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

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HIGHLIGHTS

- A Delphi study validated the findings of an earlier literature study using experts.
- The necessity of science teaching competencies was confirmed and refined.
- Distinction was made between requirements for novice and experienced teachers.
- Attitude toward science should be positive from pre-service level onwards.
- Content knowledge and pedagogical content knowledge may grow through experience.

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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.

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 (Akerson & Hanuscin, 2007; Dietz & Davis, 2009; Howes, Lim, & Campos, 2009; Luera & Otto, 2005).

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, and Mulder (2012) identified twenty-three elements of competence. These competencies were categorized in the groups subject matter knowledge (SMK) elements, Pedagogical Content Knowledge (PCK) elements, and Attitude elements (see Fig. 1). The purpose of this Delphi study was to

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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

Fig. 1. Preliminary teachers' inquiry-based science teaching competence profile.

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 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?"

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, 2011) 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 (2011). 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 (Rohaan, Taconis, & Jochems, 2008). 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 min out of a 25-h lesson week) education (Martin, Mullis, & Foy, 2008).

2. Inquiry-based science teaching competencies

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).

2.1.1. Subject matter knowledge (SMK)

Subject matter knowledge, 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 subject matter knowledge 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 pedagogical content knowledge is a significant focus in teacher education.

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, and 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 (see Fig. 1). Park and Oliver (2008) reported the importance of teachers' understanding and practical implementation by taking into account contextual, cultural and social limitations in the learning environment. Davis (2004) 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.

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 (Liang & Richardson, 2009; Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998). 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 (Bhattacharayya, Volk, & Lumpe, 2009, Liang & Richardson, 2009).

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 (see Fig. 3 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 (Bhattacharayya et al., 2009). Additional self-efficacy contributes to teachers' PCK through enthusiasm, pupils' success, teaching performance (Liang & Richardson, 2009; Tschannen-Moran et al., 1998), 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., 2008). 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). Fig. 3 presents these complex links schematically (see Appendix).

3. Method

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 (Bolger & Wright, 2011; Wiersma & Jurs, 2005). 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.

3.1. 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 (see Tables 2 and 3). For an item to be classified as important, the mean needed to be equal to or higher than 2.5. A 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.

3.2. Respondents

Respondents were identified by two informants: a policymaker and a teacher trainer who also act 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 (see Table 1).

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 (see Table 2 and Fig. 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.

3.4. 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

Table 1
Number of respondents representing five groups of experts.

	Policymaker	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%

Table 2
Competence importance for teachers.

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

[a] Round 1 based on $N = 33$, round 2 based on $N = 17$, round 3 based on $N = 10$.

differences between the competence element ratings for novice and experienced teachers. Because of multiple testing, tests were considered significant at the .01 level.

4. Results

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 2. 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.

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 (see Table 3). 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.

4.3. Detailed results for SMK, PCK, and attitude of teachers

4.3.1. SMK for all primary education science teachers

Respondents required a sixth-grade level for subject matter knowledge of isolated facts and concepts on all sub-systems 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 Fig. 2 and Fig. 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. Subject Matter Knowledge 1.2 was expanded accordingly (see Fig. 2 and Fig. 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 (see Table 2). The application of research

Table 3
Competence importance for novice and experienced teachers.

Group of teachers	Novice			Experienced			*p*-Value
Round	1[a]	2[a]	3[a]	1[a]	2[a]	3[a]	
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
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

*$p \leq .05$.
**$p \leq .01$.
[a] Round 1 based on $N = 33$, round 2 based on $N = 17$, round 3 based on $N = 10$.

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.

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 gender and background differences 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."

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 (see also Fig. 2 and Fig. 4 in Appendix).

4.4. SMK, PCK and attitude for novice versus experienced teacher

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."

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 teacherś 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 teacherś ability to connect new knowledge to real life or to overall science concepts.

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

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

Fig. 2. Teachers' inquiry-based science teaching competence profile.

the awareness of existing opinions, and their own, on the nature of science.

5. Conclusions, discussion and recommendations

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, 2002).

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 (2008) 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 et al., 2008) concluded that primary science is taught an average of only 45 min 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 (Akerson, 2005; Davis, 2004).

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 Avraamidou 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.

5.1. Strengths and limitations of the research

The Delphi study provides a well-established methodology for obtaining information from experts (Bolger & Wright, 2011; Wiersma & Jurs, 2005). 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 dropout. 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.

5.2. Recommendations for future research and practice

Recommendations for future research are in line with Guerra-Ramos, Rijder, and Leach (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, 2011). 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' subject matter knowledge are not enough (Mulder, Weigel, & Collins, 2007). There is a need to go beyond lecturing teachers on how to teach science and how to become science teachers (Kang, 2007; Moseley, 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

Table 4
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
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
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.

(*continued on next page*)

Table 4 (*continued*)

Label	Short label	Description	Number of items	Example of item	α
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.
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.
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.
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.

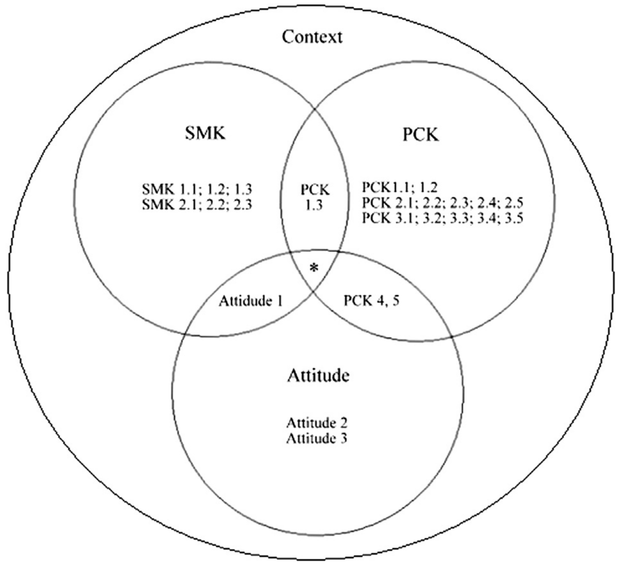

Fig. 3. Competence categories connected.

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

Fig. 4. Changes to the original elements of teachers' inquiry-based science teaching competence.

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