Driestar, Gereformeerde Hogeschool, CHE	2013-2014	2
Member of the "regiegroep onderzoek"	Hogeschool Iselinge	2012-2014	2
Total (30 - 45 ECTS)			31,5