DISSERTATIONES PEDAGOGICAE SCIENTIARUM
UNIVERSITATIS TARTUENSIS

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# KLAARA KASK

# A study of science teacher development towards open inquiry teaching through an intervention programme

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# LIST OF ORIGINAL PUBLICATIONS

The dissertation is based on the following original publications, which are referenced in the text by their Roman numbers.

I. **Kask, K**. & Rannikmäe, M. (2006). Estonian teachers' readiness to promote inquiry skills among students. *Journal of Baltic Science Education*, 1 (9), 5–15.

II. **Kask, K.,**. Rannikmäe, M. & Mamlok-Naaman, R. (2008). A Paradigm Shift in Science Teaching – Teacher Development for Inquiry Teaching. In: J. Holbrook, M. Rannikmae, P. Reiska & P. Isley (eds.). *The Need for a Paradigm Shift in Science Education for Post-Soviet Societies*. Peter Lang Internationaler Verlag der Wissenschaften, 47–66.

III. **Kask, K**. & Rannikmäe, M. (2009). Towards a model describing student learning related to inquiry based experimental work and linked to everyday situations. *Journal of Science Education*, 10 (1), 15–19.

IV. Laius, A., **Kask, K**. & Rannikmäe, M. (2009). Comparing outcomes from two case studies on chemistry teachers' readiness to change. *Chemistry Education Research and Practice*, 10 (2), 142–153.

V. Holbrook, J., Rannikmäe, M. & **Kask, K.** (2008). Teaching the PARSEL Way: Students' Reactions to Selected PARSEL Modules. *Science Education International,* 19 (3), 303–312.

Components where the Author is a contributor to the papers:

| | I | II | III | IV | V |
|---|---|---|---|---|---|
| Developing the philosophy | * | * | * | * | |
| Methodology | * | * | * | * | |
| Review of literature | * | * | * | * | |
| Data collection | * | * | * | * | * |
| Data analysis/discussion | * | * | * | * | * |
| Manuscript preparation | * | * | * | * | * |

Paper IV is based on two separate studies; for study A in the paper, the major contributor was the Author. The Author did not contribute to study B.

# 1. INTRODUCTION

The history of human society has been one of continual development. In recent times societal changes have not only taken place in social, economic and political directions, but more and more attention has been drawn to environmental problems. Such rapid changes in society are affecting the need for changes on the educational landscape.

However, educational changes in schools are slow. Not surprisingly, it is still very common for the teacher to stand at the front of the class and teach by "chalk and talk". This is a stereotype for all that is encompassed under the term "traditional teaching". Traditional teaching means teacher directed, subject-oriented learning, very much in a logical positivist manner, whereby students acquire a body of knowledge and gain skills linked to simple explanations in discrete, isolated subject components (Bloom, 1956; van Aalsworth, 2004; Yager, 2007). However, memorizing facts and information is not the most important educational component in today's world (EC, 2007). In a rapid changing society, facts relevant to learning in a differing society also change and information in today's society, while increasing exponentially, is becoming more and more readily available. The needed is for students to understand how to obtain in a appropriate manner and then make sense of the mass of accessible data. In today's world, citizens are needed who are able, not only to cope with their lives in a complex, rapidly changing society, but also who are able to play an active role in guiding the society debates (Driver, Leach, Millar & Scott, 1997; Roth & Barton, 2004; Jarman & McClune, 2007).

Such objectives, however, require students to possess skills and values which are far removed from traditional teaching. To be involved in society, students need such skills as problem identification and problem solving, where the solution becomes an obtainable objective. Students need decision-making skills in which reasoning, interpreting and justifying are important components (Sadler, 2009). And above all, students need communication skills so as to be able to interact meaningfully with others. As we are all too aware from stories of indoctrination, brain washing and so on, students need to build up their own characters and develop clear goals for their future life. This means developing a sense of belonging, a set of personal values to uphold and most certainly a global sense of the issues facing the rapid changes in society (Hodson, 2003; Zeidler, Sadler, Simmons & Howes, 2005).

Some countries have made attempts at tackling these factors. Using developments in the field of science education as examples, the United States began to address such concerns, especially during the 1990s. As a result, the US adopted a fundamental document on education reform – the *National Science Education Standards* (NRC, 1996; 2000). Also, a little earlier, the American Association for the Advancement of Sciences (AAAS, 1990) recognized that while major changes were needed, these could not be effected overnight and they planned for an extended one lifetime (76 years – the time it take for a return of Haley's comet) to determine ways in which students could be taught meaningful science in such a manner that it provide a useful learning experience, and also putting students in good stead for coping with a rapidly changing world. The core target was to change science learning so that the promised science education reforms were achievable by all students (Marx, Blumenfeld, Krajcik, Fishman, Soloway, Geier & Tal, 2004).

**The Place of Inquiry in Science Teaching**

One key element, promoted by the National Science Education Standards, was that inquiry was central to the teaching and learning of science (NRC, 1996; 2000). However, research studies following the lack of pursuit of this direction, in particular the exploratory approach to the implementation of science lessons, have highlighted a number of obstacles. One such hurdle was that teachers lacked pedagogical knowledge to teach in an inquiry manner (Hogan & Berkowitz, 2000; Akerson, Hanson & Cullen, 2005; van der Valk & de Jong, 2009), while another was the lack of practical experience related to undertaking inquiry teaching approaches (Llewellyn, 2002; Windschitl, 2002; 2004; Windschitl, Thompson & Braaten, 2008).

Important policy decisions by the European Commission, expressed through publications related to science education (EC 2004; 2007), recommended moves to change the teaching of school science from mainly deductive to student-centred pedagogical methods and to shift the balance towards inquiry-based teaching approaches, which assumed:

- active teaching;
- active student learning;
- giving more attention to processes related to an appreciation of the nature of science.

Supported by research, the last assumption could be expanded as:

- careful observation (while recognising its potentially subjective nature);
- experimentation (while recognising that the seeking of evidence can be by a number of approaches or methods);
- construction of knowledge (while appreciating that it has a degree of tentativeness in that science cannot be equated with the truth and that falsification is an important consideration in the testing of science knowledge);
- development of skills (recognising that the process skills go well beyond acquiring know-how associated with “recipe” type procedures (Bybee, 2006; Deboer, 2006; Zion, 2007; Hofstein & Mamlok-Naaman, 2008).

Research has convincingly demonstrated the benefits of learning which contribute to students' cognitive development (Wallace, Tsoi, Calkin & Darley, 2003; Hofstein, Navon, Kipnis & Mamlok-Naaman, 2005), the development of flexible and adaptive thinkers and the encouragement of students' creative thinking and handling risk-taking situations (Trumbull, Bonney & Grudens-Schuck, 2005; Gürses, Açıkyıldız, Doğar & Sözbilir, 2007; Zion, 2007). Furthermore, research has also pointed to the importance of students' motivation and positive attitudes towards undertaking science learning (Hofstein, Shore & Kipnis, 2004; Chin & Kayalvizhi, 2005; Blumenfeld, Kempler & Krajcik, 2006).

Research has provided evidence also about two tendencies of concern in science education. Most disconcerting is that traditional teacher-centred teaching approaches in science classes have caused decreasing students' interest to science (Millar, 2005) and associated with this, the poor level of students' inquiry skills (Beaumont-Walters & Soyibo, 2001; Abd-El-Khalick, Duschl, Lederman, Mamlok, Hofstein, BouJaoude, Niaz & Tuan, 2004; Kanari & Millar, 2004, Watson, Swain & Robbie, 2004; Henke, 2006).

Today, inquiry is widely held as a key instructional approach and learning strategy and it has taken on a crucial importance in science curricula of a range of countries: for example, Canada (CME, 1997), Australia (Science Curriculum Framework, 2004, New Zealand (Science in the New Zealand Curriculum, 2004) and UK (QCA, 2005; National Curriculum for England, 2006).

Yet the situation in Estonian schools, in common with other post-Soviet countries, is that it is influenced by the almost 50 years long vision of science education within the former Soviet Union and the emergence into a market economy only from 1991. Furthermore, in 2004, Estonia joined the European Union. These important events led to the need for a serious reassessment of current pedagogy and although the importance of inquiry teaching was recognized in the 1960s (Deboer, 2006), this form of teaching was not really mentioned in Estonia. Nevertheless, taking the chemistry curriculum as a example (Estonian Government, 2002), key words related to an inquiry approach became very much in evidence in the general part of the curriculum, although in the more specific subject list, only a few learning outcomes geared to the acquisition of inquiry process skills were included.

Unfortunately, the real picture in Estonian classrooms tended to be very different from the intentions in the general part of the chemistry curriculum. A previous study (paper I), carried out in 2002/2003, concluded:

- without in-service courses, Estonian science teachers are not ready to use inquiry teaching approach; and
- in general, students' inquiry skills are poor.

These conclusions were reinforced by other studies (Kask & Rannikmäe, 2006; Pedaste & Sarapuu, 2006; paper II).

The outcomes portrayed by the PISA international study (OECD, 2007) indicated that the general science achievement by Estonian students was high – 531 point, but the performance competencies were low. For example, identifying scientific issues (15,7 points below the average) and using scientific evidence (0,4 points below the average) on a combined scale. At the same time, the competence of explaining phenomena scientifically, commonly used by traditional teaching, was 9,2 (OECD, 2007; figure 2.13 p.63). Consequently, the picture emerged that the traditional science teaching approach was dominant in Estonia, focusing on the mastery of content, with little emphasis on the development of skills and the nurturing of the inquiry learning processes. This system of education was renowned for being teacher-centred and with the teacher focusing on giving out information about "what is known." Students were the receivers of this information, and the teacher took on the role of being the dispenser. Much of the assessment of the learner was focused on the importance of giving "the one right answer."

**Problems related to Teaching and Learning Inquiry**

Although inquiry is included in the curricula of many countries and recommended by science educators and researchers worldwide, reports of problems in its implementation in the science classroom are common-place.

- Inquiry teaching needs the science teacher to possess strong science knowledge, understanding and abilities in utilising experimental skills. Many teachers tend to use a simplified or deformed interpretation of inquiry (Llewellyn, 2002; Lee, Hart, Cuevas & Enders, 2004; Windschitl, 2004; Akerson *et al.*, 2005; Shedletzky & Zion, 2005; van der Valk & de Jong, 2009). Teachers with naïve or deformed understanding of scientific inquiry are not able to teach authentic inquiry (Chinn & Hmelo-Silver, 2002).
- Teachers are expected to design a suitable learning environment in which learners can seek, share, construct knowledge and develop skills through undertaking the inquiry process. Research has reported that teachers are not able to do that (Fraser & McRobbie, 1995; Sandoval, 2005; Hofstein & Mamlok-Naaman, 2008). It is thus not really surprising that despite the growing consensus regarding the value of inquiry-based teaching and learning, the implementation of such practices continues to be a challenge.
- Students perceived poorly planned and executed experimental work by teachers as boring and this fact decreases the positive attitude towards learning science within school (Millar, 2005). On the other hand, some students expressed a strong sense of frustration of not "knowing the right answer," instead of the expectation that students arrive at an outcome on their own using the inquiry process (Wenning, 2005).

Why is it that the inquiry process is considered so important and strongly supported by research, yet science teachers are tending to shun its implementation, this being especially true in Estonia? Where do teachers gain their perceived sense of importance for imparting content knowledge in their science teaching? Why is it that teachers fail to see that motivational aspects are important in giving students' positive attitudes towards science learning and inquiry teaching can play a strong role in this respect? Why is it that teachers fail to see the need for students to be guided to the actual gaining of meaningful and long lasting science ideas so crucial in a rapidly changing world? This research is an attempt, within the Estonian situation, to seek answers to such questions.

## The Goals and Hypotheses for the Current Study

This research has been designed to determine ways to enhance inquiry teaching among Estonian science teachers and, in particular, with Estonian chemistry teachers.

The goals of the study are sub-divided into three domains:

*Philosophical*

- To specify theoretically justified criteria for carrying out inquiry-based experimental work, which is motivating for students and meaningful for teachers.
- To develop a set of instructional materials corresponding to these criteria.

*Related to teachers*

- To design and run an in-service course to enhance teachers' knowledge and skills related to carrying out open inquiry and to raise their professionalism related to applying an inquiry-teaching approach.
- To describe teachers' change as a result of participating in the in-service course and in subsequent activities, through carefully specified categories of teacher development.

*Related to students*

- To investigate and map changes in students' affective and cognitive gains related to inquiry learning as a result of the teacher development from the intervention with teachers.

The following research hypotheses are posed:

- Criteria can be identified and theoretically justified related to the carrying out of inquiry-based experimental work which is motivational for students (published in papers II and III).
- A set of instructional inquiry-related materials can be developed which correspond to the criteria identified (published in papers II and III).
- It is possible to raise the professionalism of teachers, with respect to knowledge and skills, through participation in an in-service course focussing on the carrying out of open-inquiry (published in paper IV).
- Teacher change can be described as a result of participating in an in-service intervention, geared to inquiry-based teaching approaches, using carefully specified categories (published in papers II and IV).
- Changes in students' affective and cognitive gains, related to inquiry learning, can be determined and mapped (published in paper III).
- The relationship between teacher developments, with respect to inquiry-based teaching attributes, can be mapped, by means of a model, against student cognitive and attitudinal gains (Kask, Rannikmäe & Holbrook, 2009).

# 2. REVIEW OF THE LITERATURE

One important purpose of the current study was to guide teachers to create a learning environment through which laboratory work could be meaningfully conducted within chemistry lessons. For this reason, this section of the literature gives an overview, on the one hand, of approaches to laboratory work and its objectives, plus the place of inquiry learning, student cognitive development and the need for students motivation through laboratory work. On the other hand, the overview highlights teacher pedagogical development (PCK), both in general and that specifically related to inquiry teaching.

## 2.1. Practical Work as a Tool for creating a Classroom Environment

The creation of a classroom environment to support meaningful learning is one of the purposes of teaching (Penick & Bonnstetter, 1993; Fraser & McRobbie, 1995). In science teaching it is tightly connected to laboratory/experimental/practical work as was pointed out by Hodson (1992). Hodson proposed three aims for science education:

- to learn science: to understand scientific concepts, models, and theories;
- to learn about science: to understand important issues in the philosophy, history, and methodology of science;
- to learn how to do science: to be able to take part in activities what lead to the acquisition of scientific knowledge (Hodson, 1992).

The last aim assumes that the carrying out of learning by doing is unique to science and relates to the need for a laboratory. Laboratory equipment and the activities carried out, are very different from those of mainstream classroom teaching and this adds to the interest and emotion appeal for students (Hofstein & Lunetta, 1982; Hofstein *et al*., 2004; Hofstein & Lunetta, 2004). The laboratory offers many more opportunities for satisfying students natural curiosity, for individual initiative, for independent work, for working in one's own time and for obtaining constant feedback regarding the effects of what one has been doing (Tamir, 1991).

Practical work in school science is often defined as laboratory work where students encounter ideas and principles at first hand. To some it merely means hands-on science (Yager, 1991; Rollnick, Zwane, Staskun, Lotz & Green, 2001). This relates to the major curriculum projects in the 1960s which used the work of Piaget and Bruner to justify a hands-on framework for practical work (Lunetta, 1997). However, while practical work should involve hands-on activities on the one hand, it should include minds-on activities on the other (Watson, 2000). Interestingly, some authors also include teacher demonstrations in practical work (Henke, 2006; Baddock & Bucat, 2008). This study defines the term "practical work" as only the aspects involving student activities, whereas the terms "laboratory work" and "experimental work" are taken as equivalent and defined as students' cognitive and manual activities, which involve, at some point, the students in observing or manipulating real objects and materials.

Many scientists and science educator are convinced that experimental work must play an important role in learning science, but the reasons for its prominence are less clear. This lack of clarity is connected to questions about the role of practical work (Hofstein & Lunetta, 1982).

**The changing goal of laboratory work**

The history of laboratory work as an integral part of school science learning has its roots in the 19$^{th}$ century. However, only at the beginning of the last century did John Dewey advocate the approach "learning by doing" (Dewey, 1997), thus providing a theoretical justification for carrying out practical work in school. During the last century, great technological changes took place in society and this was reflected in education. Among the rethinking of the purposes of practical work put forward in the last decades of the last century, the most popular, in the opinion of teachers, were:

- to encourage accurate observation and description;
- to make phenomena more real;
- to arose and maintain interest;
- to promote a logical and reasoning method of thought (Watson, 2000).

This wider message regarding practical work is clear. Teachers see both procedural and content aims as part of the core of practical work and that they are inextricably related to one another. For example, in order "to encourage a real and accurate description" one has to observe some phenomenon, and, reciprocally, accurate observation and description leads to making phenomena more real. Similarly, the interrelationship between affective and cognitive aspects of teaching in the laboratory was pointed out. Students generally like to be involved in the handling of equipment and this leads to understanding as was shown in a study carried out by Pekmez, Johnson and Gott (2005) with 24 science teachers from eight English schools. This study illustrated also the value placed by the teachers on the acquiring of subject matter knowledge by students through experimental work. All the teachers believed that practical work was a good thing, citing reasons covering four domains: acquisition of substantive ideas, student motivation, procedure related ideas and development of students' communication skills. However, the number of teachers who valued practical work in meeting these domains differed; half stated purposes related to substantive ideas: practical work helps understanding, reinforces, backs up and illustrates or visualises theory and cements knowledge; one teacher highlighted the need for student motivation, a marginal part of the objectives identified by the procedure, and the rest to the development of students' communication skills.

Accordingly to Driver, Leach, Millar and Scott (2000) the purpose for undertaking experimental work in science teaching is more strongly associated with preparing scientific literate citizens who understand the surrounding world and who can participate actively in debates about issues in society, solve problems, and make reasoned decisions. In this context, the former scientific goals for experimental work are seen as insufficient and also point to a shift of focus. This shift in focus means the teaching of science and conducting experimental work has moved, first in the direction of developing high order thinking skills, including inquiry skills, to provoke conceptual change (Llewellyn 2002; Watson *et al.*, 2004; Hofstein *et al.*, 2005; Kipnis & Hofstein, 2005; Millar, 2005) and second, to place emphasis on encompassing the social and personal domains of education (Holbrook & Rannikmäe, 2007), including cooperation skills, peer consideration skills, development of students' creativity, curiosity, accuracy, *etc*. (Hofstein, Levi-Nahum & Shore, 2001; Blumenfeld *et al.*, 2006; Lee & Erdogan, 2007).

**The effectiveness of laboratory work**

It is a common notion that laboratory work in the science class is effective (Woolnough & Allsop, 1985; Hofstein *et al.*, 2005; Kipnis & Hofstein, 2005; Millar, 2005). Based on an analysis of the literature, five criteria for describing this effectiveness can be extracted.

*The first criterion* for the effectiveness is to measure this in terms of the development of conceptual understanding. For example, Kirschner and Meester (1988) wrote about acquiring a body of knowledge and about the aid of the laboratory in the development of conceptual thinking. However, many research studies have compared the effects of the methods used in the teaching of practical work in the laboratory with other instructional methods. Often the literature indicated that there was little to show that practical work was effective in helping students to learn scientific knowledge (Ben-Zvi, Hofstein, Kempa & Samuel, 1976). A study by Watson, Prieto and Dillon (1995) affirmed this statement by comparing the understanding of two groups of 150 15–year-old pupils. One group had been exposed to a curriculum with a high practical content (in England) and the other group with a low practical content (in Spain). In spite of having substantially more practical experience with combustion, the student group from England showed few differences from the Spanish sample in either their scientific, or naïve conceptions about combustion. Not surprisingly, the one area in which the teaching approach using practical work showed measurable advantage over other teaching methods was the development of laboratory skills (Hofstein & Lunetta, 1982). However we also need to bear in mind that research has shown that the most effective environment for the development of conceptual understanding is group work (Crook, 1994; Larkin, 2006; Robertson, 2007). Undertaking practical work is one common approach to the use of group work.

*The second criterion* for effective experimental work is related to the need to connect practical work with everyday life. Research results indicate that the science in school has a theoretical nature and is often taught separately from the context in which it is to be implemented i.e. everyday life (Rollnick *et al.*, 2001;

van Aalsworth, 2004). This is seen as one reason why school science is not relevant to students (Holbrook, 2003; Gilbert, 2006). Psychologists in the domain of students' development have found that 14–16 year old secondary school students are interested in phenomena and events related to their direct surroundings and/or concerning themselves (Bransford, Brown & Cocking, 2001) and studies about relevance indicate the interest of the students where themes relate science to real-life (Teppo & Rannikmäe, 2003). The importance of designing experimental strategies, which help students to improve their ability to identify solutions to everyday societal issues and problems, has led to positive outcomes (Marques, Praja & Thompson, 2002; Bulte *et al*., 2006; Bremkes & Ralle, 2008).

*The third criterion* for the effectiveness of practical work is linked to the teacher. It is clear that the science teacher must have the competence to guide the carrying out of practical work. Hofstein and Lunetta (1982) showed that not all science teachers were competent to use the laboratory effectively. Too many trivial experiments were performed and laboratory work in schools was often remote from, and unrelated to, the capabilities and interest of the students. However, student practical work, guided by a competent science teacher, was shown to influence students' values, develop the abilities and skills necessary for everyday life, such as the ability to work together and communication skills, and the development of characteristics such as punctuality, regularity and honesty (Woolnough & Allsop, 1985; Watson, 2000; Millar, 2005).

*The fourth criterion* for effectiveness is related to fostering attitudes and motivation. White saw the fostering of motivation to learn science as one of the roles of laboratory work and Woolnough (1999) emphasised the enjoyment of doing science as an important factor of laboratory work. Hofstein and Lunetta (2004) emphasised that students enjoy laboratory work and their experiences led to more positive attitudes and interest in science. Kirschner & Meester (1988) showed students were able to gain academic ideas and develop critical attitudes towards science from undertaking experimental work in the laboratory.

*The fifth criterion* for effectiveness is related to the format of laboratory work. While experimental work may be used in a variety of formats, (such as practical work following a prescribed recipe; investigations related to subject conceptual learning and exercises developed explicitly for process skills training), research has shown that traditional routine "recipe" style practical work has little value, projecting practical work as a tedious and dull activity and as such does not play a strong role in promoting cognitive learning (Hofstein *et al*., 2005; Kipnis & Hofstein, 2005; Millar, 2005).

The need to undertake laboratory work using an inquiry mode has been emphasised by politicians (EC, 2004; 2007) and by researchers (Anderson, 2002; Llewellyn, 2002; Abd-El-Khalick *et al*., 2004; Hofstein *et al*., 2005; Kipnis & Hofstein, 2005; Shedletzky & Zion, 2005; Paper I; McDonnell, O'Connor & Seery, 2007; Zion, 2007).

In the recent years there has been more contemplation that the process of inquiry learning has been overlooked. Even though the aforementioned five criteria have been brought out in the context of laboratory work, they are also important when it comes to carrying out inquiry learning.

**The importance of cooperation and collaboration in an inquiry oriented classroom environment**

Experimental work is usually carried out by small groups of students (called peer groups) and guided by the teacher. The students cooperate with each other as they perform the various tasks which have been assigned. Cooperation (students share tasks and hence work together) is really a part of collaboration (students work together and reinforce each other's contribution). Collaboration takes place when the students interact with each other and determine, collectively, the appropriate tasks, the manner in which they are performed and the way outcomes are handled. Collaborative work can motivate students in the learning of science and provide students with opportunities to learn from each other. In this way students of all ages can be challenged to learn and be stretched beyond their own expected potential in order to improve the quality of the common collaborative effort, output, conclusion, or judgement (Yager, 2007). Not only can collaboration foster good attitudes towards, and concerning, science learning, it also models the nature of the scientific enterprise. Scientists rarely work in a vacuum – for example, laboratories involve many people. In fact, a team, or group approach is often necessary in order to solve complex problems. Collaboration encompasses a variety of actions, such as communication, obtaining information from others and building knowledge, coordination cooperation, problem solving and negotiation (Williams & Sheridan, 2006). Cooperation and collaboration become more essential in an inquiry oriented classroom than in the context of carrying out any other type of laboratory work.

Vygotsky argued, in his Social Development Theory (SoDT), that social interaction precedes development; consciousness and cognition is the end product of social and cultural interaction (Vygotsky, 1978). He indicated that learning occurs in the Zone of Proximal Development (ZPD) which is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). In the context of instruction, ZPD determines the lower and upper bounds of the zone within which instruction should be pitched. According to Vygotsky, instruction is only useful when it moves ahead of a child's development and provides activities that enable students to rise above them, but are not beyond their capability. Thus, the ZPD is the distance between a student's ability to perform a task under teacher guidance and/or with peer collaboration and the student's ability for solving the problem independently. According to the commonly accepted understanding, working in ZPD provides potential for the development of all group members (Wells, 1999), not simply the less skilful, or knowledgeable students as Vygotsky proposed initially. In accordance with this, the ZPD concept has been explained as bi-directorial teacher-student and also student-student (Goos, Galbraith & Renshaw, 2002).

When students work together, in a "learning community", it is expected that they generate collective energy or "synergy". From studying peer interactions of students working in collaboration, a range of attributes have been identified – *cognitive benefit* as learning **(**Robertson, 2007); articulation, conflict and co-construction (Crook, 1994); learning the language of explanation and negotiation (Larkin, 2006), and developing independent thinking, plus making sense of chemical concepts (Kipnis & Hofstein, 2005). In terms of cognitive and academic growth, group work helps students use the perspectives of other persons, both individual and group perspectives, to clarify and expand their own thinking and conceptualisation of ideas (Duschl, 2003). For attaining cognitive benefits, students should be encouraged to explain, clarify, debate, and critique their ideas (Blumenfeld *et al*., 2006). From studying peer interactions of students working in collaboration, Crook (1994) identified three cognitive benefits: a) articulation, b) conflict and c) co-construction. He contends that students working in collaboration have to articulate and make public their ideas and this helps them clarify their conceptions. To resolve conflict when disagreement arises, students are called upon to justify and defend their positions and this forces them to reflect on and review their understanding. When working jointly on a task, students can complement and build on each other's ideas and incrementally co-construct shared understanding. Conflict is based on a Piagetian perspective of learning (Piaget, 1953), whereas co-construction is based on the Vygotskian perspective (Vygotsky, 1978).

Laboratory work can also be considered from the point of view of other educational goals, which emphasise students' development, including the need for communication skills, and also the habits and skills of working together with classmates (both cooperation and collaboration). The learning environment created by the teacher contributes to the achievement of these goals.

In addition to changes in the cognitive dimension, students working together and the development of communication skills, a change can also occur in the *affective dimension* (Newton & Sacney, 2005), through interpersonal relationships and leadership (Arvaja, Häkkinen, Rasku-Puttonen & Edeläpelto, 2002), or change from the influence of one's peers in the culture domain (Hamada & Scott, 2000). McDonnell *et al.* (2007) emphasised the importance of the emotional component for learning science and undertaking inquiry. In a review about the benefits of collaboration, made in perspective psychology students, Blumenfeld and co-authors (2006) emphasized that collaboration enhances motivation because it meets students' needs for relatedness as they work with their peers and the teacher.

The benefits of group investigations enable the *social development* of students, for example: collaboration has been shown to increase positive feelings toward one another, reduce alienation and loneliness, build relationships, and provide affirmative views of other people; while cooperation has been shown to increase self-esteem, not only through increased learning, but through the feeling of being respected and cared for by others (Hofstein *et al*., 2001; Joyce, Calhoun & Hopkins, 2002).

A potential *negative side* of collaborative experimental work is group conflict, as emphasised by Chin & Kayalvizhi (2005). Research has shown that students tend to work *cooperatively,* but they did not necessarily work *collaboratively* (Maloney & Simon, 2006). They suggested that an important role for the teacher in developing the classroom environment was to guide students to know how to work together as a group.

Collaboration was used in the current study as a key component in carrying out experimental work. It was defined in a rather more limited manner that given above and seen as students working together at the same cognitive level. Cooperation, on the other hand, was used in the sense of involving students working together at different cognitive levels (paper II and III).

## 2.2. Inquiry

> *If a single word had to be chosen to describe the teaching goals put forward by science educators during the period that began in the late 1950s, it would have to be INQUIRY* (Deboer, 2006, p 206).

Inquiry means looking into, or investigating something; it is a process of searching, or finding out (Chiappetta, 1997). Inquiry has been defined as seeking for the truth, for information, or for knowledge – seeking information through the skill of questioning by the learner (Flick, 2006). Philosophers emphasised the focus of an inquiry as the way to collect data and to verify it (Chalmers, 1999). To some researchers, inquiry is seen as a process, which involves a number of inquiry skills (Champagne, 1997; Millar, 2005; Apedoe, 2007); others stress the target of this process – scientific inquiry is the general process of investigation that scientist use as they attempt to answer questions about the natural world (Deboer, 2006). According to St. John (1999), inquiry means the perception of depth. It has the quality of penetrating into something, going deeper, so it is possible to see something which you have not been able to see before. Inquiry is setting out to search for something not known.

Scholars have promoted inquiry-based teaching methods for science classrooms since the time of Dewey (1997). Trumbull and co-authors (2005) evaluated Schwab's research role in this area as follow:

- it was not Schwab's primary purpose that students should be able to conduct scientific inquiries, although he emphasised the conditions in practical lessons: *when science is presented as a stable body of expert knowledge, learners are discouraged from developing their own explorations and explanations of observed phenomena* (Schwab, 1962);
- Schwab was the first who stressed that students should understand the dynamic and ongoing nature of scientific inquiry;
- he clearly distinguished inquiry as content and inquiry as pedagogy:

*"Of the two components – science as enquiry and the activity of enquiring – it is the former which should be given first priority as the objective of science teaching in the secondary school. It is a view of science as enquiry which is necessary if we are to develop the informed public which our national need urgently demands"* (Schwab, 1962, p.72).

According to Schwab (1962) the term "inquiry" in education is equivocal: first it can relate to a teaching approach, which helps students develop understanding about science content and shape related skills. Second, inquiry learning goals include abilities to undertake inquiry as a process including the development of relevant inquiry skills and inquiry for understanding (Anderson, 2002; Abd-El-Khalick *et al*., 2004). Abd-El-Khalick and co-authors (2004) suggested "*Inquiry as means*" (or inquiry *in* science) refers to inquiry as an instructional approach intended to help students develop understanding of science content (i.e., content serves as an end point for instructional outcome). "*Inquiry as an end*" (or inquiry *about* science) refers to inquiry as an instructional outcome: students learn to carry out inquiry in the context of science content and develop an epistemological understanding about the nature of science and the development of scientific knowledge, as well as relevant inquiry skills (e.g. identifying problems, generating research questions, designing and conducting investigations, and formulating, communicating and defending hypotheses, models and explanations).

These different aspects of inquiry have been identified. The National Science Education Standards (NRC, 2000) includes both these scientific perspectives, discussed in the content standards section "Science as Inquiry" and the teaching perspective, discussed in the section of "Science Teaching Standards". The National Science Education Standards (NRC, 1996, p. 23) actually defines inquiry as:

*"The diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. But scientific inquiry is also referred to as the short laboratory intervention modules through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world."*

**The inquiry process**

Different reforms have emphasised different conceptions for the role of the inquiry process, as well as different conceptions of meeting inquiry teaching goals (Krajcik, Mamlok & Hug, 2001). Whenever the goal of science education is perceived as preparing individuals to become scientists, a discipline-centred, as well as an intellectual development, is put forward as the major focus. From the 1970–1980's focus on generating "little scientists", the focus has now shifted from disciplinary teaching to preparing citizen with inquiry process and decision making skills so as to function effectively in a scientific world (Kanari & Millar, 2004; Kipnis & Hofstein, 2005). The inquiry process has variously been expressed as:

- including investigation of natural phenomena, often through the use of experimentation, but may also involve obtaining data from secondary sources, and definitely involves higher order thinking (i.e. thinking going beyond the mere recording of data or mechanically applying concepts). At the heart of the inquiry process is identifying problems and posing questions (Llewellyn, 2002);
- being associated with increased involvement of students: the students themselves pose research questions and hypotheses, look for answers to their questions and rely less on the textbook and the teacher's help (Krajcik, Mamlok & Hug, 2001; Hofstein *et al*., 2004);
- having motivational power and provides an opportunity to increase students' interest and positive attitude to learning science (Watson, 2000; Hofstein *et al.,* 2004; Chin & Kayalvizhi, 2005; Paper III). Moreover, Blumenfeld and co-authors (2006) stressed not only the importance of motivation through inquiry, but saw this as an opportunity to develop students' creativity;
- if properly developed, having a potential to enhance students' constructive and conceptual learning, conceptual understanding and understanding of the nature of science (NOS); inquiry-based learning offers the development of habits of mind that can last a lifetime and guide learning (Hofstein & Lunetta, 1982; Wallace *et al.,* 2003; Zion, 2007);
- offering opportunities for students to learn through inquiry-based laboratory work. In this process, inquiry goes beyond the teaching of skills, which often are applicable and needful in everyday life to developing personal attributes e.g. observing, posing questions, planning, experimenting, communication; capability to work together, accuracy, objectiveness etc (Pekmez *et al.,* 2005; Sandoval, 2005; Deboer, 2006; McDonnell *et al*., 2007).

By the end of the 20$^{th}$ and into the beginning of the 21$^{st}$ century, the inquiry process also involved a social dimension (Arvaja *et al*., 2002; Wee, Fast, Shepardson, Harbor & Boone, 2004).

Based on the above, the links between the components that related to the inquiry process can be illustrated using the following derived schema.

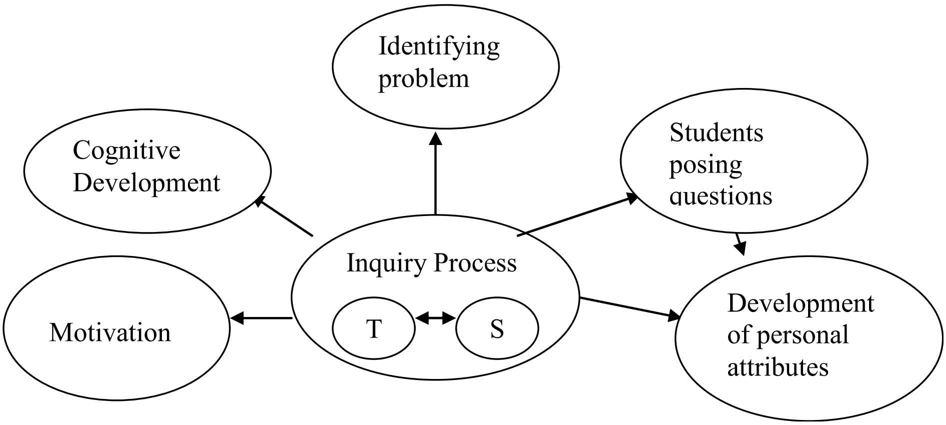


**Figure 1.** Schema of relationships in the inquiry process.
T = teacher and inquiry teaching;
S = students and inquiry learning.

The schema involves student motivation for intriguing and attracting the attention of the students and through this involves students in the inquiry process. Cognitive development takes place through learning subject matter topics. Learning is not carried out by traditional methods, but is based on the principles of constructivism and social constructivism. Wallace and co-authors (2003) highlighted the relationship between inquiry and cognitive learning. Inquiry as a possibility to develop separated inquiry skills was studied by Bransford *et al.,* (2001) and shaping positive attitudes through inquiry was examined by Adesoji and Raimi (2004).

In the current study, the inquiry process follows the highlighted model, where students are expected to identify problems and then solve them. Inquiry process is defined as process, in which students acquire new knowledge and develop relevant skills through an investigative process, designed to answer questions posed by the students themselves (Paper III).

**Inquiry learning**

Engaging students in inquiry-based learning is a major goal of current efforts in science education (Abd-El Khalick *et al.,* 2004). Inquiry learning is defined as constructivist learning that takes place in problem solving situations, where the learner draws on his or her own past experience and existing knowledge to find answer to his or her questions (Hofstein *et al*., 2004; Bybee, 2006). Students interact with the world by exploring and manipulating objects, wrestling with questions and controversies, or performing experiments. Inquiry learning increases the interest in, and positive attitude to, science learning (Hofstein *et al*., 2005; Blumenfeld *et al*., 2006; McDonnell *et al.* 2007; Zion, 2007).

Engaging students in inquiry activities, as presented in the National Science Education Standards (1996), is expected to contribute to greater:

- understanding of scientific concepts;
- appreciation of "how we know" what we know in science;
- understanding of the nature of science;
- developments of skills necessary to become independent inquirers about the natural world;
- disposition to use the skills, abilities, and attitudes related to science (NRC, 1996, p.105).

One aspect of inquiry learning relates to the development of inquiry skills. A number of studies have been conducted which characterise inquiry skills and its development (Kanari & Millar, 2004; Hofstein *et al.*, 2005; Millar, 2005; Sandoval, 2005; Rakow, 2006). The development can be measured on two levels: low and high (Lin, Hong & Cheng, 2009).

In early studies, inquiry skills were often taken as the same as a set of process skills (Brotherton & Preece, 1996; Ostlund, 2002). But Zachos, Hick, Doane and Sargent (2000) stressed that inquiry skills involved both process skills and problem solving skills. Padilla (1997) expanded on this and divided inquiry skills into basic and integrated skills. Basic skills were expected to be acquired at primary school. These encompassed – observing, measuring, inferring and classifying. Integrated process skills (or problem solving skills) involved posing research questions, hypothesing, planning investigations or experiments, collecting data for and compiling tables and graphs, analysing and interpreting data. These were seen as more appropriate for secondary or high school (Yager, 1996). Chiapetta (1997) and Champagne (1990) focused on the importance of cognitive activities in undertaking the acquisition of inquiry skills, dividing the cognition into low order and high order. Low order cognition was generally related to the basic skills and high order to being able to initiate problem solving.

**Inquiry cycle**

A cycle of inquiry skills, mentioned in the standard (NSCS, 1996) and by Dunkhase (2003), was later modified by Bybee (2006). The skills form a sequence which can be repeated should first attempts fail. Generally, there is common agreement that the inquiry process begins with recognising the problem and putting forward the research question (Hofstein *et al.,* 2004; 2005). But to undertake inquiry, students need to develop further skills interrelated to those mentioned above. For example, Dunkhase (2003) developed a coupled inquiry cycle involving:

- asking a question about a natural phenomenon;
- designing an investigation to try and answer the question;
- conducting the investigation to collect data and evidence;

- using reason and logical thinking to interpret the evidence to create the best answer to the question;
- presenting the results of investigation to the community (Dunkhase, 2003, p.11).

Based on the standards for grades 5–8, Bybee (2006) developed a list of skills on undertaking scientific inquiry forming a cycle:
- identify questions that can be answered through scientific investigation;
- design and conduct a scientific investigation;
- use appropriate tools and techniques to gather, analyse and interpret data;
- develop descriptions, explanations, predictions and models using evidence;
- think critically and logically to make relationships between evidence and explanation;
- recognise and analyse alternative explanations and predictions;
- communicate scientific procedure and explanations;
- use mathematics in all aspects of scientific inquiry.

If Dunkhase's first step in the inquiry cycle is the skill related to asking various questions, then Bybee goes further and demonstrates the need to identify, among the all questions about natural phenomenon, only these which provide the opportunity to investigate. The next two steps (2 and 3) – designing and conducting investigation – are pointed out by both researchers- although Bybee described more exactly the interpretation and presentation stages. In the light of the model created earlier (Figure 1) both the Dunkhase and Bybee cycles are narrow and focused on going through inquiry stage by stage without attention to motivation, development of personal attributes and cognitive development.

The inquiry cycles put forward by Dunkhase and Bybee begin by asking questions about natural phenomenon. Researchers from Europe have supported this approach of identifying the problem and then posing the research question based on this problem (Hofstein *et al.*, 2004; 2005; Pekmez *et al.*, 2005). This came to be called "the European model." The European model in the UK is often written as "enquiry" to utilise the British way of spelling (Osborne, 2003). However such an activity assumes prior observation of natural phenomenon. When inquiry begins with the observation, as most inquiry models do when created by researchers from the USA, the model has been called "the American model" (Llewellyn, 2002; Windshitl, 2004).

Following Bybee (2006) and Millar (2005), inquiry skills are defined also as practical and cognitive skills, supposedly used in inquiries and perceived as appropriate for the school science laboratory. Both problem solving skills and the inquiry process skills have been combined to be called inquiry-based problem solving.

Based on the literature, the best way to develop student inquiry-based problem solving skills is suggested as undertaking short laboratory intervention modules, involving: observing objects and events, posing questions, designing investigations, proposing explanations, collecting data, analysing data, and comparing proposed explanations with new data (Wallace *et al.*, 2003). The development identifies with the constructivist approach, the need to recognise the problem and pose the scientific question to investigate, illustrate the cognitive gains from undertaking an investigation, checking that understanding has been achieved and that students are able to communicate their understanding and findings to others using written or oral means. This is illustrated in Figure 2.

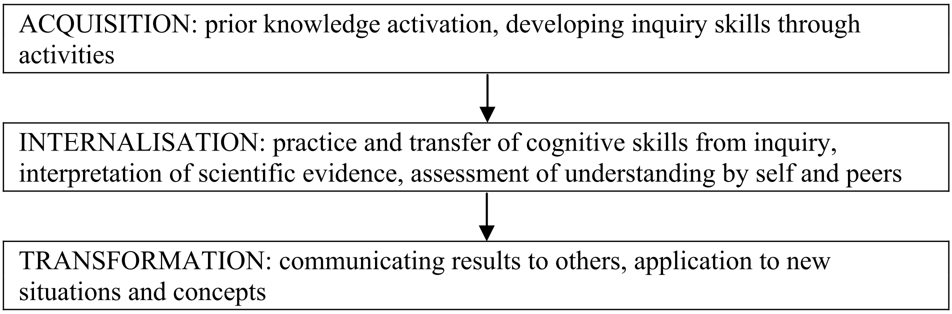


**Figure 2.** Ant approach to the development of inquiry skills (based on a model developed by Millar, 2006).

In the current study, the development of inquiry-based problems solving instructional material follows a similar approach, although it is based on a wider consideration of the inquiry skills to be developed and a stronger theoretical construct, especially related to the constructivist and scaffolding manner in which the teacher develops students' inquiry skills (paper II, III, IV and V).

**Inquiry teaching**

Research indicates that the studying of science in school does not match the requirements of the society; the approach is in need of change – inquiry, discovery and creativity skills need to be emphasised (Anderson, 2002; Llewellyn, 2002; Abd-El-Khalick *et al.,* 2004; EC 2004; 2007; Hofstein *et al.*, 2005; Khan, 2007; Yager, 2007; Windshitl *et al.,* 2008). This need is not really new, Dewey (1997) was stressing inquiry teaching in the early part of the last century; today it is regarded as a prominent feature for the teaching and learning of science (NRC, 1996; EC, 2007).

Inquiry teaching is not seen as the same as the teaching of "science process skills", or the "discovery" science teaching strategy of the 60s (Bybee, 2006). Inquiry-based teaching has come to mean a set of instructional practices and beliefs about learning. Inquiry teaching refers to a pedagogical approach that model aspects of scientific inquiry (Deboer, 2006). According to the Exploratorium (1998): inquiry is an approach to teaching that involves students in a process of exploring the natural and material world that leads to asking questions and making discoveries in the search of new understanding.

Based on the literature, it was possible to point out key elements of inquiry teaching. It is important that the teacher is able to develop and sustain a *student-centred* learning environment. Such an environment demands that the teacher is a facilitator of the learning and improves students' academic achievement as well as positive attitude towards science learning (Millar, 2005; Toplis & Cleaves, 2006). Controversially, Chang and Tsai (2000) studied the outcomes of teaching two groups of $10^{th}$ grade students, one using student-centred methods and other, teacher-centred methods. They did not find statistically significant differences in the student achievement, although differences ($p<0.05$) in attitudes between the student groups were found. It appears that teacher-centred teaching is preferred by students favouring a less constructivist-orientation while a student-centred learning environment is preferred by more constructivist-oriented students.

Different aspects of student-centred classrooms can be highlighted. There is more emphasis on "how we come to know" and less on "what we know" (Zion, 2007). Teaching inquiry and teaching about the nature of inquiry means teaching in appropriate ways that support students in the development of meaning and in finding ways to engage students in investigative activity. Active student involvement, prompting the use of relevant skills, goes to the core of what teachers are striving to do in any subject (Flick, 2006). Zion (2007) suggests three different *models of inquiry teaching* based on whether the inquiry question was presented by the teacher, or thought out by students. Differences related to the manner in which the experimental procedure or design is developed, as well as the data analysis, can also be considered. Table 1 shows this extension of the Zion model. In this study, all are taken as key components in describing the manner in which an investigation is carried out.

**Table 1**. Different models of inquiry teaching.

| **Model of inquiry teaching** | **Question investigated presented/posed by** | **Procedure prescribed/ designed by** | **Procedure for data analysis/ making conclusion** |
|---|---|---|---|
| Structured inquiry | Presented by teacher | Prescribed by teacher | Teacher directed and prescribed |
| Guided inquiry | Presented by teacher | Designed or selected by students | Teachers guided |
| Open-inquiry | Posed by students | Designed by students | Student led activities |

Structured inquiry relates to a teaching approach, which involves an active teacher but passive students: the student activities are directed and guided by the teacher. The students are given little freedom to do something by themselves. In structured inquiry, the students investigate a teacher-presented question through an exactly prescribed procedure, often coming from the textbook or a worksheet. It tends to follow reasoning in a narrow subject matter context (Wee *et al*., 2004). For example, in a report of inquiry-based chemistry laboratory work, it was found that teachers assessed only the writing of the chemical equation related to the experimentation and nothing on the development of experimental skills (Kask & Rannikmäe, 2006). Assessment of inquiry skills is important, otherwise there is a danger that students perceive science learning as boring and uninteresting (Holbrook, 2003; van Aalsworth, 2004). In fact the use of structured inquiry approaches could be one of the reasons why Estonian students achieved good results in knowledge and reasoning domains, but poor results in identifying research questions (OECD, 2007).

Guided inquiry involves the teacher in presenting the investigation question but allows students to design or selecting procedures. Its strength over structured inquiry is that it includes student-created final stages, such as interpreting findings and drawing conclusions. This form of inquiry teaching does involve students in taking some responsibility for their activities and is a step on the way to the full involvement of students as is the case in open inquiry (Zion, 2007).

In open-inquiry, also called authentic inquiry, the teacher takes the responsibility to define the knowledge framework in which the inquiry is to be conducted, but leaves the students with the task of considering a wide variety of possible inquiry questions. In the course of open inquiry, the students investigate topic-related questions through student-designed procedures and take responsibility for the data collection, analysis reporting and the drawing of conclusions. The students experience decision-making throughout each stage of the inquiry process (Krajcik, Czerniak & Berger, 2003; Wee *et al*., 2004; Zion, 2007).

As open inquiry demands students being engaged in high order thinking, the key to such inquiry is the teacher's ability to bring his or her students to ask the questions that would guide them on their inquiry. Thus in this form of teaching, the students are involved in determining the whole inquiry process and teacher skill is required to "set the scene" for this to occur. In the current study, the teachers are guided to set up open inquiry for their students by making use of a scenario and then allowing the students to pose the appropriate questions, plus the manner in which the investigation should proceed (Paper III).

The third characteristic stressed for the learning environment as supporting inquiry teaching is adopting ideas from *constructivist theory*. Today, constructivism is the preferred approach by science educator for enhancing the teaching of science Chin & Chia, 2004; Kang, Scharmann & Noh, 2004). Students are more involved in the construction of knowledge where it is based on previous knowledge and skills and is conducted through active involvement. The more interested and engaged students are by a subject or project, the easier it will be for them to construct in-depth knowledge of it (Wu & Tsai, 2005; Tsai, 2000).

The fourth learning environment characteristic emphasised is the *motivation of* students. The concern is that the teaching of science as a theoretical subject makes it distant from everyday life and uninteresting for students (Lunetta, 1997; Chinn & Hmelo-Silver, 2002; van Aalsworth, 2004). Inclusion of these key ideas into science teaching, are given in Table 2 (Bybee, 2006, p. 5).

**Table 2**. Inquiry learning actions by science teachers enhancing student motivation.

| | |
|---|---|
| A. | Teachers of science plan for inquiry-based science programs, initiated and developed by their students. |
| B. | Teachers of science guide and facilitate learning. |
| C. | Teachers of science engage in ongoing assessment of their teaching and of student learning. |
| D. | Teachers of science design and manage learning environments that provide students with time, space and resources needed for learning science. |
| E. | Teachers of science develop communities of science learners that reflect the intellectual rigour of scientific inquiry, as well as attitudes and social values conductive to science learning. |
| F. | Teachers of science actively participate in ongoing planning and development of the school science programme. |

In the current study a major characteristic of the learning environment was the focus on *open-inquiry*. To enact this different authors have emphasized the need for other accompanying skills related to teaching. For example, it is considered important that the teacher:

- have knowledge and skills about inquiry (Windshitl, 2004);
- have practical experiences in inquiry activities (Lotter, Harwood & Bommer, 2007);
- have knowledge about teaching inquiry (Scherz, Bialer & Eylon, 2008).

The first of these has been made more explicit by Hofstein *et al*., (2005), focusing on chemistry teachers:

- able to lead and tutor students' work while conducting inquiry-type experiments;
- being familiarity and experienced with alternative and continuous assessment methods;
- able to develop teacher-based learning materials and activities related to the implementation of inquiry learning in the chemistry classroom and laboratory.

These key elements are embraced in the current study on open inquiry teaching and the in-service provision paid attention to ensuring teachers understood the meaning of open inquiry and the manner in which the teacher needs to set about conducting open inquiry and ensuring the teachers gained practical experience in carrying our inquiry activities. The model used for such inquiry training involved four stages:

- initial motivating stage: suggesting an approach to motivating students through connections with everyday life situation. The first introductory step of inquiry was designed as a "hook" to increase students own curiosity, wonder, interest, or passion to provide the intrinsic motivation to focus students on the problem and its solution;
- the second, pre-experimental stage: suggesting how the teacher can guide students to identify social and scientific problems (related to subject matter) in the scenario; ask questions; select an appropriate research questions which involves dependent variables, which one could change, and independent variables;
  - ✓ which could be answered through experimentation in science laboratory conditions, and
  - ✓ planning an appropriate experiment. This stage involved also the learning of subject matter topic;
- the third, experimental stage: guiding students to carry out their experiments to collect and recording data in appropriate forms, for example tables and charts;
- the fourth, post-experimental stage: guiding teachers how to help students analyse outcomes and draw relevant conclusions. This includes interpreting (transmitting) data in an everyday context for that which is possible by using constructivist teaching approaches (Paper III).

Open inquiry teaching is thus taken to mean a process in which the teacher guides and involves students' in identifying problems and based on that, posing the questions and finding the answer through interventions and the ability to relate this to everyday life.

**Difficulties in applying inquiry teaching**

Although student-centred, teachers nevertheless play a critical role in open inquiry learning. This role incorporates guiding, focusing, challenging, and encouraging students to engage in this kind of activity.

There are many teaching difficulties in implementing the open-inquiry teaching approach among science teachers. It is inevitable that a teacher with a lack of understanding is unable to guide open-inquiry. Moreover, even with limited individualised conception, teachers tend to assess the process in parts and in this way stifle students' understanding about the learning they are undertaking through the inquiry process (Llewellyn, 2002; Lee *et al.*, 2004; Windschitl, 2004; Shedletzky & Zion, 2005; Paper I).

Research has shown that the outcomes from teaching carried out by teachers with a poor understanding of inquiry and inquiry-based teaching, lead to low levels of students' inquiry skills and at the same time students' attitudes towards learning science tend to be negative (Beaumont-Walters & Soyibo, 2001; Kanari & Millar, 2004; Watson *et al*., 2004). Moreover, student perceptions about inquiry learning are limited and hardly bear any resemblance to carrying out the inquiry process, other than an ability to follow the steps involved procedurally. In such cases, the inquiry process is rather an epistemological task, and not a systematically way of thinking. As a result, the acquired skills of students, developed through undertaking so-called inquiry learning, do not attain the expected level.

Teacher anxiety can be a concern when carrying out open inquiry, as the teacher can have a feeling of being "out of control" over what is going on in the class (Llewellyn, 2002). To avoid difficulties with discipline, teachers tend to provide their students with full instructions concerning the procedure of investigation and in this way, unfortunately, provide minimal opportunity to allow the students to design an investigation using the inquiry approach (Gott & Duggan, 2002). Teachers may feel unconfident while facilitating students in the pedagogically risky process of open inquiry, in which results are unexpected, cannot be predetermined, and can trigger further investigations (Windschitl, 2002).

These constraints were carefully considered when designing the intervention for this study, especially for teacher sessions and workshops.

**Motivation of students**

One of the needs which emerged in recent times in inquiry classrooms is the creating of a learning environment which motivates students to like and enjoy their science studies.

To be motivated means *to be moved* to do something (Ryan & Deci, 2000a). Motivation concerns energy, direction, persistence and equifinality of all aspects of activation and intention (Ryan & Deci, 2000b). In science classrooms, motivation is highly valued because of the consequences motivation produces. Research has shown that motivation is a unitary phenomenon (Printrich & Schunk, 2002) and varies not only in the level of motivation (how much motivation), but also in the direction of that motivation (what type of motivation). As pointed out by Watts and Alsop (2000), to ignore the affective domain is to exclude consideration of a seminal part of the learning that can take place in school science; that successful learners value the task, whilst at the same time believing that they can succeed at the task. Creating an effective learning environment has played an important role in motivating students and many studies in science education have focussed on this (Séré, 2002; Hofstein & Lunetta, 2004; Lang, Wong & Fraser, 2005; Millar, 2005; Blumenfeld *et al.,* 2006; Schelfhout, Dochy, Janssens, Struyven & Gielen, 2006; Solzbacher, 2006; Watanabe, Nunes, Mebane, Scalise & Claesgens, 2007).

Printrich, Marx and Boyle (1993) criticised the common model of science teaching, which concentrated on conceptual change. They characterised this model as "cold" and presented a counterbalancing "hot" model, involving motivational components. Taking into account a psychological viewpoint, various motivational components connected to the teaching and learning of science have been put forward (Glynn, Taasoobshirazi & Brickman, 2009), such as:

- personal relevance, which is the relevance of learning science related to students' goals;
- self-determination, which refers to the control students believe they have over their learning of science;
- self-efficacy, which refers to students' confidence that they can achieve well in science;
- assessment anxiety, which is the debilitating tension some student experience in association with grading in science.

However, other ideas have been reflected in literature. According to Von Glasersfeld (1987), sustaining motivation to learn is strongly dependent on the learner's confidence in his or her potential for learning. Marzano and Kendall (2007) elaborated and pointed out that an individual's motivation to initially learn, or increase competence in a given component, is a function of three factors: 1. perceptions of its importance, 2. perceptions of efficacy relative to learning, or increasing competency, and 3. one's emotional response to the component. Glynn, Taasoobshirazi and Brickman (2009) developed a students' motivation model to learn science in more details, which involved five components: intrinsic motivation and personal relevance, self-efficacy and assessment anxiety, self-determination, career motivation, and grade motivation. In this context, intrinsic motivation involved intrinsic value, learning goal orientation, self-efficacy, and performance goal.

In the light of a prominent theory of motivation – Self-Determination Theory (SDT) – different types of motivation can be distinguished, based on different reasons, or goals which arouse student actions. The most basic distinction is between extrinsic motivation, which refers to doing something because it leads to a separable outcome and intrinsic, which refers to doing something because it is inherently interesting or enjoyable (Ryan & Deci, 2000a, 2000b).

**Extrinsic motivation**

Students can perform extrinsically motivated actions with resentment, resistance, and disinterest or, alternatively, with an attitude of willingness which reflect an inner acceptance of the value or utility of a task (Ryan & Deci, 2000a). Extrinsic motivation for learning is promoted through the motivational learning environment: working in the ZPD (Zone of Proximal Development) (Vygotsky, 1978), attractive and intriguing tasks sufficiently interesting for the learner (Yung & Tao, 2004) and a context-based approach (Lubben, Campell & Dlamini, 1996; Gilbert, 2006). In discussing the nature of context in chemical education, Gilbert (2006, p.966-970) identified four different models related to extrinsic motivation:

*Model 1* – direct application of concepts to illustrate the use and significance of the concepts. While this approach might exhibit the relevance of topic subject matter, it does not use the social dimension and is this driven by the classroom environment for its extrinsic motivation for students.

*Model 2* – context is considered as having reciprocity between concept and applications. Extrinsic motivation is thus heavily dependent on the classroom environment.

*Model 3* – context as provided by a personal mental activity. Where the context are situations from a student's life, transformed through mental activities, the emphasis is on motivating students to undertake the mental activity and hence is again dependent on the classroom environment and is another example of extrinsic motivation.

*Model 4* – context as the social circumstance. A context here was situated as a cultural entity in society; and it involved teachers and students as perceiving themselves as participants of a "community of practice".

Lubben *et al*. (1996) observed that conceptualised activities, which linked science to students' everyday live and helped students to select and apply their scientific knowledge to solve everyday problems, improved students' conceptual understanding. Using relevance to the student as a trigger for science learning is thus perceived as an important motivational approach. It is more difficult to determine whether this should be considered as intrinsic or extrinsic motivation, but based on the Ryan and Deci model (2000a), where motivation in school science is, in the main, extrinsic and driven by the classroom environment, this example probably fits in this mould.

In the current study, the creation of an authentic context for learning the whole of a particular topic was not considered important, but the link between components of subject matter and everyday life was stressed. Research has shown that it is an important criterion for making learning in science class relevant to students (Brophy, 1999; Joyce *et al*., 2002; Teppo & Rannikmäe, 2003). Yet rarely does typical instruction, or standard curricula, begin in such a manner. Instead, they start with content (big ideas), agreed as important ideas to "present" to students. This approach makes it more difficult to motivate students, as it heavily relies on extrinsic motivational stimulus by the teacher. Research results indicated that the science taught in school has a theoretical nature and is often taught separately from the context in which it is to be implemented i.e. the emotion driven intrinsic motivation coming from everyday life. This was one reason why school was not seen as relevant to the students (Holbrook, 2003; Gilbert, 2006).

**Intrinsic motivation**

This emerged as an important phenomenon for educators, because intrinsic motivation results in high-quality learning and creativity (Ryan & Deci, 2000a). At the same time, Goudas and Others (1995) emphasised that intrinsic motivation means students participating in activities for themselves, not for external rewards. Intrinsically motivated students dedicate their energy to their own work; they enjoy and find them interesting (Printrich & Schunk, 2002). From Brophy's point of view, intrinsic motivation involved emphasis on aspects of values, need, interest and appreciation (Brophy, 1999).The role of this interest component was stressed by Yager (2007) who created a model for science teaching described by six "C's." This suggested science education needed to start with curiosity, a key component of motivation which, when in the form of a question, can be both intrinsic or extrinsic - intrinsic if the question has everyday relevance raised at the initiation of the teaching and extrinsic where the question stems from the teaching approach adopted by the teacher.

Thus, the model of the intrinsic motivation could involve a number of components, all very tightly related to personality of student.

In the current study, the teaching of a topic is initiated by means of a scenario. The scenarios are introduced to stimulate the intrinsic motivation of students and as such are short stories about students' everyday life, which involve both social and subject matter problems. The model used is most closely related to model 3 in the Gilbert list. Everyday situations used were familiar to students and most students had personal experiences related to these situations. Meaningful problems create a "need-to-know situation" for specific ideas and concepts, and provide a reason to understand. They provide students with a variety of opportunities to work with concepts as the class keeps returning to the driving question, based on the everyday problem under study. The development of the final outcome enables students to apply content and skills learned during lessons. In addition to motivating students through stimulating real-life value, these outcomes provide an opportunity for cognitive engagement and transformation of the acquired knowledge and skills (Blumenfeld *et al.,* 2006). This is not to deny the importance of the classroom environment in the continuing extrinsic motivation of the students, as the teaching of the topic proceeds and the recognition that sustained motivation is likely to need the application of extrinsic motivation by the teacher.

Inquiry teaching includes a variety of components that have the potential to be motivating. For instance the teacher can provide opportunities for students to design experiments, or decide on ways to collect, analyze and interpret information (Blumenfeld *et al*., 2006). Deci and Ryan (2000b) suggested that according to Self-Determination Theory, a person has a need for competence. When such needs are met, student motivation is increased and endeavours become more effective. This theory is supported by the achievement goal theory (AGT), which focuses on two types of student achievement goals: mastery and performance (Pintrich, 2000). Both goals can be realised during the process of inquiry. Not a small part of motivation in the inquiry-based laboratory work is caused from working in small groups (Kipnis & Hofstein, 2005; Newton & Sacney, 2005).

**Cognitive development**

Cognitive development is expected to be a major outcome of teaching. Unfortunately traditional teaching is the adoption of information by students and the result of such teaching is developing isolated inert knowledge. Students are capable of answering questions by recall, but not through using acquired knowledge or skills in the same or analogous situations. The learner with inert knowledge lacks connections and relationships between ideas, and cannot retrieve or use knowledge in appropriate situations (Perkins, 1992).

On the other hand, constructivist views of learning contrasts with the traditional mode. Constructivist learning models bring to the forefront the constructing of mental schemas. According to Piaget (1953), the mental schemas involved terms, connections between them and conceptions. In this process, the students associated the new knowledge with the current so as to modify their schemas. The student does not possess *tabula rasa* on which new knowledge is etched; he or she has an individual schema based on their own experiences. Piaget (1953) suggested that through two processes: *accommodation* and *assimilation*, student construct new knowledge from their experiences. When students assimilate, they incorporate the new experience into an already existing framework without changing that framework. In contrast, when individuals' experiences contradict with their internal schemas, they may change their perceptions. That is reframing students' mental representation of the external world to fit new experiences. Students are active throughout this process: they apply current understandings, note relevant elements in new learning experiences, judge the consistency of prior and emerging knowledge, and based on that judgment, they may modify knowledge.

Von Glasersfeld (1987) emphasizes the role of learners. He opined that learners construct their own understanding and that they do not simply mirror and reflect what they observe or read. Students look for meaning and try to find regularity and order in the events of the world, even in the absence of full or complete information.

Constructivism, as a teaching theory, is associated with pedagogic approaches that promote active learning, or learning by doing. Most approaches that have grown from constructivism suggest that learning is accomplished best using a hands-on approach. So acquired knowledge is dynamic and therefore applied in new situations and for solving problems.

In the classroom, the constructivist view of learning can be expressed through a number of different teaching strategies. In the most general sense, it usually means involving students in using active techniques (experiments, real-world problem solving) to create more knowledge and then to reflect on and talk about what they are doing and how their understanding is changing.

The efficacy of constructivist oriented science teaching has been demonstrated through a number of studies (Chin & Chia, 2005; Wang & Lin, 2009). For example, Wu and Tsai (2005) determined that students working as a group, following constructivist-oriented instruction, attained better usage of information processing strategies than their associates in traditional instruction groups.

The importance of cognitive conflict, as an influence on learning, has been acknowledged by researchers and teachers. Piagetian assimilation has been used to describe the integration of new ideas with old and accommodation has been used for the revision necessary when conflict is created as a result of the new ideas (Piaget, 1953). For learning to occur, however, students must feel some dissatisfaction with current ideas and the need for new information. It can take place during a discussion when students need to express clearly their own thoughts, or in a situation where students want to clarify the existing situation, or a lack of knowledge, or where a conflict arises in a student's everyday life and scientific language use.

The using of cognitive conflict and its benefits has been highlighted in a number of studies (Kang *et al*., 2004; Zohar & Aharon-Kravetsky, 2004; Wu & Tsai, 2005; Baddock & Bucat, 2008).

The current study is based on constructivism as a teaching theory and shares the notions that

- learning is an active process of constructing knowledge, whereby new information is linked to prior concepts;
- instruction is a process of acquiring through construction rather than the transmitting of information; and
- through creating cognitive conflict, the students were put in the situation where they "want to know" – the laboratory work begun to clarify an interesting problem related to everyday life of which they had little knowledge.

Social constructivist scholars agree with this and emphasize that individuals make meanings through the interactions with each other and with the environment they live in. Knowledge is thus a product of humans and is socially and culturally constructed (von Glasersfeld, 1987).

In the current study, the students' logical and conceptual growth was designed for small groups and the different knowledge and skills levels within peer groups were expected.

## 2.3. Teacher Professionalism

Teaching is an example of one profession in which continuous development of personnel is expected (Scherz *et al.,* 2008). Teacher familiarisation begins when the teacher is a student in school, albeit that the student is playing a far different role than that expected of the teacher. The first preparative step of teacher development is at the higher education level, where prospective teachers acquire or consolidate subject matter knowledge and gain general basic pedagogical knowledge. But the longest period of development time, and the most crucial level for shaping beliefs and procedures, is their own classroom experiences as teachers (Bond-Robinson, 2005). Noticeable research shows that teaching experience reduces the importance of the subject matter knowledge as the teaching focus and increases the importance of the pedagogical knowledge (Wellington, 2000). It is the attention to this last step, on pedagogical knowledge, which becomes the focus for designing the teacher's professionalism and its development. And for this step, different models have been created; arguably the best known and most used being the model proposed by Shulman (Berry, Loughran & Driel, 2008).

**Shulman's PCK model and subsequent developments**

Shulman considered it necessary to describe teacher's actions through the introduction of a new concept called pedagogical content knowledge (PCK). At the beginning, he identified PCK as a sub-category of teacher content knowledge (the other two sub-categories being subject matter content knowledge and curricular knowledge):

> *"A second type of content knowledge is pedagogical knowledge, which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge* ***for teaching****. I still speak of content knowledge here, but of the particular form of content knowledge that embodies the aspects of content most germane to it's teach ability"* (Shulman, 1986, p.9).

He found this knowledge, associated with *the most regularly taught topics in one subject area* (p.9), included representations of knowledge (analogies, illustrations, examples, explanations, and demonstrations), student learning difficulties and strategies to deal with them. According to this conceptualisation, Shulman suggested that PCK:

- was a sub-category of content knowledge;
- was topic-specific; and
- included various ways of representing knowledge, identification of learning difficulties and putting forward teaching strategies to overcome them.

In a following article, Shulman (1987) identified PCK as one of 7 categories of teachers' knowledge and proposed these components as:

- content knowledge;
- general pedagogical knowledge;
- curriculum knowledge;
- PCK;
- knowledge of learners and their characteristics;
- knowledge of education contexts; and
- knowledge of educational ends, purposes and values.

PCK was conceptualised as a category on its own, and not as a sub-category of content knowledge. He specified:

> *"[PCK] represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interest sand abilities of learners, and presented for instruction"* (Shulman, 1987, p.8).

In summary, Shulman presented a strong case for pedagogical content knowledge (PCK) as:

> *"A special amalgam of subject matter and pedagogy; a specific form of knowledge for teaching which refers to the transformation of subject matter knowledge in the context of facilitating student understanding" (Shulman, 1987, p.8).*

In the past 15 years, a plethora of articles on studying and integrating PCK into teacher education have been published in the research literature. Much has been written about the importance of PCK as a foundational knowledge base for teaching (van Driel, Verloop, & de Vos, 1998; Bucat, 2004; Loughran, Mulhall & Berry, 2004; 2006), about components of PCK (Hashweh, 2005; van Dijk & Kattmann, 2007; Lee and Luft, 2008;) and about different models of PCK (Fernandez-Balboa & Stieh, 1995; Nilsson, 2008). Teacher professional development has become a focus for a number of research studies in recent years (Henze, van Driel and Verloop, 2008; Loughran, Mulhall and Berry, 2008; Nilsson, 2008) and often has been measured in terms of PCK. These, mainly qualitative studies, have resulted in describing the teachers' accomplishment profiles and, based on them, categories of teachers' change have been determined (Scherz *et al.,* 2008).

A number of publications have focused on the teaching of various subjects, including mathematics (Kinach, 2002), history (Husbands, Kitson & Pendry, 2005) and primary education (Johnston & Ahtee, 2006). However, it is in the field of science that PCK has been most often been the focus of research and publications highlighting key knowledge required of the teacher for the teaching of school science (NRC, 1996; van Dijk & Kattmann, 2007).

**The Nature of PCK**

Different interpretations of PCK have arisen in the literature. One discussion topic is related to the foundation of PCK. Some researchers claimed that PCK is rather generic and PCK results from the integration of different knowledge components (Fernandez-Balboa & Stieh, 1995; van Driel, de Jong & Verloop, 2002). Controversially, Geddis (1993) pointed out a different position: pedagogical content knowledge is viewed as a set of special attributes that help someone transfer the knowledge of content to others. Similar conclusions about PCK, as a rather transformational process, were made by Nilsson (2008).

Although the initial model developed by Shulman involved three domains: subject matter, pedagogy and context, different components have become central in research. It is clear, that subject matter knowledge is a pre-requisite for the development of PCK because subject matter knowledge functions as a source to be transformed for teaching. Teachers need to develop subject matter knowledge that enables them to follow students' reasoning and analyse representations of the subject matter (Geddis, 1993; van Driel, Veal & Janssen, 2001; van Driel *et al.,* 2002). Australian researchers (Loughran, Milroy, Berry, Gunstone & Mulhall, 2001) have stressed the importance of this component for the beginning stage of investigations. They defined PCK as "the knowledge that a teacher uses to provide teaching situations that help learners make sense of particular science content" (p. 289). However, PCK is seen as more than subject content knowledge and involves components of teaching skill. Loughran and his colleagues built the basis for representing PCK starting with a "classroom window" methodology and followed this with PaP–eRs (Pedagogical and Professional-experience Repertoires), which characterised teachers' knowledge around a specific topic. This approach described science teachers' PCK, based on concepts of content representation (CoRe) and teachers' pedagogical and professional experience repertoires (PaP–eRs) (Loughran, *et al.,* 2001).

A few years later, the focus of investigations was moved to the components of the PCK related to pedagogy and was bound to the development of the teacher. It is possible to differentiate two domains: general pedagogy and content-specific pedagogy. The balance between these two domains was characterized by Geddis (1993). He pointed out, that the:

> *"Outstanding teacher is not simply a "teacher", but rather a "history teacher" a "chemistry teacher" or an "English teacher". While to some extent there are generic teaching skills, many of the pedagogical skills of the outstanding teacher are content-specific. Beginning teachers need to learn not just "how to teach", but rather "how to teach electricity", "how to teach world history" or "how to teach fractions*" (Geddis, 1993, p.675).

De Jong and co-authors found the essential part of PCK to be the teaching strategy – where a substantive part of developing PCK is reflection in the teacher's own teaching of science so as to help make insightful shifts in their thinking (de Jong, van Driel & Verloop, 2005).

Van Driel and co-authors (2002) sees practical knowledge as the core of teacher professionalism and identified five important, describing features:

- it is action-oriented knowledge, acquired without direct help from others;
- it is person- and context-bound. It allows teachers to achieve the purpose they personally value. It is affected by teacher concerns about their own teaching context;
- it is implicit or tacit knowledge. Teachers are not used to articulate their practical knowledge: they emphasised "doing" learning environment, not "knowing" learning environment;
- it is integrated knowledge: scientific and everyday knowledge;
- in building practical knowledge, teacher beliefs play a very important role (van Driel *et al.*, 2002).

Knowledge about the context was shown to involve social, political, cultural and physical characteristics of the learning environment (Valanides, 2002). Unfortunately, teacher training often falls short of this ideas and focuses more on decontextualized generic approaches, such as, for example collaborative or constructivist learning (Bransford *et al.,* 2001).

The borders between these domains, or components continued to move and new aspects were added. In particular, the component of the pedagogy was specified in research by Lee & Luft (2008) who constructed their PCK model based on a longitudinal study, which involved four science teachers.

Some studies which focus on exact descriptions of the PCK components have been selected from the literature and are illustrated in Table 3. These studies very much consider PCK from a knowledge perspective.

**Table 3.** Overview of components of PCK used in selected literature studies.

| Study | Components of PCK |
|---|---|
| Magnusson, Krajcik, & Borko, (1999) | 1. Orientations toward science teaching;<br>2. Knowledge and beliefs about science curriculum;<br>3. Knowledge and beliefs about students understanding of specific science topics;<br>4. Knowledge and beliefs about assessment in science;<br>5. Knowledge and beliefs about instructional strategies for teaching science. |
| Nilsson (2008) | 1. PK (pedagogical knowledge) – teaching activities (teaching procedures an strategies, questioning techniques etc);<br>2. CK (contextual knowledge) – reflections connected to students behaviour (cooperation);<br>3. SMK (subject matter knowledge) – teachers conceptual understanding and understanding of the structure and nature of the discipline. |
| Henze, van Driel & Verloop (2008) | 1. Knowledge about instructional strategies;<br>2. Knowledge about students understanding;<br>3. Knowledge about ways to assess students understanding;<br>4. Knowledge about goals and objectives of the topic in the curriculum. |
| Lee & Luft (2008) | 1. Knowledge of science;<br>2. Knowledge of goals;<br>3. Knowledge of students;<br>4. Knowledge of curriculum organization;<br>5. Knowledge of teaching;<br>6. Knowledge of assessment;<br>7. Knowledge of resources. |
| Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, (2008) | 1. Knowledge of subject matter;<br>2. Knowledge of students;<br>3. General pedagogical knowledge;<br>4. Knowledge of context. |

| Study | Components of PCK |
|---|---|
| Timmerman (2009) | PCK1 (related to teacher)<br>a. Representations of subject matter;<br>b. Teaching strategies and teaching style;<br>PCK2 (related to students)<br>c. Specific student learning difficulties;<br>d. Students' conceptions. |
| Jang, Guan, & Hsieh, (2009) | 1. Subject Matter Knowledge (SMK);<br>2. Instructional Representation and Strategies (IRS);<br>3. Instructional Objects and Context (IOC); and<br>4. Knowledge of Students' Understanding Subject Matter Knowledge (SMK). |

Alternative models have also been created which also consider PCK as an educational concept in which beliefs also figure. ERTE (educational reconstruction for teacher education) is a model for the study of science teachers' PCK (van Dijk and Kattmann, 2007). This model is established in the German *Fachdidaktik* tradition. The components of this model are:

- knowledge and beliefs of students' pre-scientific (alternative) conceptions;
- knowledge and beliefs of representations of the subject matter; and
- subject matter knowledge for teaching, in relation:
  - ✓ the designing of learning environments or teaching-learning sequences;
  - ✓ the study of students' pre-scientific conceptions; and
  - ✓ subject matter analysis (van Dijk & Kattmann, 2007).

Controversially, Hashweh (2005), presented a new conceptualisation of PCK using teacher pedagogical construction (TPC). His conception emphasised the part of pedagogy and did not include the part on content. Studies have been conducted also on the experience of teachers. Nilsson (2008) illustrated that the skills of young and experienced teachers in these fields are different and PCK improved during the teaching process. The same results were also obtained by de Jong and co-authors (2005).

Vogrinc and Zuljan (2009) analysed the other side of the teacher's experience and found that the teacher's desire to improve their teaching depended on years of work experience. In their study, the teachers were divided into four groups: 1. novice (one-three years of work experience); 2. teacher (4–6 years of work experience); 3. experienced teachers (7–18 years of work experience) and 4. senior teacher (worked more than 19 years). Among the teachers whose seniority was 4–6, years of experience, the desire to improve their work experience was the greatest, and teachers, who had worked more than 19 years, showed the least desire. These results demonstrate the dependence of PCK on the teacher experience.

Describing the nature of PCK is important to show not only areas, or components of PCK, but also possibilities to improve it. Thus while the evaluation of teaching and a teacher, can be developed by researchers, teaching cannot be assessed only by scientists; it needs to feature assessment on a far wider range of attributes and also undertaken by others such as students.

Schulte, Slate and Onwuegbuzie (2008) examined the characteristics that high achieving students perceive as being indicative of an effective classroom teacher at the high school level. The results indicated that students described a good teacher as a person who knows the subject, knows new changes in education, is knowledgeable about student needs and is knowledgeable about events outside classroom. The students recognised that for teachers to teach well, the teachers needed to be competent, possess good teaching skills, portray the curriculum well and were able to prepare students for careers. They communicated well, and were a disciplinarian in the sense of motivating students. These characteristics of a teacher were covered by PCK components using terms such as: subject matter knowledge, pedagogy and context. However, students valued also a number of facets connected with the personality of the teacher: patience, caring, being understood, and good personality, passion for teaching, fairness, flexibility, creativity and friendliness. These facets were not considered part of PCK and provide an opportunity for further research.

Other researchers treated PCK as a theoretical framework (Berry *et al*., 2008). By analysing across studies, four characteristics can be pointed out:

- PCK is dynamic, not static; teacher developments whether cognitive or emotional, can be described in terms of PCK;
- although PCK can be described using particular components, PCK is greater than the sum of these components;
- in many cases, content knowledge (subject matter knowledge) is a central part of PCK. It is not surprising that the PCK hierarchy is described in terms of subject matter knowledge (Bond-Robinson, 2005);
- teacher's use of PCK involves hidden components related to personality.

However, regardless of the different interpretations, the term PCK has become an accepted academic construct. And although PCK has attracted much attention, there is no universally accepted definition (Nilsson, 2008; Loughran, Mulhall & Berry, 2006; Hashweh, 2005; van Driel *et al*., 2002).

In the current study, PCK was taken as a complex of personal tacit knowledge, which was formed through education and teaching experiences and involved values, use of teaching strategies and content knowledge. Values were added to PCK, because previous research has shown its importance in teacher development (Paper I; Rannikmäe, 2001).

Little is known about the process of PCK development, in particular for experienced teachers, and especially in innovative contexts. The innovation in this study concerned the shifting of the teaching paradigm from teacher-centred to student-centred teaching; from narrow goals of teaching to a wider set of goals; and from traditional teaching approaches to teaching through an inquiry process (inquiry being a term, characterising learning and teaching in school today).

Similarly, few studies have investigated PCK specifically for the teaching of inquiry, as PCK has been treated in the context of professional development in general (Lotter *et al.,* 2007). However there is a hypothesised difference in emphasis between general PCK and PCK for inquiry teaching. This difference is hypothesised to be related to readiness or willingness to change his or her understandings about teaching goals and strategies.

# 3. METHODOLOGY

## 3.1. Design of the study

**Sample**

The target group for the current study was a purposeful sample of eight voluntary science teachers from participants taking part in an eight-month in-service course. The course was designed to introduce inquiry and issue-based approaches in the framework of experimental problem solving. All eight teachers had graduated from the chemistry department in the University of Tartu during soviet times and had more than ten years chemistry teaching experience. All teachers were female and were employed in schools with non-selected students. Table 4 gives the profile of the eight teachers.

**Table 4.** Profile of the Teachers participating in the study.

| Teacher | Age | Teaching Experience (years) | Degree Subject | Current Teaching subject |
|---|---|---|---|---|
| 1 | <40 | 14 | Chemistry | Chemistry |
| 2 | 40–50 | 23 | Chemistry | Chemistry, science |
| 3 | ≥50 | 26 | Chemistry | Chemistry, science |
| 4 | ≥50 | 32 | Chemistry | Chemistry, science |
| 5 | 40–50 | 23 | Chemistry | Chemistry, science |
| 6 | ≥50 | 34 | Chemistry | Chemistry |
| 7 | 40–50 | 19 | Chemistry, science | Chemistry, science |
| 8 | ≥50 | 13 | Physical education, chemistry | Chemistry, science |

Data were also gathered from students taught by the eight teachers (age range 15–16 years), all in the 9th grade (N=233). The sample was formed from students (N=174; 76 male and 98 female) who completed both the pre- and post questionnaires and interacted with worksheets for all five experimental sessions in which the instructional materials, specifically designed for this study, were used.

**Design of the in-service course**

The goals of the in-service course were: 1. introduce teachers to the philosophy of inquiry teaching, 2. improve teachers' knowledge about open inquiry, and 3. develop teachers' skills in carrying out laboratory inquiry teaching.

The structure and content of the meetings were as follows:

- **Introduction – stage I** on the philosophy of a new teaching approach. This included the following sections: goals of education, connections between school chemistry and real-life as well as other disciplines, inquiry and problem solving approach, motivating students, and collaborative work.

- **Introduction – stage II** providing practical experiences. An introduction to the process of inquiry and principles of inquiry based teaching. Practical inquiry experience using five instructional materials.
- **The operational stage** involved teaching using 1. instructional materials which included students' worksheets and teacher's guide with supplementary material, 2. gaining skills and knowledge.
- **The reflecting and supporting stage**. Involving teachers in presenting and discussing. Every teacher reflected on their experimental lessons and tried to analyse what went well, what did not succeed and what were the obstacles. Teachers presented this and also stressed students' reactions. Discussions took place with colleagues and researchers.

The in-service programme took place over 8 months and within this time 4 sessions were held, each lasting 8–16 hours (1 or 2 days). Between the sessions, the researcher frequently communicating with the teachers so as to determine progress and difficulties encountered. The teachers were encouraged also to telephone colleagues (teachers) as well as the researcher to consult about different aspects of inquiry teaching.

**Instruments**

In total, six different instruments were devised, four for use with teachers and two with students. The four teacher instruments used to describe and map the teacher's development, were:

1. a questionnaire for teachers,
2. worksheets for students' experimentation, composed by each teacher in the first and latest in-service sessions,
3. semi-structured interviews with each teacher four times during the intervention and once one year later,
4. transcriptions of the teachers reflecting on their practice and their discussions with colleagues during the intervention sessions.

The questionnaire for teachers (instrument 1) examined the goals of education and the goals of teaching chemistry, valued by the teacher. Instrument 2 measured teachers' understanding of inquiry teaching and characteristics of the teachers' learning environment before using the modules and again after carrying out experimental lessons. The semi-structured interviews 3 were used to illustrate teachers' attitude towards the inquiry learning environment, particularly in relation to the degree of teacher or student-centeredness, inquiry or problem solving, students' motivation, perceived constraints and assessment strategies. Instrument 4 gave a description of the teacher's development during the sessions in terms of inquiry teaching.

Students' evaluation of the inquiry learning environment, created by teachers, was measured through a pre- and post-questionnaire. This questionnaire involved 32 items on a 5-point Likert scale in five domains: 1. developing inquiry skills during the laboratory work, 2. interaction between students in small group and in a whole class setting, between students and the teacher, 3. type of experimental work carried out in science class, 4. preferred type of experimental work, and 5. students' opinion about teacher's activities related to the teacher as a guide in the inquiry process and assessment of experimental work. Data about developing students' inquiry skills (problem identifying, posing research question, planning experiment, interpretation in subject matter context and everyday context using knowledge and skills acquired through experimental work) were collected through a document survey (the second and fifth instructional materials, completed by students).

All questionnaire and interview instruments for teachers were checked for comprehension by four chemistry teachers and three independent experts.

**Timetable**

The following timetable gives an overview of the procedures undertaken during the 8-month intervention. The intervention started in November 2005 (the first month in the table) and ended in June 2006.

**Table 5.** Timetable for the 8 month intervention component of the research.

| Procedure \ Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Administrating teacher questionnaire | X | | | | | | | X |
| Interviews with teachers | X | | X | | X | | | X |
| Collecting instrumental material created by teachers | X | | | | | | | X |
| In service sessions | X | | X | | X | | | X |
| Carrying out experimental lessons by teachers | | X | X | X | | X | X | |
| Administrating students' questionnaire | X | | | | | | | X |

X – month of happening

A follow-up interview was conducted with teachers a year later, in the spring of 2007. The teachers were asked how many experimental sessions they had undertaken and in which classes they had carried them out during the previous academic year, using their assigned instructional materials.

**Data analysis**

The number of teachers in the sample (N=8) and the type of instruments used dictated the use of qualitative analytical methods.

To facilitate the measuring of each teacher's development from the intervention, teacher ideas, knowledge and understanding at each stage were divided, using the judgement of the researcher, into one of three hierarchical levels analogous to a 3-point Likert type scale:

1. at prior level,
2. change by one subscale of the component,
3. double change, or change in the 2 to 3 subscale (3 constituting the level of component of PCK for inquiry teaching).

The teacher's progress and development was defined in terms of "headways." The headway was a way of recording teacher's change during the intervention in terms of PCK for inquiry teaching. The magnitude (progress) of the headways was calculated for each teacher, in each component. Subsequent analysis allowed the findings of both:

1. the personal headway for each teacher to describe her development of PCK for inquiry teaching, and
2. the teacher's progress across the components.

Two independent experts were invited to divide the data into three levels. Differences between these three results were found to be minimal.

Students' responses to the pre- and post-questionnaires were used to describe the inquiry learning environment created by the teacher. Data describing the development of students' inquiry skills were collected using student worksheets from two instructional materials that were completed by students and assessed by teachers.

The results were decoded and processed with Microsoft Excel and SPSS 17 programs.

## 3.2. Instructional materials

Instructional materials for conducting the following five chemistry experiments with 9$^{th}$ grade students were composed by the researcher:

1. How to construct a fire extinguisher? (corresponding subject theme in the curriculum: the properties of oxides of carbon).
2. Why do you have to keep open bottles of juice in the refrigerator? (fermentation).
3. Why hunters prefer special sausages? (the burning process).
4. How to bake a good cake for Mothers Day? (gels).
5. How many metres can you run using energy from one hazelnut? (the calorific value of food).

Each set of instructional material:

- included a student worksheet, an extended teacher's guide, and supplementary material for the teacher;
- covered 3–4 chemistry lessons; and
- involved:
  - ✓ an opportunity to construct subject matter knowledge,
  - ✓ an opportunity to identify and solve the problem through a chemistry experiment,
  - ✓ an assumption for inclusion of group work so as to
  - ✓ develop students' inquiry and social skills.

The inquiry-based materials were composed so as to be motivational for students, based on the theoretically justified criteria extracted from the literature (papers II and III).

**Structure of the students' worksheets**

The student worksheets included in the instructional materials, are described by means of three elements, as shown in Table 6 below.

**Table 6.** Characteristics of the student worksheets.

| No | Structural element | Description | Goal |
|---|---|---|---|
| 1 | Scenario | A story including an open-ended problem taken from everyday life and having societal or personal dimensions. The solution to the problem involves experimentation in a chemistry context | To (a) intrigue students and to arouse their curiosity, (b) involve open discussion in class, (c) put students in a situation, where they do not know the answer, but would like to know. |
| 2 | Experimental inquiry-based problem solving | Includes students identifying and formulating the problem; posing research questions, planning the experiment, collecting and recording the data, analysing the data, making a conclusion. | To be able to undertake inquiry-based problem solving. |
| 3 | Individual quiz | Testing problem solving based on acquired knowledge and skills in the context of the subject matter and real-life situations. | To measure student gains in applying inquiry in a new situation. |

The coverage of domains in the grade 9 curriculum, the focus of the experimental work in relation to everyday life needs, the skills emphasised in the experimental activity and the focus of the quiz included within each instructional material are described in Table 7.

**Table 7.** Overview of instructional materials.

| **Title of the experimental work** | **Domain covered in 9th grade chemistry curriculum** | **Focus of experimental work** | **Skills developed (in addition to planning, experimenting and interpretation skills)** | **Quiz (supplementary to any calculation task)** |
|---|---|---|---|---|
| 1. How to construct a fire extinguisher? | Preparation and the properties of carbon dioxide | Technological aspect of making a device to extinguish a fire | Problem solving, inferring, constructing skills, evaluation skills | Evaluation, comparing and explanation related to experimental problem solving |
| 2. Why an opened bottle of juice must be preserved in a refrigerator? | Fermentation | Food preservation, selling/buying food | Problem identifying and formulating, high order thinking skills (concept map) | Interpretation and evaluation, using acquired knowledge or skills in a new situation |
| 3. Why hunters prefer specially prepared sausages? | Burning of carbon compounds | The chemical and biological aspects of the combustion process | Problem identifying and formulating, problem solving, high order thinking skills (concept map), presenting collected data in a table | Interpretation, using acquired skills in a new situation |
| 4. How to bake a good cake for mother's day? | Preparation and properties of gels | Relating school chemistry to processes in the kitchen | Problem solving, posing research questions, evaluation, presenting collected data in a table | Using acquired inquiry skills in a new situation, |
| 5. How many metres can you run using energy from one hazelnut? | The calorific value of food | Interrelationship of energy in physics, biology and chemistry | Problem identifying and formulating, problem solving, high order thinking skills (concept map), presenting collected data in a table, calculating averages | Using acquired inquiry skills in new situation, transferring skills to develop a dietary schedule for oneself |

The issue is indicated by means of the title of the experimental work, while column 2 in table 7 points out the curriculum area to which the activity relates. This leads to the need for experimentation to undertake the scientific problem solving and column 3 indicates the focus of the experimental work. The skill of problem solving is a key feature of each set of instructional materials and encompasses planning, the actual carrying out of the experimentation and the interpretation of the findings. Additional skills which are included are indicated in column 4. Cognitive learning is also a key component of each set of instructional materials thus ensuring that the experimental work is not concentrating on manipulative skills only, but playing an important role in elucidating the cognitive learning. Feedback for the experimental work and the degree to which the instructional materials promote inquiry learning is stressed by questions included in the quiz and forms the major evaluative criterion. Column 5 indicates the stress placed on this feedback for each set of instructional material.

## 3.3. Validity and reliability

In the current study, questionnaires, interviews and observations of study materials are used as measuring devices. Such measuring devices are not exact and furthermore, compared to real sciences, there is also no exact methodology. Thus the validity and reliability of the devices and the methodology must be carefully checked (Table 8).

The current study emphasises the importance of *internal validity*, which shows the extent to which side effects that can affect the phenomena researched have been taken into account. In compiling the selection the following aspects were taken into account:

- All the chemistry teachers had graduated from University of Tartu Physics-Chemistry department;
- None of the teachers was an author of the published instructional materials;
- All of the teachers had worked as chemistry teacher for more than 10 years;
- None of the teachers had taken part in prior training related to inquiry based learning;
- All students involved in the study came from the ninth grade, thus all of them had taken the same subjects from the same curriculum.

The requirement of *external validity*, related to the generalisation of the out-comes to the whole teacher community of Estonia, is a limiting factor in the study at hand. However, the characteristics of teachers are described and in the discussion part there are references to the application of the outcomes to teachers with similar characteristics.

*Content validity* shows the extent to which the content corresponds to the meaning to which it is ascribed, in other words, how well single questions reflect the measurements of students' achievements and skills. In the current study, the expert opinion method was used.

*Reliability* characterises the stability, consistency and suitability of the methodology used. Reliability shows how well the results of repeated measurements (by either the same researcher, or different researchers) carried out in the same circumstances, coincide. Reliability also indicates whether a certain indicator measures consistently and continuously, in other words, how reliable the result of the measurement is. In the current study, *Cronbach's alpha* is used as an indicator of *internal consistency* to assess to what extent questions measuring the same phenomenon coincide.

**Table 8.** Validation and reliability of instruments used in the study.

| **Problematic instrument/method** | **Issue** | **Validation/reliability method used** |
|---|---|---|
| Questionnaires for teacher | Content validity | Expert opinion method: two independent chemistry teachers and two independent scientists |
| | Reliability | Cronbach's alpha = 0.904 |
| Questionnaires for students | Content validity | Expert opinion method: two independent chemistry teachers and two independent scientists;<br>Piloting using 32 ninth grade students who did not participate in the actual study |
| | Reliability | Cronbach's alpha = 0.893 |
| The formation of categories to describe teacher development and the description of development on the basis of movement between these categories | Validity | The method of expert opinion: two independent chemistry teachers and two independent scientists |
| | Reliability | The difference in opinions is measured by Cohen's kappa = 0.82 (acceptability > 0.70). |
| The division of students' inquiry skills into three hierarchical levels (analogous to the Likert 3-level scale) | Validity | Expert opinion method: two independent chemistry teachers and two independent scientists |
| | Reliability | Cohen's kappa =0.88 |
| Forming and describing the groups of students' verbal reasoning answers | Validity | Expert opinion method: two independent chemistry teachers and two independent scientists |
| | Reliability | The difference in opinions measured by Cohen's kappa = 0.84 |
| The description of the inquiry based orientation of a class | | Triangulation used: data was collected about the same characteristics (the motivating of students, the type of practical work used in class, the amount of research activities) from three different sources: teachers' questionnaire, teacher's interviews and students' questionnaire. |
| Models | Validity | Expert opinion method. |

# 4. RESULTS AND ANALYSIS

This chapter gives the results obtained from a study investigating the development of teacher's PCK for inquiry teaching through an intervention study and the subsequent development of students' inquiry skills and their attitudes towards inquiry learning.

## 4.1. The learning environment prior to the intervention

**The learning environment described from the teacher position**
In the first in-service session, a pre-questionnaire, and in the last session, a post-questionnaire were administered, each designed using a 4-point Likert scale (agree, rather agree, rather disagree, not agree) so as to check on four aspects of teaching – perceived goals of education, type of learning environment for teaching, understanding of inquiry learning and emphasis on content knowledge in teaching. The questionnaires were validated using experts to remove overlap of items, administered to the participating teachers. The responses "agree" and "rather agree" in the pre- and post-questionnaire were expected to illustrate dominating aspects from a teacher's perspective. Table 9 gives an overview of teacher's responses.

**Table 9.** Teacher's (N=8) beliefs and understanding about creating an inquiry learning environment and undertaking inquiry teaching.

| Questionnaire items (translated from Estonian) | Purpose of Item | Number of teachers 'agreeing' or 'rather agreeing' to each item | |
|---|---|---|---|
| | | Pre-questionnaire | Post-questionnaire |
| The goal of teaching science is to provide students with particular knowledge. | GE | 5 | 2 |
| The goal of teaching science is to develop students. | GE | 3 | 6 |
| The aim of teaching science is to develop intellectual abilities/skills rather than social and personal abilities/skills. | GE | 5 | 1 |
| Experimental work in chemistry should be connected to everyday life. | LE | 4 | 8 |
| It is enough to bring real-life examples to make teaching science more interesting to students. | LE | 4 | 2 |
| I use experimental work mostly to illustrate the material and to develop the manipulative skills of the students. | LE | 4 | 0 |

| Questionnaire items (translated from Estonian) | Purpose of Item | Number of teachers ‘agreeing’ or ‘rather agreeing’ to each item | |
|---|---|---|---|
| | | Pre-questionnaire | Post-questionnaire |
| The students’ interests are more important than the curriculum. | LE | 0 | 3 |
| I think that an experimental lesson has to be introduced with a scenario. | LE | 0 | 7 |
| I get better results if I pass on my knowledge to the students and train them. | CK | 6 | 4 |
| Experimental work has to be subject (chemistry)-centred. | CK | 4 | 1 |
| I inspire interaction between students in small groups during experimental work. | LE | 2 | 4 |
| When making my own instructional material I use an inquiry approach. | IL | 5 | 5 |
| Inquiry is more about passing certain steps than a way of thinking. | IL | 5 | 2 |
| Inquiry is acting according to the instructional material or working according to the teacher’s guidance. | IL | 5 | 2 |
| I demand that there are both research questions and reasoned answers in the report of the experimental work. | IL | 6 | 6 |
| Students themselves should articulate the research question. | IL | 3 | 7 |
| It is important that the students themselves learn to identify the problems. | IL | 4 | 6 |
| The inquiry approach requires the development of problem solving and conclusion making abilities (and the ability to justify) from the students. | IL | 3 | 6 |
| In experimental work I value the results more than the process. | IL | 6 | 3 |
| For science teaching the subject training of teachers is more necessary than methodological advanced training. | CK | 5 | 4 |
| Until the content of the curriculum and examinations are altered, I do not see the need to change science teaching. | IL | 8 | 8 |
| Science teaching goals should be changed in order to develop a citizen who can cope with everyday life. | IL | 4 | 8 |

Key GE = goals of education sub-category
LE = learning environment sub-category
IL = inquiry learning sub-category
CK = content knowledge sub-category

Interviews were used to validate and illustrate data collected from the questionnaires in greater depth. It was found that initial understanding by five chemistry teachers about the purpose of teaching chemistry was narrow and they emphasized science education as acquiring a body of knowledge.

A typical comment was:

> *"I must prepare my students to pass the exam in the spring and to cope with chemistry lessons in the high school; hence I give them the appropriate knowledge and train them through exercises"* (Teacher 6).

The understanding of three chemistry teachers (teacher 1, 4 and 7) was wider and included social and personal components also:

> *"My students should cope with different difficulties in everyday life and I want to help them to build a basis for that"* (Teacher 4).

Again five teachers considered it necessary to bring problems of everyday life into the chemistry lessons. However, in their view, bringing in life-related examples was enough and using everyday life to frame the chemistry lessons was not considered significant. This suggests that teachers are not modelling chemistry-related problems in a social context as one possible way for increasing the relevance of the problem to students. This is reinforced by a comment by teacher 8:

> *"I do not consider it necessary to introduce problems of everyday life, because it would mean a great waste of time for me – after all, I would have to think through the themes in the textbook and try to look up examples of situations in the media or internet with which to link the theme. Moreover, I consider that I do not have time for that during the lessons. Also, my students are satisfied with the teaching (and practicing) and their results are good in the examinations and competitions."*

Surprisingly, five teachers stated that they use an inquiry approach. However, it appears that their understanding about inquiry is poor and this is not considered a reliable evaluation.

> *"Of course, I let the students investigate in practical work. For example, lately we explored the preparation and properties of $Al(OH)_3$. This instructional material was in the textbook and therefore well applicable. In my opinion, it was an inquiry-based material, as the students investigate the properties of amphoteric compounds. Written into the instructional material was which substances to use, how much they have to use and what they have to do. The research question, however, is contained in the title – and that is what I asked the students to write in their copy-books"* (Teacher 3).

Such activities were described in the 9$^{th}$ class chemistry textbook (Tamm & Timotheus, 2007). They are examples of recipe-type materials If, however, the teacher links the topic title with the research question, it suggests little appreciation of what is meant by a research question. This is further illustrated by a teacher explanation:

> *"I graduated from the university during the soviet time. At that time we were not taught the inquiry-based teaching approach. How should I know it?"* (Teacher 6).

All teachers claimed to appreciate the results of experimental work. The skills necessary for carrying out experimental work and the development of process skills were not, however, mentioned by any of the teachers.

A lack of a clear understanding of the purpose of experimental work was also confirmed by the analysis of the instructional materials compiled by the teachers before the beginning of intervention. These instructional materials reflected clearly the teacher's knowledge and understanding about inquiry and inquiry teaching. The characteristic learning environment features in the chemistry laboratory class were teacher, as well as subject, centred, which is emphasised by the following facts:

- the titles of instructional materials were related to the subject taught – chemistry.
- none of the instructional materials began with a part motivating the students.
- most of the materials did not contain a connection with everyday life.
- all the materials gave instructions that needed to be followed directly by students.

The student reasoning consisted of writing down the chemical molecular equations, without indication of the state of matter of either the reactants or the products. Hence the analysis of instructional materials leads to the conclusion that experimental work is not based on open inquiry, but rather it is based on very structured inquiry teaching and what is more, subject centeredness is strongly emphasised (papers I and IV).

**The learning environment described from the students' position**

The students' opinion about the teacher-created learning environment was determined by the orientation of lessons towards inquiry and the role played by the teacher. Data were collected from students' using a pre-questionnaire. Averages of student responses to items pertaining to learning outcome, based on a 5-point Likert scale (from: never = 1 to always = 5), are shown in table 10.

**Table 10.** Student responses (N=174 from 8 schools) evaluation of the learning environment.

| A Section of the Questionnaire showing items about learning (translated from Estonian) | Student means before intervention | SD |
|---|---|---|
| The teacher explains what to do before the experiment. | 4.20 | 0.88 |
| The teacher explains which equipment to use before the experiment. | 4.19 | 0.92 |
| The teacher explains before the experiment the outcome to be obtained. | 2.79 | 0.99 |
| The students include the scientific problem or research question in their reports of the experimental work. | 3.90 | 0.90 |
| The students including a list of the experimental equipment. | 3.80 | 1.11 |
| The students include the results of the experiment in their report. | 3.80 | 0.96 |
| The students answered questions and gave reasons in their reports. | 4.17 | 1.00 |
| Experimental work carried out was connected to everyday life. | 2.44 | 0.85 |
| Knowledge and skills acquired through experimental work are needed in real-life. | 2.28 | 0.86 |

Table 10 illustrates that in the students' opinions, the teacher uses traditional teaching strategies rather than those characteristic of inquiry based learning: before engaging in experimental work, the teacher explains what must be done (mean = 4.20) and specifies the equipment to be used (mean = 4.19). The students generally suggested that the experimental work was little related to everyday life (mean = 2.44). What is more, students didn't find the knowledge and skills acquired in laboratory work too relevant and applicable to everyday life (mean = 2.28).

The student reports of experimental work, carried out before the intervention, included a subject-based task (preparation and properties of $Al(OH)_3$), where the purpose of the experiment (mean = 3.90), the equipment used (mean = 3.80), the results (mean = 3.80) and reaction equations (mean 4.17) were written to illustrate outcomes. The teacher did not demand more.

**The findings**

Data from tables 9 and 10 and from teacher interviews, pointed to the following characteristic features of the initial teaching situation:

- The teachers consider acquisition of specific chemistry knowledge to be the aim of science teaching. Traditional teaching is preferred, where the emphasis is on the acquisition of knowledge and training in specific experimental techniques.

- A strong teacher centred and discipline centred teaching approach dominated in science classes. Students' involvement in the design of experimental work was low, rather teachers were active and the teacher presented the problem to be solved and instructed students what to do.
- The teacher assessed the results of the experimental work rather than the process and relied on the correct writing of equations.
- Teachers did not value linking chemistry lessons with everyday life.
- The understanding by teachers about inquiry and inquiry teaching was poor. The inquiry approach was equated to the work done related to the exact experimental prescriptions given.
- The teachers were not motivated to change their teaching methods and considered this unnecessary unless the curriculum and content of the examinations were changed. Students were taught to get through the examinations and be in a position to cope at the next school level (papers I, III and IV).

The above findings suggest that the chemistry classroom learning environment, as described by teachers and indicated from the students', is not conducive to inquiry learning and needs to change. To achieve this goal, an 8 month in-service course, including teacher workshops, was conducted so as to present a new philosophy and to provide teachers with the knowledge and practical experience needed for inquiry teaching. Based on this course, an intervention study was developed which set out to justify the criteria used as motivational for students in carrying out inquiry-based experimental work. The study also determined whether that the set of instructional materials created by teachers for inquiry-based experimental work reflected the criteria identified the degree to which open inquiry experimental sessions were developed and conducted and student gains, associated with the learning, developed.

The criteria used as motivational for students in carrying out inquiry-based experimental work were selected from that justified in the literature. In this manner, the criteria were considered to be theoretically justified, supporting hypothesis 1

*Hypothesis 1:* Criteria can be identified and theoretically justified related to the carrying out of inquiry-based experimental work which is motivational for students

As the instructional inquiry-related teaching materials were developed, based on the criteria identified (papers II and III), hypothesis 2 was also supported.

*Hypothesis 2*: A set of instructional inquiry-related materials can be developed which correspond to the criteria identified.

## 4.2. Outcomes from the intervention

Findings geared to the post intervention situation are related to hypotheses 3-6. As hypotheses 1 and 2 are related to justified criteria for carrying our inquiry-based experimental work and the development of a set of inquiry-related instructional materials, their outcomes were reported in section 4.1.

**Teacher development**

*Hypothesis 3:* It is possible to raise the professionalism of teachers through participation in an in-service course with respect to knowledge and skills focussing on the carrying out of open inquiry (paper IV).

To compile a wider picture about teacher development and to seek triangulation of the findings, data were collected through a teacher's post-questionnaire, teacher interviews and instructional material that the teacher had developed. This is detailed in sections (i) to (iii) below:

(i) Data were obtained from the post-questionnaire related to four components of PCK for inquiry teaching:

1. Goals of education valued by the teacher.
2. Creating an inquiry learning environment.
3. Inquiry learning skills.
4. Appropriateness of content knowledge (papers II and IV).

As shown in table 9 (items 1–3), the teachers extended the vision of the goals of education. For the majority of teachers the goal was no longer related solely to intellectual learning (item 3), nor in providing students with particular knowledge. The major goal of teaching was seen as developing students.

Findings from the 6 learning environment items were divided into three hierarchical levels, analogous to a 3-point Likert type scale, using the judgement of the researcher. These showed that few teachers thought it sufficient only to bring examples from real life to make chemistry teaching interesting, or that student interest was more important than the curriculum. More teachers were willing to use groupwork and all teachers indicated they used experimental work beyond illustrating the material, or simply developing manipulative skills.

There was strong development in inquiry learning ideas. Most teachers indicated that they demand from their students that there are both research questions and reasoned answers in the report of the experimental work, that students themselves articulate the research question, that students themselves learn to identify the problems and that the inquiry approach requires the development of problem solving and conclusion making abilities (and the ability to justify) from the students. Nevertheless, all teachers continue to feel that until the content of the curriculum and examinations are altered, they did not see the need to change science teaching. But they did indicate that science teaching goals should be changed in order to develop a citizen who can cope with everyday life.

While the teachers generally agreed that experimental work does not have to be subject centred, there was far less agreement on whether subject training of teachers is more necessary than methodological advanced training and also whether better student outcomes are related to teacher training or students' self-development.

(ii) Findings based on the interviews

1. Teachers indicated they had a wide understanding of the concept of *teaching goals* and the development of the students; this they claimed providing them with the knowledge and skills necessary for everyday life:
   *"As a contribution to the development of my student, I can and must play my part in my Chemistry lessons in carrying out laboratory work"* (Teacher 4).
2. Teachers showed an increase in competency through the intervention:
   *"At first I did not understand the matter. It was thanks to carrying out the instructions in the materials about the role of the student that I started to understand inquiry. Carrying out the work together with students, I not only understood the stages of the inquiry but also the way of thinking"* (Teacher 7).
3. Teachers referred to an important characteristic of inquiry-based learning process as connecting school chemistry and everyday life. Results show that teachers understood the importance of this connection, not through theory, but through experience.
   *"For the first time I noticed that my students took part in the experimental work very actively. Even those who were repeating a class with younger boys, who were many years older than the rest, and who usually don't pay attention to the teacher, discussed with others how to plan and what to do. And that was also because everyday life is more relatable to them. In the future, I will definitely use this technique again"* (Teacher 1).
4. The teachers indicated that the learning environment for the inquiry-based chemistry experimental work can be described by means of accompanying emotions.
   *"The carrying out of the first experimental work was a very exceptional event in our school. During the second work the whole school knew, that something interesting was coming and younger students were asking the ninth grade students what on earth was being done in the chemistry class"* (Teacher 4).

(iii) Findings related to instructional materials

After the in-service course, each teacher presented, for analysis, an experimental instructional material which the teacher had composed and used in an experimental lesson of 9th grade chemistry. And after the intervention, every teacher compiled a new set of instructional materials for carrying out chemistry experimental work in the 9$^{th}$ grade. Expectations were that the teachers would use the emphasis placed in the intervention sessions on the introduction of experimental work to motivate the students using a scenario from everyday life and an inquiry approach.

The structure of the short laboratory intervention modules, developed by each teacher, was analyzed according to the following components:

1. involving scenario (motivating students);
2. identifying a problem;
3. posing a research question;
4. planning the experiment;
5. collecting and analysing the data;
6. reasoning, summarising and drawing conclusions, (b-f are inquiry skills).

Table 11 presents the components which were embedded in each module, prior to and after the intervention, illustrating the change of teacher perceptions.

**Table 11.** Components embedded within each module by each teacher before (PM) and after (FM) the intervention (the column numbers represent the 8 different teachers).

| Components \ Teachers | | 1 | 2* | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Involving scenario | (PM) | – | – | – | – | – | – | – | – |
| | (FM) | + | – | – | + | + | + | + | + |
| Identifying a problem | (PM) | + | – | – | + | – | – | + | – |
| | (FM) | + | – | – | + | – | – | + | + |
| Posing a research question | (PM) | – | – | – | – | – | – | – | – |
| | (FM) | + | – | – | + | – | – | + | + |
| Planning an experiment | (PM) | + | – | – | + | – | – | – | – |
| | (FM) | + | – | – | + | + | + | + | + |
| Collecting and analysing the data | (PM) | + | + | – | + | + | + | + | + |
| | (FM) | + | – | – | + | + | + | + | + |
| Reasoning | (PM) | + | + | + | + | + | + | + | + |
| | (FM) | + | – | + | + | + | + | + | + |
| Summarizing the problem | (PM) | – | – | – | + | – | – | + | – |
| | (FM) | + | – | – | + | – | – | + | – |

+ indicates the component is included in the manual compiled by the teacher
– indicates the relevant component is lacking in the manual compiled by the teacher
* FM of Teacher 2 was not produced

The biggest change was seen in the motivation of students using scenarios from everyday life. The teachers indicated that they adopted this because of positive feedback from the students:

> *"I would not have believed that the students are so susceptible to such stories. One of my students justifies the need for a scenario like this: they bring everyday chemistry into the classroom and show the way for research. Obviously I have been underestimated their role"* (Teacher 5).

The other components in the instructional materials characterised inquiry and were more varied in the case of the different teachers. However, in terms of questions asked based on reasoning, not only did these include the writing of equations of the reaction, but also the use of knowledge acquired either in the same or a different context.

**Teacher change**

*Hypothesis 4:* Teacher change can be described as a result of participating in an in-service intervention, geared to inquiry-based teaching approaches, using carefully specified categories (published in paper II and IV).

The teacher's progress and development was defined in terms of their "headway". To determine how far each teacher was progressing across the range of attributes related to inquiry teaching (taken as goals of education, classroom environment, and content knowledge) (paper II), the magnitude (progress) of the headway was calculated for each teacher within each PCK component. For example, if a teacher moved from the first level to the second in the goals of education component, the magnitude of progress (headway) was indicated by 1 and, if a teacher moved from the second level to the third, the magnitude of headway was 2. Such analysis allowed the determining of both: 1. the personal headway for each teacher to describe their PCK development for inquiry teaching, and 2. teacher's progress across the PCK for the inquiry teaching components (papers II and IV).

A major factor was the following up of this analysis of teacher headway to determine the categorisation of teacher's change as a result of the 8-month in-service intervention. It was determined that these categories should form a hierarchy which was derived from the level of student centeredness in the teaching approach, determined from perceived goals of teaching, teaching strategy preferred, instructional material used and obstacles observed in teaching. Three categories were identified, based on K-means cluster analysis (paper IV). The categories were named against the teaching approach as *non-adapters* (category C), *teacher users* (category B) and teacher of *student-users* (category A). These categories heavily related to the teacher headway.

Teachers in the lowest, C category (*non-adapters*) carried out little experimental work with their students, but when they did so, it was based on instructional materials collected from the in-service course. They did not understand the philosophy behind the instructions and followed the format of inquiry linked with everyday life situations as the motivating component. They did not catch the meaning of the whole inquiry process and used only one part of the instructional materials – experimenting ("practical work") as this was comprehendible for them. Not surprisingly, their headway was very limited, as shown in figure 3.

Teachers in the next category (B) valued and accepted the method – inquiry, but did not change their overall teaching philosophy. These teachers focussed on following the inquiry stages from identifying the problem to presenting results. These teachers were characterised by the term "teacher users". Instructional materials created by "teacher users" were activity driven, often involving students only in a few, selected stages of inquiry. The headway of these teachers involved more steps than for teachers described by attributes for category C.

Teachers in the highest, A *student users*, category recognised the new philosophy and inquiry approach. Besides modifying instructional materials, they composed new instructional materials in the format of open inquiry with which the students interacted. This category was not represented among teacher's views before the intervention. These outcomes were published in paper II and paper IV.

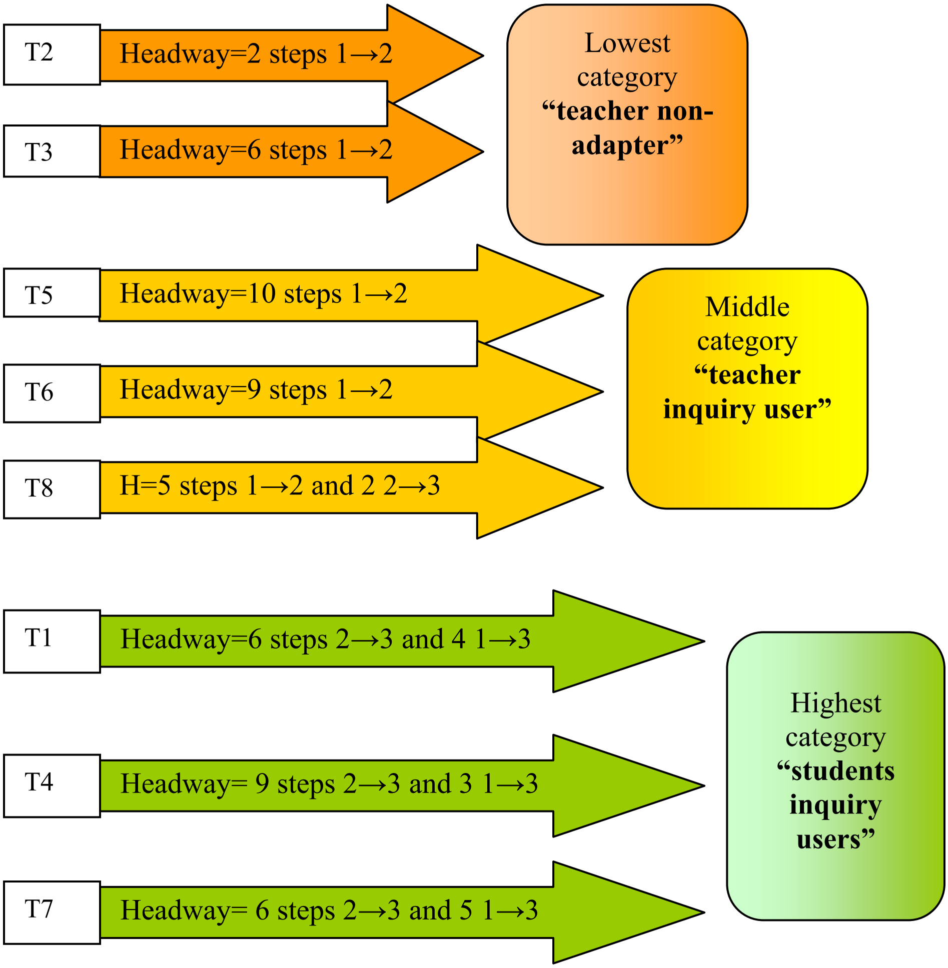


**Figure 3.** Teacher headway findings and achieved categories from the intervention

These headway findings stimulated further description of the PCK component, not included in the literature review undertaken in chapter 2. This permitted consideration of a further, but crucial, PCK component for inquiry teaching as shown below.

**Teacher willingness to change**

The willingness of a teacher to change was seen as an additional component of PCK, specifically geared to inquiry teaching. It was interpreted from teacher comments and from data collected in the previous section.

An example of teacher comments, related to willingness to change was:

> *"I think the most important factor to change is the teachers themselves. If teachers want to change, they use these things in their lessons, and your proposed methods. But if they do not consider it necessary to change, they look for more and more arguments as to why they should not do it"* (Teacher 7).

Willingness to change was considered as the driving force for teacher's change. Given its importance it was included as an additional component of PCK related to inquiry teaching and after discussion with science teachers, it was suggested this could be determined for Estonian teachers by their personality characteristics, using five important features:

- Type of advanced in-service courses the teacher had taken;
- According to self-assessment, the amount of time spent on preparation to gain both subject-based and methodological competence;
- How active the teacher was in participating in workshops discussions (VA – very actively, discussed in all domains related to inquiry and inquiry teaching; SF – subject focussed, preferred discussing experiences; NO – did not take part in discussions and preferred to remain silent, answering only when directly addressed);
- What obstacles were perceiving using the new teaching approach;
- How the teacher used the inquiry-based instructional material in the following academic year.

Table 12 gives an overview of these features, where the first subscale is marked as "In-service," the second as "Time," the third as "Participation", the fourth "Obstacles," and the fifth as "Using."

*The first feature* (in table 12: in-service) shows, from data gathered by interviews before the intervention, what kind of in-service courses the teacher has chosen and gone through in addition to the knowledge acquired in the university. When teachers appreciate subject-based knowledge and feel the need to improve in that field, then they choose to attend training courses in the field where such knowledge is given. If teachers wish to improve in the field of methodology, it was noted that they choose the relevant training courses. Therefore the choice of training is described by the teacher's values when it comes to teaching – either subject-based or methodological. It also gives evidence when describing the background of the teacher.

**Table 12.** A description of the 5 PCK "willingness to change" components ascribed to each teacher.

| **Teacher** | **Type of In-service** | **Preparation Time** | **Participation in in-service** | **Obstacles to implementation** | **Use of instructional materials** |
|---|---|---|---|---|---|
| 1 | Methodology and subject-related training | More than 3 hours. | VA | No claimed obstacles | Used all five instructional materials and also modified for using in other (grade 8 and 11) classes. |
| 2 | Individual subject-based training | 1–2 hours | NO | Lack of reagents, laboratory equipment, time. Most of students in the class were low academic achievers | Asked to send all the instructional materials electronically, but used only once in grade $9^{th}$ |
| 3 | A few subject-based training | Less than 2 hours | NO | Difficulties with discipline and ensuring safety; seeing an overloaded curriculum | Used two instructional materials in grade $9^{th}$ |
| 4 | Methodological and subject-based training | More than 3 hours | VA | No claimed obstacles | Used all five instructional materials and modified these for using in other classes (8 and10) |
| 5 | A few subject-based training | About 2 hours | NO | Lack of time & reagents, laboratory equipment. Difficulties with ensuring safety.<br>Poor understanding of inquiry | Did not use instructional materials, because they did not teach in $9^{th}$ grade; did not use in other classes either. |
| 6 | Subject-based training | About 2 hours | SF | Recognising lack of time, seeing an overloaded curriculum. Recognising lack of competence to carry out inquiry | Used three instructional materials in grade $9^{th}$, but only one in the format of open inquiry |
| 7 | Methodology and subject-based training | More than 3 hours | VA | No claimed obstacles | Used all five instructional materials and modified for using in $8^{th}$ and $10^{th}$ grades. |
| 8 | Subject-based training | About 2 hours | SF | Poor understanding inquiry. Recognising lack of competence to carry out inquiry and understanding of the philosophy | Used four instructional materials in grade $9^{th}$ |

*The second feature* (the second section in the table) illustrates the average time spent by the teacher on preparing laboratory work (it does not include the copying of instructive materials, but rather explaining the matter to oneself, searching for extra materials and organising the lesson) obtained from teacher interviews after the intervention. Three categories were formed by the researcher for the responses supplied by the teachers. All teachers indicated that the most time was spent on preparing the first laboratory work and substantially less time was spent on the last one.

*The third feature* characterises the teacher's participation in workshop discussions gathered by the researcher during the intervention in-service workshops. The data was recorded as VA – very active, SF – subject focused and NO – did not participate.

*The fourth feature* is connected to the obstacles indicated by the teacher that appeared during the carrying out of inquiry based practical work. This data was obtained from the post-intervention interviews as well as discussions during the in-service workshops

*The fifth feature* describes the carrying out of five laboratory sessions during the next academic year (the data was collected from interviews carried out at the end of the next academic year). The teachers were asked what kind of work and also how and in which classes they carried out the laboratory work during the year following the study. This data was obtained from individual interviews held one year after the intervention.

It was clearly indicated that if the teacher had benefited from both subject and methodological change (teachers 1, 4, 7), the teacher wished to gain competence in inquiry teaching and uses significantly more time for that:

> *"I had to familiarise myself at first. I searched for help from the internet, from books and even the media. And then I had to think carefully how I can do it, and how I can carry everything to the students. At first it was difficult, but then I took the manual and did some thinking. Of course, with the students, I learned more thoroughly as it was not always easy to answer all their questions"* (Teacher 4).

Outcomes showed that the teachers who spent more time on preparation were more self-confident in the lessons, changed more in PCK for inquiry teaching, did not identify any obstacles and used the 5 instructional models both in the experimental lessons of the grade 9$^{th}$ and, in a modified way, in lessons for 8$^{th}$, 10$^{th}$ and 11$^{th}$ grades.

Teachers, who had received single subject-based training in previous years (teachers 2 and 3) and had not been introduced to new trends in teaching, used much less time to get updated. As the inquiry teaching approach was not introduced to them during their initial training, their reasoning was objective and focused on the lack of resources and the overloaded curriculum.

Correlation analysis between the 6 characteristics of instructional material, which were created by the teachers, and the 5 aspects of the PCK component “willingness to change” showed interesting aspects related to teacher development. As expected, correlations were positive and particularly strong correlations were found between the characteristic involving social problems within the instructional materials and the PCK characteristic of time needed for preparation of experimental work (Spearman’s rho = 0.906, p=0.000). A high correlation also emerged between the PCK characteristics, involving questions where answering required the use of acquired knowledge and experience by the teacher in assessing the inquiry process, not just the results (Spearman’s rho = 0.755; p=0.023).

**Student development related to inquiry learning**

*Hypothesis 5:* Changes in students affective and cognitive gains, related to inquiry learning, can be determined and mapped (paper III).

**Change in students’ affective domain**

According to the teachers, change in the learning environment was described foremost by the formation of emotions. The students’ opinion was measured by the change:

1. in their preference of the type of practical work (either short and illustrative, or longer and involving some recourse to analysis), and
2. by determining motivating factors during the experimental work.

Data related to attitude were collected using the students’ post questionnaires on a 5-point Likert scale. In these questionnaires, students were asked to answer questions on what they liked in the lessons where laboratory work was carried out and the reasons for this.

The change of students’ attitude in the course of the intervention, for different categories of teachers, is described in table 13 by comparing the averages for each school between the pre- and post-questionnaire data.

**Table 13.** Change in means student attitudes towards inquiry-based experimental work based on pre- and post-questionnaire data across schools.

| School | Teacher Category | Student preference for short illustrative work | | Change of mean value | Student preference for inquiry-based experimental work | | Change of mean value |
|---|---|---|---|---|---|---|---|
| | | Pre-questionnaire | Post-questionnaire | | Pre-questionnaire | Post-questionnaire | |
| 1 | A | 4.21 | 3.96 | –0.25 | 3.81 | 4.09 | +0.28 |
| 2 | C | 4.00 | 3.89 | –0.11 | 3.50 | 3.52 | +0.02 |
| 3 | C | 3.93 | 3.86 | –0.07 | 3.46 | 3.20 | –0.26 |
| 4 | A | 4.23 | 3.60 | –0.63 | 3.85 | 4.23 | +0.38 |
| 5 | B | 4.50 | 3.93 | –0.57 | 3.49 | 3.79 | +0.30 |
| 6 | B | 4.24 | 3.64 | –0.60 | 3.72 | 4.26 | +0.54 |
| 7 | A | 4.27 | 3.84 | –0.43 | 3.86 | 4.12 | +0.26 |
| 8 | B | 3.96 | 3.54 | –0.42 | 3.57 | 4.16 | +0.56 |

The pre-questionnaire data, showing mean student preferences for short illustrative experimental work, as opposed to inquiry-based experimental work, did not show a link with the teacher's category. But there was a distinct preference for inquiry-based experimental work, post intervention, by the students of the A and B category teachers. Surprisingly, the biggest change was in the mean attitudes of students taught by the B-category teacher-users (paper II), although the small number of teachers involved makes the reliability of this finding suspect and the magnitude of the change to be taken with precaution.

**Motivational factors through experimental work highlighted by students**

In addition to the post-questionnaire, each student was asked to answer, why he or she preferred a particular kind of experimental lesson. The number of responses permitted was not limited. Based on a semantic analysis (classifying on the basis of the meaning of the written word), four motivational aspects were extracted:

- emotions (key words: surprised reactions, fun, wonder, excitement);
- connection to everyday life (key words related to home and friends);
- interest (key words: interesting and novel);
- learning, developing high order skills (key word: learning, thinking and investigating). (Kask *et al.*, 2009)

Students of category A teachers (Kask *et al.*, 2009) described motivating factors in all four fields, with interest and connection to everyday life especially being mentioned, but with less attention tuned to emotions. Many of these students also determined studying as a source of motivation (20–26 % of students). According to Self Development Theory (SDT), interest and the perceiving of emotions show the occurrence of intrinsic motivation, while connections to everyday life are extrinsic motivational factors for the students (Ryan & Deci, 2000a). Thus, it can be concluded that only teachers who have reached the highest level of development were creating a learning environment, where both motivation aspects contributed to the learning of students.

The students of category B teachers were most motivated towards laboratory work by emotional factors and by the association of school chemistry to everyday life. Students of category C teachers indicated they were motivated by emotions brought about by laboratory work (in the classroom of teacher 2–64% students) and to a lesser extent, the relevancy of practical work to everyday life. The students' evaluation of the motivational aspect of the learning environment created by teachers showed that the students valued the emotional experience which occurred during the experimental lessons, as the main internal motivation source (Kask *et al.*, 2009).

**Change in students' cognitive learning**

Cognitive change was described from 2 aspects:

A. change in the students' inquiry skill level, and

B. comments by students describing their learning in the course of inquiry-based laboratory work.

As there is a strong correlation between the learning environment and change in students' inquiry skills (Kask *et al*., 2009), then the use of learning environment data to support the development of the students' inquiry skills was seen as a suitable surrogate. This was taken also to show that the role of the teacher was through the learning environment.

A. A three-level scale, before and after the intervention, analogous to a Likert's 3-level scale, was used to collect data illustrating the dynamics of students' inquiry skills. The 3 level scale was taken to be 1– irrelevant, 2– only connecting with variables and 3– inquiry skill, as derived in paper III. Table 14 illustrates the improvement in students' inquiry skills during the intervention, related to the teacher developmental categories (papers III; Kask *et al*., 2009). The table clearly shows students progressed during the intervention but virtually all students taught by category A teachers progressed beyond level 1 and indicators of attainment at level 3 were prevalent. Less progress was shown overall by students taught by teachers categorised by level B and the overall progress by students taught by teachers categorised by level C was the least.
B. To determine students' comments about their learning, students were asked to complete an open-ended question, following a post intervention student questionnaire, asking questions such as: What did you learn during the laboratory lessons?

For analysis, student answers to the open-ended questions were broken down by splitting responses into three broad hierarchical groups, based on the purpose, or outcomes of learning, in the opinion of students (paper II). The lowest group was labelled as "knowledge acquisition" (for example: *I got to know*). This group contains knowledge and skills that are necessary to finish basic school.

The responses by the highest, personal development, group included knowledge and skills that were necessary to continue studies in high school: higher order skills (*I learned how the fire extinguisher works and to discuss its effectiveness; I learned to plan an investigation*). The middle group "science for citizenship" contained responses related to knowledge and skills necessary for everyday life: social and technology skills (*I learned to work together with my classmates; my skill to express my ideas increased*). This division into groups was validated by two independent chemistry teachers and one researcher. The variance between the results was marginal (Cohen's kappa = 0.84; 0.78).

**Table 14.** The progress in student inquiry skills.

| Teacher number (No of students) | Teacher category | Before/ after intervention | LEVELS OF INQUIRY SKILLS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | No of students at each problem identifying skill level | | | No of students at each posing research questions skill level | | | No of students at each planning skill level | | | No of students at each interpretation skill level | | |
| | | | Level 1 | Level 2 | Level 3 | Level 1 | Level 2 | Level 3 | Level 1 | Level 2 | Level 3 | Level 1 | Level 2 | Level 3 |
| 1 (N=28) | A | before | 9 | 17 | 2 | 7 | 18 | 3 | 7 | 21 | 0 | 6 | 18 | 4 |
| | | after | 0 | 19 | 9 | 0 | 18 | 10 | 0 | 19 | 9 | 0 | 19 | 9 |
| 4 (N=30) | A | before | 6 | 21 | 3 | 2 | 21 | 7 | 6 | 21 | 3 | 6 | 15 | 9 |
| | | after | 0 | 18 | 12 | 0 | 18 | 12 | 0 | 15 | 15 | 1 | 13 | 16 |
| 7 (N=26) | A | before | 8 | 17 | 1 | 6 | 16 | 4 | 4 | 17 | 5 | 1 | 16 | 9 |
| | | after | 0 | 14 | 12 | 0 | 15 | 11 | 0 | 15 | 11 | 0 | 10 | 16 |
| 5 (N=15) | B | before | 5 | 10 | 0 | 8 | 7 | 0 | 5 | 9 | 1 | 4 | 10 | 1 |
| | | after | 1 | 11 | 3 | 0 | 13 | 2 | 1 | 10 | 4 | 1 | 12 | 2 |
| 6 (N=24) | B | before | 9 | 14 | 1 | 5 | 18 | 1 | 5 | 16 | 3 | 4 | 18 | 2 |
| | | after | 0 | 15 | 9 | 3 | 12 | 9 | 0 | 14 | 10 | 1 | 16 | 7 |
| 8 (N=22) | B | before | 7 | 14 | 1 | 7 | 15 | 0 | 6 | 14 | 2 | 2 | 18 | 2 |
| | | after | 0 | 16 | 6 | 1 | 14 | 7 | 0 | 17 | 5 | 1 | 13 | 8 |
| 2 (N=14) | C | before | 9 | 5 | 0 | 9 | 5 | 0 | 10 | 3 | 1 | 4 | 7 | 3 |
| | | after | 3 | 8 | 3 | 2 | 10 | 2 | 3 | 8 | 3 | 0 | 9 | 5 |
| 3 (N=15) | C | before | 7 | 8 | 0 | 10 | 5 | 0 | 2 | 13 | 0 | 8 | 7 | 0 |
| | | after | 2 | 10 | 3 | 6 | 8 | 1 | 1 | 11 | 3 | 3 | 10 | 2 |
| **Total (before intervention)** | | | **60** | **106** | **8** | **54** | **105** | **15** | **45** | **114** | **15** | **35** | **109** | **30** |
| **Total (after intervention)** | | | **6** | **111** | **57** | **12** | **108** | **54** | **5** | **109** | **60** | **7** | **102** | **65** |

All the changes measured according to the Wilcox Z test were statistically substantially different. (Kask *et al.*, 2009)

Table 15 illustrates the number of student opinions in the groups related to their teacher. It shows that students of category A teachers considered all the three grouping to be related to their learning in the laboratory. However a dominating tendency is the appreciation of personal development. To be more exact, the understanding of those teachers developed from the traditional "delivering of knowledge" to the development of a student as a personality. It is clear that the understanding and the approach of the teacher are reflected in the understanding of the students.

One of the characteristics of category B teachers was substantial subject centeredness. The data shows that in their classroom learning, acquiring knowledge was the dominating component.

Two teachers were described associated with category C. The orientation of their created teaching environment in each case was very different. It was subject centred dominated in one class (similar to category B teachers), but student opinions were dominated by a preparation for future life in the other class (unlike either category B or A teacher situations).

**Table 15.** Number and percentage of student, categorised into 3 levels of opinions about learning, against teacher category and total number of responses given.

| **Teacher's number/ No of students) (Teacher Category)** | **Total No of responses** | **Responses related to knowledge acquisition** | **Responses related to personal development** | **Responses related to preparation for future life** |
|---|---|---|---|---|
| 1/28 (A) | 56 | 11 (20%) | 23 (41%) | 22 (39%) |
| 4/30 (A) | 62 | 22 (35%) | 23 (37%) | 17 (27%) |
| 7/26 (A) | 53 | 16 (30%) | 23 (43%) | 14 (26%) |
| 5/14 (B) | 19 | 8 (42%) | 6 (32%) | 5 (26%) |
| 6/25 (B) | 70 | 53 (76%) | 14 (20%) | 3 (4%) |
| 8/22 (B) | 37 | 15 (41%) | 12 (32%) | 10 (27%) |
| 2/14 (C) | 21 | 7 (33%) | 3 (14%) | 11 (52%) |
| 3/15 (C) | 22 | 13 (59%) | 6 (27%) | 3 (14%) |
| **Total of students (N = 174)** | **340** | **145 (43%)** | **110 (32%)** | **85 (25%)** |

**Mapping teacher development against student cognitive and attitudinal gains**
*Hypothesis 6:* The relationship between teacher developments, with respect to inquiry-based teaching attributes, can be mapped by means of a model against student cognitive and attitudinal gains (Kask *et al.*, 2009)

The sixth hypothesis assumes that the different developments of the teachers are reflected in the creation of their learning environment and that the effectiveness of the learning process can be measured using indicators of student skill gains in cognitive and affective skills.

To illustrate a full picture of the interrelated components impacting on the learning environment, models were created based on considerations of all aspects of students' learning and the links between them. For this, data for individual students were obtained as indicated below.

The stages employed in creating the models:

- Stage 1 – Factor analysis was conducted on the items in the post questionnaire plus the student responses to the open ended questions and outcomes from an analysis of responses to the final instructional material. Six factors were formed. Items not in the factors were eliminated.
- Stage2 – K-means cluster analysis was undertaken by inputting components individually from the 6 factors: 3 clusters were formed.
- Stage 3 – Within each of the 3 student cluster groups separately, correlations were determined between the components. Only statistically significant correlations (correlations that were significantly different from zero) were taken into consideration. From the 39 components, 11 were selected in the case of model 1, 14 for model 2 and 13 for model 3.
- Stage 4 – these correlations were placed into two groups indicated by using arrows of two thicknesses. If the average strength of the correlation was middle or strong (Spearman's rho values 0.3 or more), and this was statistically significant at the level of $p \leq 0.001$, a thick black arrow (➡) was used to show the link between the two components. Where the correlation was weak ($\rho < 0.3$) and a significant level of $p \leq 0.05$, the link was illustrated by a thin green arrow (⟶). A dotted line (- - ►) was used to indicate a negative correlation at a significance level $p \leq 0.05$.

The use of the 4 stage approach made it possible to create three different models (Figures 4–6) which described the study patterns of students in the different clusters. At the initial (pre-intervention) stage, no links existed between the components of the models in all classrooms.

The development of inquiry skills depended on how all skills are related to each other and also, to the extent that these skills relate to students' motivation and outcomes from the intervention. Inquiry skills were thus treated separately within each model although grouping of motivational and learning factors was found to be appropriate. (Kask *et al.*, 2009).

*The components indicated in the models were identified as:*

IS1 – problem identifying inquiry skill,
IS2 – inquiry skill related to posing research question,
IS3 – inquiry planning skill,
IS4 – inquiry interpretation skill,
MO1 – motivational aspect related to generated emotions,
MO2 – motivational aspect related to connections to everyday life,

MO3 – motivational aspect related to interest,
MO4 – motivational aspect related to learning,
LE1 – learning outcomes related to knowledge acquisition,
LE2 – learning outcomes related to "science for citizenship",
LE3 – learning outcomes related to personal development for future studies
CE1 – communication as a component of classroom environment,
CE2 – feedback from laboratory work as a component of classroom environment,
CE3 – teacher activities as a component of classroom environment,
CE4 – assessment as a component of classroom environment.

In the models, thick black arrows are used to signify statistically significant correlation (Spearman's rho 0.3 or more at level p=0.01) between the specific components. Green thin arrows are used to signify weak correlations at the level p=0.05. A dotted line is used to indicate a negative correlation. Components having a number of significant correlations with other components (correlated 6 or more times), are coloured yellow. Components coloured yellow are surrounded by a red dotted line to illustrate the focus of attention. The three models have been drawn to highlight 3 component levels – the inquiry level (labelled IS1-4), the motivation level (labelled MO1-4) and the classroom environment level (CE1-4).

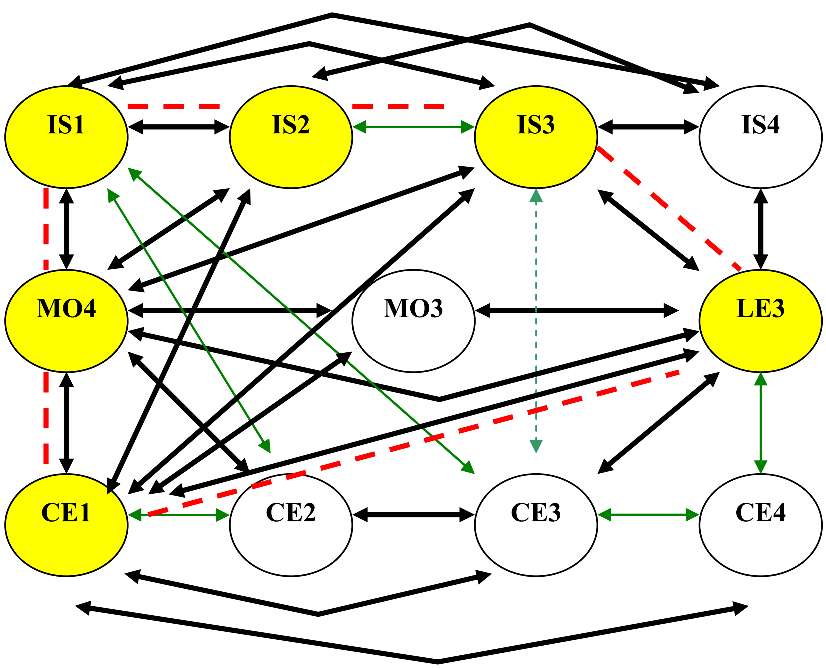


**Figure 4.** Model exhibiting student gains for students within cluster 1.

The main feature characterising the learning by students related to the model depicted in figure 4 is that many components in the model are closely related to one another. This suggests that, with the guidance of the teacher, these students were able to acquire the tightly connected set of skills which formed the complex of an extended inquiry, or inquiry framework. The learning associated with this model illustrates the development of inquiry skills in a framework, rather than just the attainment of isolated skills. In such a network, cognitive, as well as affective change, are the greatest and students are motivated in all four areas covered by both internal and external motivational sources. Learning as an outcome is influenced by four key components, the result of which is that these students acquired learning at all levels, with communication and motivation for learning seen as an important component. This model is labelled "inquiry for understanding" as the learning, classroom environment and motivation for learning all have multiple links to inquiry learning.

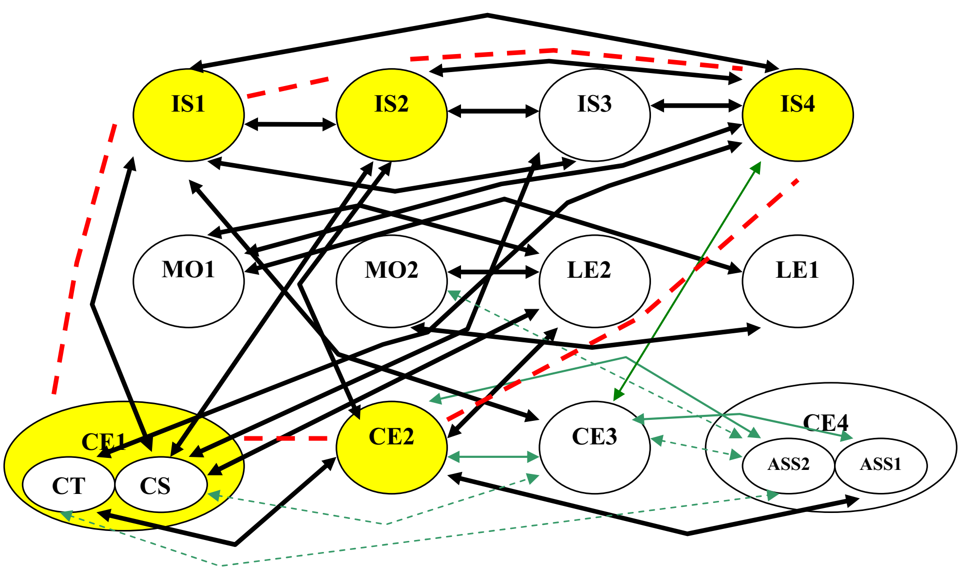


**Figure 5.** Model exhibited student gains for students in cluster 2.

There is a clearly distinguishable inquiry triangle in the model illustrated in figure 5, which is delineated by the dotted red line. Students illustrating in this model of learning are involved in doing inquiry which is heavily influenced by communication, especially between students. Learning tends to be guided by instructional materials and this represents the dominant model for students of teachers whose own change stopped at the midway level (level B). Teachers categorised by inquiry teaching development at level B are not sufficiently able to guide the majority of their students to form a complete model, especially in interlinking motivation with inquiry learning.

This model contrasts with the previous model in that MO3 and MO4 do not figure (MO1 and MO2 are included instead) and LE1 and LE2 figure rather than LE3. This model was labelled as "inquiry for doing" as both the motivational sources as well as the learning outcomes were linked to the problem identifying skill.

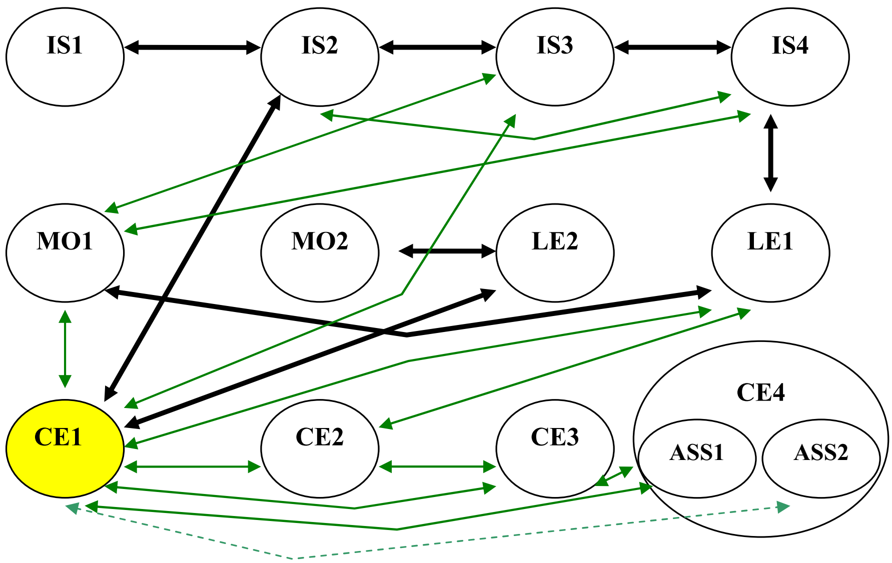


**Figure 6.** Model exhibiting student gains for students in cluster 3.

In the model portrayed in figure 6, the components are less connected to each other, but at the same time they exhibited some single strong links which are related to an approach highlighted in the instructional materials. Students are involved in doing inquiry, but are guided more by instructional materials and less by teachers, The model indicates that students see the connection with the problem emphasised in the scenario of the instructional materials, as motivational aspects only, whereas the process of inquiry is not perceived as strongly motivating. The external motivation that comes from the worksheet dominates and the teacher does not create intrinsic motivation. There is also less factors influencing learning outcomes in this component than in the previous models. It is clear that as a result of such a learning pattern, student acquisition of knowledge, as well as developing skills necessary for everyday life, is highlighted.

All three models described learning of some students taught by all teachers. The number of such students varied between the teachers. Nevertheless, the results obtained clearly showed the correlation between the major learning level of the students and the developmental level of the teacher. Table 16 gave an overview of the degree of student learning associated with the models in the classrooms of the different categories of teachers. The learning pattern which dominated within the different classrooms of the specific category of teachers was also highlighted.

**Table 16.** The relative description of student inquiry skills by means of models in classrooms of different category teachers.

| Teacher category | No of students | Model 1 | Model 2 | Model 3 | No match |
|---|---|---|---|---|---|
| A | 81 | **45 (56%)** | 25 (31%) | 11 (14%) | 3 (4%) |
| B | 60 | 20 (33%) | **30 (50%)** | 10 (16%) | 1 (2%) |
| C | 29 | 4 (14%) | 8 (28 %) | **17 (59%)** | 0 (0%) |
| **Total** | **170** | **69 (41 %)** | **63 (37 %)** | **38 (22%)** | **4 (2%)** |

Table 16 shows that, in total, model 1 (inquiry for understanding) describes the learning pattern of the largest number of students in the sample, whereas model 3 (inquiry for participating) is applicable only for 22% of students. Only the learning patterns of 4 students who participated in the study cannot be described using these models

The percentage of students whose learning is associated with model A is the greatest when taught by teachers categorised as A, whereas the highest percentage of students associated with model 2 are taught by teachers categorised by level B and most students fitting the learning model labelled as model 3 are associated with teachers categorised at level C.

# 5. DISCUSSION

The central goals of this study were to improve students' inquiry skills, enhance the classroom environment and develop teacher's PCK for inquiry teaching through an intervention and then portray these changes. Resulting from this intervention, six important findings, each related to the hypotheses put forward in chapter 1, are discussed below.

*The first hypothesis* relates to the identification of theoretically justified criteria for experimental work which is motivational for students. The process of determining these criteria based on the literature is described in papers II and III. The main justified criteria extracted were 1. connection to everyday life, 2. involving students in inquiry activities, 3. working collaboratively and 4. using an interdisciplinary teaching approach.

The first criterion emphasises the importance of relating the teaching topics to situations in everyday life. Utilising Gilbert's (2006) classification of social context models, his third criterion was considered in the current study. The characteristic feature use for this criterion is a story from everyday life that most or all of the students have experienced and with which they have had personal experiences. The literature also includes other references to the use of a social context in studying sciences and its effect on learning (Bolte *et al*., 2006), as well as the need to raise the interest level in students for the subject or topic taught (Blumenfeld *et al*., 2006; Yager, 2007). However, in the current study one further step was taken and carefully constructed scenarios were used not only to create the context, but also to raise students' interest and promote intrigue through the use of social and subject based problems contained in the scenario. Such an issue-based approach appears to be novel and is not specifically reported in the literature.

The second motivating factor is related to inquiry. The inquiry approach is not widely used in Estonian schools and due to its perceive novelty and self-applying hands-on approach, the feedback from students in this study was very positive. This kind of finding is supported by Self Determination Theory (Ryan & Deci, 2000a; 2000b), as well as the studies of inquiry based learning in science lessons by Hofstein and Maamlok-Naaman (2008) and Blumenfeld and co-authors (2006). However, when structured or guided inquiry is used, rather than open inquiry, it is noted that laboratory work can be boring and uninteresting for students (papers II, III and V).

In this study, laboratory work was carried out with students working in small groups. The students appreciated the opportunity to work together and a few commented that in the course of the laboratory work they learned how to communicate with their classmates and their family. The positive effect of collaboration on increasing motivation has also been emphasized by Watanabe *et al*. (2007), Wu (2007), Schelfhout *et al*., (2006) and Solzbacher (2006). The students pointed out the importance of collaboration in cognitive development. Such a result supports the findings of Robertson (2007), Kipnis & Hofstein (2005), Larkin (2006) and Crook (1994). The current study also highlighted the affective aspect of collaboration among students. Similar findings were reported by Kipnis & Hofstein (2005), Newton & Sacney (2005) and Arvaja *et al.* (2002).

*The second hypothesis* was related to developing a set of instructional materials which correspond to the criteria identified. These criteria were put forward by the researcher in paper III, p 16 and amplified in table 7 for each specific instructional material.

The format of the materials built on that developed as supplemental teaching materials (Holbrook & Rannikmae, 1997) and modified by Rannikmae (2001). A major different in these instructional materials was that they concentrated on the inquiry learning process. Although the starting issue derived from everyday life and the discussion which following considered the issue in this light, the student worksheets guided students to reflect on the scientific problem (problem finding). The focus then shifted to the scientific problem solving area and the manner in which the experimental work could be carried out. No attempt was made to consider the issue in a socio-scientific decision making sense, this being outside the focus of the in-service course.

Each of the 5 instructional materials developed by the researcher specifically related to the learning components in the in-service course for teachers. As such the materials included the following:

1. an issue;
2. guidance for the teachers to involve students in a problem finding activity;
3. directed the students towards cognitive learning related to the topic in the curriculum;
4. involved students in planning the experimental activity;
5. involved students in putting forward explanations or reasons for the outcomes of the experimentation;
6. provided the teacher with the opportunity to assess students' inquiry skills from the lesson, or series of lessons.

Teachers in category A showed that the materials were suitable in evoking student opinions about inquiry learning, although such opinions were largely absent for students taught by teachers in category C (paper II, p.61). Likewise the influence of the instructional materials on the attitudes of students towards laboratory work as indicated in the post- invention student questionnaire were rated more highly than in the pre- intervention student questionnaire, with the change being highly significant for students of category A teachers but much less so for students of teachers in category C (paper II, p 62).

It is thus suggested that where teachers were able and willing to embrace open inquiry teaching, the instructional materials were appropriate for student learning and meaningfully met the criteria on which they were developed. It is thus proposed that the instructional materials were in line with meeting hypothesis 2.

*The third and fourth hypotheses* were related to the change of teacher's professionalism through participation in an in-service course, focussing on the knowledge and skills for carrying out open inquiry (papers II and IV). In the current study, the increase in teacher professionalism came about from teacher PCK change, as described through three components:

1. teacher valuation of teaching goals;
2. adopting inquiry teaching strategies, and
3. creating instructional materials.

Data were collected from teacher post-questionnaires, teacher interviews/ discussions both during and after the intervention and about the use of the instructional materials.

In general, the data obtained from the questionnaires, the interviews and instructional materials reinforced the notion that teachers were paying greater attention to students' learning, moving towards a more student-centred form of teaching, thus encouraging students to become more motivated and were willing to embrace elements of inquiry learning in their teaching. However subject related teaching was still seen as important, even though relating the learning to everyday life was recognised as an advantage. This suggested that teachers were revaluing the teaching goals and were adopting inquiry teaching strategies.

There was evidence that teachers did create more meaningful instructional materials. As indicated in table 11, teachers indicated that they adopted the use of a scenario because of positive feedback from the students. They also included the use of knowledge acquired either in the same or a different context in asking questions on reasoning rather than simply relying on the writing of an equation.

The change related to inquiry teaching was characterised in this research by means of a "headway of progress" component whereby each step towards inquiry teaching in sub-components from a lower to a higher level indicated one headway unit.

The determination of the headway combining three components contrasted with approaches in earlier studies which described single developments of PCK components as a result of teacher training (Loughran, *et al.*, 2001) and in line with later studies which emphasised the need to research PCK as a network of components (Henze, *et al.*, 2008; Lee & Luft, 2008; Nilsson, 2008). Furthermore, while teacher development through intervention has been researched earlier and categories have been described by Scherz, Bialer and Eylon (2008). This was not through using PCK as the background, but rather continuous professional development.

A major finding was that a fourth PCK component related to inquiry teaching was determined, called "willingness to change," Willingness to change was considered  as the driving force for teacher change. This was interpreted from teacher comments and from data collected in interviews.

Table 12 illustrates how willingness to change was connected to the teacher personality and especially the teacher's ability to create instructional materials. The identified components provided a powerful indicator of a teacher's "willingness to change" and subsequently in describing the various teacher inquiry levels. Only teachers categorised as A had a perception of in-service needs for both methodological and subject courses. Only category A teachers claimed they participated frequently (VA) in in-service courses, were strongly committed to the intervention (as illustrated by preparation time), considered they had the competence to be sufficiently skilful to overcome potential obstacles and possessed the interest to undertake inquiry teaching using all 5 instructional materials. It is thus clear that teachers' willingness to participate in professional development and to play their part in the intended learning is a crucial PCK factor which needs for more attention than has been given hitherto in the literature. While many researcher may have encompassed this factor within the knowledge acquisition, or emotion (motivational) component, its important is such that it is considered here as a separate and key component which researchers and in-service provides need to take into consideration. This research shows that one way in which to undertake this is to gather background data on previous in-service courses undertaken and the frequency of undertaking such courses. Also during the in-service provision it is useful to take note of preparation time, obstacles perceived and the teacher willingness to participate fully in the intervention.

*The fifth hypothesis* was related to describing changes in students' affective and cognitive gains, related to inquiry learning, which can be determined and mapped as described in papers II and III.

Table 13 illustrates that changes in the students' affective domain response to inquiry work can be determine by means of a pre- and post questionnaire. And table 14 and 15 show that changes in students' cognitive development through inquiry learning and opinions about the appropriateness of the learning can also be mapped by means of data obtained from completed student worksheets during the intervention and analysing types of responses to open ended questions by students after the intervention.

Students of teachers described by category A clearly benefitted in their cognitive gains towards inquiry learning and, in general, the opinions of students taught by such teachers are more diverse than those by students taught by category B and C teachers, The manner in which the opinions of the students have similarities across the categories of teachers, lends itself to a degree of reliability and reflects the classroom atmosphere pertaining to the class. With this in mind, students taught by teachers descried by category A have an advantage in developing inquiry based skills which is assisted by the range of opinions gained for the teaching situation. This is an area where further research could be conducted to discuss the impact of the teacher on science learning in general and the role played by learning through open inquiry.

Thus in general it would seem that teachers of category A strongly promote level 3 learning (table 14) and opinions about learning in knowledge, personal development and preparation for future life. The teacher is thus promoting education across a wide front.

Teachers of category B are less able to promote inquiry learning at the level 3 and heavily promoted knowledge acquisition. Teachers at level C mainly enable students to reach level 2, but are not perceived to encourage learning by way of personal development and encouraged knowledge development or preparation for future life.

The finding that inquiry learning increases the interest in, and positive attitude to, science learning supported the findings of McDonnell *et al.* (2007), Zion (2007) and Hofstein *et al.* (2005). Where teachers were able to develop a more open inquiry approach (teachers fitting the descriptions in category A), the majority of students gained both in positive attitudes and in the overall approach to inquiry teaching. However where teachers fitting category C, little change of teaching approach was detected and the majority of students gained their learning from well developed instructional materials rather than any teacher input and illustrated attributes shown in model 3.

*The sixth hypothesis* related to looking for patterns, illustrating the relationship between teacher development, with respect to inquiry-based teaching and students' cognitive and attitudinal gains.

All the models can be contrasted in three concurring levels: inquiry, motivational learning and learning environment. As the current work focused on the development of students' inquiry skills, then the key characteristics relate to those at the inquiry level which can be indicated by four inquiry skills (identifying the problem, posing inquiry questions, planning and interpreting the knowledge acquired) and measured on three hierarchical levels.

In order to allow the development of these aforementioned skills, it is necessary to create a learning environment which is relevant to and motivating for students and which triggers their development (Yung & Tao, 2004; Gilbert, 2006). On the basis of students' responses, four motivation aspects were distinguished in the model: emotions, connection to everyday life, interest and chance to learn. Such a division is similar to those proposed by Marzano and Kendall's (2007) with three factors covering internal motivation. However, they are also clearly distinguishable from the previous proposal which was on the basis of psychologists' internal components, because students' answers did not contain keywords such as wellbeing, fear and confidence (Glynn *et al.,* 2009).

The result of the process describes three components of learning: acquiring knowledge to finish primary school, personal development to succeed in future life and development of knowledge and skills to continue studies in high school and higher education institutions. The level of motivation-learning contains in every model one or two aspects of motivation and learning. The characteristics of study environment are communication feedback of the laboratory work in the report, teacher's activities and assessment, which can be divided into two: traditional assessment or assessment of the result and inquiry based assessment.

Components are most tightly connected in the first model (the average number of important connections found in every component on inquiry level is 4.0, on motivation-learning level 5.0 and learning environment level 2.25; the number of connections connecting levels was 11). The model describes learning where the teacher is able to connect the students' inquiry based activity with motivation. Learning is also enhanced by communication with the teacher, who in the opinion of students was competent to answer all their questions that arose in the curse of the laboratory work. Such learning is described and explained by Vygotsky (1978) as learning in the zone of proximal development. The students perceived that such learning was helpful for future studies in high school and higher education institutions. This model describes learning mainly by students taught by category A teachers, who went through the remarkable development in the context of PCK components and acquired competencies in inquiry based learning. The described learning guarantees the fulfilment of all natural-science education oriented aims (Hodson, 1992).

In the second model the average number of negative connections is subtracted from the average number of positive connections causing the average numbers to be low: 4.75 at the inquiry level, 1.75 at the motivation-learning level, and 1.0 at the learning environment level. The number of connections between the levels is 6. The model describes learning concentrating on inquiry and the development of relevant skills. The most important characteristics of the learning environment are communication inside the group between students as well as communication between student and teacher. Such student opinions show that the teacher has not been successful in helping students and often questions are answered through communication inside the group. The lower competence of the teacher is also illustrated by the minor connectivity of the components of motivation and learning in the process and that is also reflected in the students' results. A similar outcome was reached by Bulte and others (2006) and by Bremkes and Ralle (2008).

In this model, the traditional or assessment of study results had a strong positive connection to the learning environment. Inquiry based assessment, which was introduced in teacher training and the assessment instructions of which were handed out to teachers, is connected only negatively. Students regarded such study results as necessary for their future everyday lives. The model describes learning mainly among students of category B teachers. It is suggested this shows that teachers of category B acquired a partial competence of inquiry based learning.

The third model contains only a small number of strong connections: the average number of important connections found in every component at the inquiry level is 2.5, at the motivation-learning level 1.5 and at the learning environment level 0.0; the number of connections connecting the different levels was only 3. It is important for students to carry out the inquiry on the basis of instructions provided and communicate in the group. The importance of such communication in learning is also emphasised by Williams and Sheridan (2007). Students' evaluation of the teacher's competence is illustrated by minimal communication with the teacher in the course of laboratory work. Assessment was illustrated by a traditional rather than an inquiry based approach. The study points to such learning being in accordance with students being guided to finish basic school.

The conclusion was that students who learned according to the model depicted in figure 4 were those who had deliberately associated their future plans with high school and university. Following constructivist ideas about the conveying of knowledge and skills, the connectivity of the learning outcome with interpretation skills referred to the emergence of skills being transformed from teacher instructed to student self-learning.

No comparable models relating teacher development and student learning, with respect to inquiry, were identified in the literature.

# CONCLUSIONS

The current situation in Estonian chemistry classrooms could be described as teacher centred, where inquiry teaching approaches are not common. The reasons cited for this were expressed as: overloaded curricula, style of textbooks and students' workbooks, as well as the type of examinations, which focussed on acquisition and control knowledge, lower-order skills and solving calculation tasks with particular algorithms. This teaching has been shown to lead to a decline in student interest to study science and to the acquisition of low-level inquiry skills. It points to the need for change realising that (paper I):

- To change science teaching, it is necessary to change teachers. To help the teachers to create classroom environment that supports meaningful learning, teacher supported is needed to:
  - ✓ change their philosophical background, which includes the goal of teaching;
  - ✓ acquire the knowledge and practical skills necessary for teaching inquiry, including the inquiry teaching approach based the instructional materials and textbooks;
  - ✓ create a motivating learning environment.

The study shows it is possible to effect teacher change through designing and carrying out theoretically justified and well-planned interventions (paper IV). And in particular, this study shows that:

- Teacher development for inquiry teaching can be described in terms of PCK. To describe teacher's change, in addition to the three factors found in the literature (educational goals valued by teacher, teaching strategies and creating instructional material), a fourth component of PCK specifically related to inquiry teaching needs to be included. In this study this additional component is named "willingness to change" and is recognised as a crucial factor in promoting inquiry teaching.
- The degree of teacher's development can be described through three hierarchical categories, In this study these categories were seen as distinct and labelled A, B and C (paper IV). It is proposed that these categories are not part of a continuum, but represent distinct levels through which teachers can pass in developing PCK for inquiry teaching.
- Through the intervention changes were observed for all students in terms of improved attitude towards the study of the chemistry, as well as an increase in the level of inquiry skills.
- The development of students' inquiry skills depends on teacher progress. Only teachers who wished to change and were willing to work for attaining the highest level of competency (category A – students inquiry users) in carrying out inquiry teaching by including experimental work were able to significantly develop students' inquiry skills. The findings allowed the creation of three models, which described developing students' inquiry skills. To illustrate the whole picture of students learning, the model, which

had already been referred to the four components of inquiry skills, in addition to the sources of motivation to describe the learning environment in students opinion and the evaluation of learning outcomes of students point of view.

**Limitation of the research:**

- Teachers, involved in the sample for the current study were all volunteers. This sample cannot be a representative sample of Estonian chemistry teachers. These teachers represent those chemistry teachers who wish to participate in such an intervention study with knowledge, understanding and beliefs are similar to teachers in sample.
- The sample of students is not representative and does not represent all Estonian grade 9th students. Data was collected from students of the eight teacher who taught these students (N = 174).
- The level of reliability of teacher and student data can be considered suspect using this small sample. However the different categories of teachers and the very different models illustrating student learning are sufficiently diverse that the validity of such findings is claimed to be sound.

## Recommendations

Based on the findings of the current study the following recommendations are made:

- Inquiry teaching in the Estonian context is an effective teaching strategy for improving students' inquiry skills and for raising students' positive attitude toward learning science. It is important, however, that inquiry skills be expressed in the curriculum as learning outcomes as well as reflected in textbooks and examination and new instructional materials developed, which are inquiry based.
- Attention is needed to the future development of teacher professionalism in higher education. Young university graduates, to be teachers of a new design philosophy require a strong grounding in PCK attributes which contribute to inquiry teaching. The positive reaction of students to their inquiry learning could be used to force colleagues to change their teaching.
- Attention needs to be focussed on the currently employed science teachers in schools. Science teachers should be enrolled on in-service courses, which include the introduction of a new philosophy and methodology, and practical experience to carry out inquiry teaching. The inhibiting nature of the curriculum, textbooks and examinations needs to be changed for inquiry learning, especially open inquiry, to flourish. The influence on teaching of textbooks and examinations is viewed by teachers as so high that the promoting of student motivation and wider learning goals, although appreciated, cannot be entertained, in the eyes of teachers.

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# SUMMARY IN ESTONIAN

## Loodusainete õpetajate uurimusliku õppe läbiviimise kompetentsuse areng teoreetiliselt põhjendatud koolitusprogrammi raames

Dissertatsiooni esimene peatükk käsitleb uuritava probleemi aktuaalsust loodusteaduslikus hariduses. Rahvusvaheliselt on tõstatatud probleem loodusteaduslike õppeainete tundide elukaugusest ja õpilaste jaoks liigsest teoreetilisusest, mis lõppkokkuvõttes viib õpimotivatsiooni langusele ja muudab loodusteadustega seotud karjäärivaliku ebapopulaarseks. Lahendustena pakutakse välja argielu probleemide integreerimist õpetamisse, uurimusliku lähenemisviisi rakendamist ning praktiliste tööde osakaalu suurendamist. Kõik see eeldab õpetamise paradigma muutmist ning viimasega kaasnevat õpetajate täiendkoolituse süsteemi väljatöötamist.

Käesoleva dissertatsiooni teises peatükis antakse ülevaade rahvusvahelistest uurimistöödest eelnimetatud probleemide valdkonnas ning esitatakse teaduslikult põhjendatud lähtealused uurimuslikke praktilisi töid väärtustava ning õpilasi motiveeriva õpetuse tervikliku kontseptsiooni väljatöötamiseks.

Doktoritöö eemärgid hõlmavad kolme valdkonda:

- teoreetilis-filosoofiline,
- loodusainete õpetajate uurimusel baseeruva õpetamise kompetentsuse arendamisele ja täiendkoolitusele suunatud ning
- õpilaste uurimuslike oskuste kujunemise protsessi uuriv.

Välja töötatud tervikkontseptsioon põhineb järgnevatele seisukohtadele:

- uurimuslikud eksperimentaalsed tööd on loodusteadusliku hariduse integratiivne ja oluline osa;
- tähendusrikkaks õppimiseks on vajalik luua õpikeskkond, mis lähtub ühiskonna vajadustest, baseerub uurimuslikul lähenemisviisil, on õpilastele relevantne ja motiveeriv ning arendab õpilaste rühma- ja koostöö oskusi;
- loodusteaduste õpetaja peab omama kaasaja teaduse arengule vastavaid ainealaseid teadmisi ja pedagoogilis-psühholoogilist kompetentsust, et tagada teadmistepõhises ühiskonnas toimetuleva kodaniku kujundamine loodusteaduste tundides.

Avatud uurimusliku õppe kontseptsiooni realiseerimiseks viidi läbi õpetajate täiendkoolitus, koostati komplekt avatud uurimuslikul õppel baseeruvaid tööjuhendeid õpilastele ja neid toetavad lisamaterjalid õpetajatele, koguti tagasisidet õpilastelt ning kontseptsiooni evalveerimiseks konstrueeriti õpilaste õppimist kirjeldavad mudelid. Uurimistööle püstitati kuus hüpoteesi:

- on võimalik välja töötada teaduslikult põhjendatud kriteeriumid õpilasi motiveeriva, tähendusrikast õppimist toetava avatud uurimusliku õppe läbiviimiseks eksperimentaalsete tööde kaudu;
- on võimalik välja töötada õppematerjalide komplekt, mis vastab avatud uurimuslike eksperimentaalsete tööde läbiviimise terviklikule kontseptsioonile;
- õpetajate kompetentsust läbi viia uurimuslikke eksperimentaalseid töid on võimalik kujundada sihipärase täiendkoolituse abil;
- õpetajate muutust uurimuslike praktiliste tööde läbiviimise kompetentsuse saavutamise suunas on võimalik kirjeldada hierarhiliste kategooriate abil;
- õpilaste uurimuslike oskuste kujunemist on võimalik kaardistada,
- on võimalik luua mudelid, mis kirjeldavad õpilaste kognitiivsete oskuste kujunemise protsessi seotust õpetaja kompetentsusega viia läbi uurimuslikku õpet.

Aastatel 2005-2007 viidi läbi pikaajaline pedagoogiline eksperiment, kus osales 8 keemiaõpetajat ja nende poolt õpetatud 233 üheksandate klasside õpilast. Uurimistöö metoodikat on käsitletud dissertatsiooni kolmandas peatükis.

Töö tulemused ja järeldused kajastuvad seitsmes artiklis rahvusvahelise levikuga teadusajakirjades. Nendest viis on esitatud käesoleva töö lisas.

I artikkel käsitleb eksperimentaalsete tööde läbiviimisega seotud probleeme keemia tunnis kümne keemia õpetaja ja nende poolt õpetatud õpilaste näitel. Tulemused näitasid, et vaatamata sihipärasele täienduskoolitusele eelistavad keemia õpetajad lühikesi illustreerivaid katseid ega ole valmis viima läbi tundides uurimuslikke eksperimentaalseid töid. Leiti statistiliselt oluline korrelatsioon õpilaste protsessuaalsete oskuste arengu ja õpetaja muutuse kategooria vahel. Sellel artiklil põhineb pedagoogilise eksperimendi ja õpetaja täienduskoolituse protsessi disain.

II artikkel oli fokuseeritud keemia õpetajate uurimusliku õppe läbiviimise kompetentsuse arengule täienduskoolituse käigus. Selle kirjeldamiseks kasutati õpetaja pedagoogiliste teadmiste (*pedagogical content knowledge* – edaspidi PCK) mudeli kolme kirjanduses enam kasutatud komponenti: õpetaja poolt väärtustatud õpetamise eesmärk, uurimusliku õpikeskkonna loomine ja kaasaegsed ainealased teadmised. Töö tulemused näitasid, et õpetajate arengut saab kirjeldada liikumisena nimetatud komponentide hierarhiliste tasemete vahel, mille alusel saab moodustada fenomenograafilised kategooriad. Liikumine hierarhiliste tasemete vahel madalamalt kõrgemale leidis aset kõigi õpetajate puhul, viies oluliste paradigmaatiliste muutuste ilmnemisele kolmel õpetajal kaheksast. Pedagoogilise eksperimendi käigus õpetajate arusaam õpetamisest laienes ja seostus õpilaste ettevalmistamisega tulevaseks eluks. Õpetajate poolt loodud õpikeskkonda iseloomustas õpilaste eelistuste kaldumine nn retsepti tüüpi praktilistelt töödelt uurimuslike eksperimentaalsete tööde suunas. Uute kognitiivsete oskuste omandamine õpilaste poolt on otseses sõltuvuses õpetaja saavutatud PCK tasemest. See artikkel seostub kolmanda ja neljanda hüpoteesi tõestamisega.

III artiklis antakse ülevaade avatud uurimusliku õppe terviklikust kontseptsioonist ning selle suhestatusest rahvusvaheliste teadusuuringutega. Õpilaste kognitiivsete oskuste muutust kirjeldatakse kolme hierarhilise mudeliga, mis reflekteerivad avatud uurimusliku suunitlusega õppematerjalide osatähtsust uurimuslike oskuste kujunemise protsessis. Loodud hierarhilised mudelid võimaldavad prognoosida õppematerjalide rolli õpilaste kognitiivsete ja afektiivsete osakuste kujundamisel uurimusliku õpikeskkonna tingimustes ning kinnitavad uurimistöö teise ja viienda hüpoteesi paikapidavust.

IV artiklis antakse põhjalik ülevaade uurimistöös osalenud õpetajate ainealaste ja pedagoogiliste oskuste (PCK) progressist täienduskoolituse ja sellele järgneva kooliaasta jooksul. PCK kirjeldamiseks defineeriti uus termin "arengutee", mida kasutati kvantitatiivse karakteristikuna õpetajate muutust illustreerivate hierarhiliste kategooriate loomiseks. Leitud kolm kategooriat kirjeldavad õpetajate oskust läbi viia avatud uurimuslikku eksperimentaalset tööd, võimaldavad kavandada vajaliku täiendkoolituse struktuuri ja sisu vastavalt õpetaja esialgsele PCK tasemele. Selles uurimuses tõestati kolmas ja neljas hüpotees.

Viienda ja kuuenda hüpoteesi tõestamisega seondub dissertatsiooni neljas peatükk, mis käsitleb põhjalikult õpilaste saavutusi afektiivses ja kognitiivses valdkonnas seostatuna õpetajate muutuste kategooriatega. Tähendusrikka õppimise protsessi tervikpildi kirjeldamiseks konstrueeriti vastavalt leitud klastritele kolm mudelit, mille komponendid määratleti faktoranalüüsi ja korrelatsioonanalüüsi tulemusena. Mudelid illustreerisid õpilaste uurimuslike oskuste seotust motivatsiooni ja õpikeskkonna karakteristikutega ning eristusid üksteisest komponentide seostatuse alusel: mõtestatud uurimuslik õpe, tegevusel baseeruv uurimuslik õpe ja osalusel baseeruv uurimuslik õpe. Nende alusel on võimalik prognoosida uurimusliku õppe rakendamisel paradigmaatiliste muutuste elluviimise etapilisust, võttes arvesse nii õpetajate esialgset PCK taset, õppematerjalide mõju õpilasele kui ka õpetaja soovi omandada kaasaegsele õpetamise paradigmale vastavat kompetentsi.

V artikkel on dissertatsiooni suhtes evalveeriva iseloomuga, tutvustades avatud uurimuslike õppematerjalide rakendusvõimalusi rahvusvahelistes teadus- ja arenguprojektides.

Käesoleva töö tulemused kinnitavad välja töötatud avatud uurimusliku õppe kontseptsiooni rakendamise vajadust ja võimalikkust keemiatundides. Kuna käesolevas töös osales vaid piiratud arv keemiaõpetajaid, ei saa töö tulemusi täiendava uurimuseta üldistada kogu keemia õpetajaskonnale.

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### Education

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|---|---|
| 2004–... | University of Tartu, Faculty of Biology and Geography, PhD student, |
| 2000–2004 | University of Tartu, Faculty of Biology and Geography, master degree (MSc) in biology didactics, |
| 1994–1995 | Tallinn Pedagogical University, biology and geography teacher, |
| 1969–1974 | University of Tartu, Faculty of Physics and Chemistry, chemist, teacher of chemistry and physics, |
| 1964–1969 | Tartu Pedagogical School, primary school teacher, |

### Professional employment

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|---|---|
| 2008–... | University of Tartu, Faculty of Science and Technology; (researcher 0.50), |
| 2008–... | Tartu Mart Reinik Gymnasium, teacher of chemistry (0.3), |
| 1992–... | Tartu Veeriku School, teacher of chemistry and biology, |
| 1985–1992 | University of Tartu, Faculty of Medicine, senior technician, researcher, |
| 1977–1985 | University of Tartu, Institute of Physics, chemist-technologist, |
| 1974–1977 | Kuressaare High School, teacher of chemistry, |

### Scientific work

The research has been concentrated on the improving students inquiry skills through experimental work in science lessons and development of teachers competency related to PCK for teaching open inquiry.

# ELULOOKIRJELDUS

## Klaara Kask



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## Haridustee

| | |
|---|---|
| 2004–... | Tartu Ülikool, bioloogia ja maateaduste hariduse doktoriõpe |
| 2000–2004 | Tartu Ülikool, magistrikraad (MSc) bioloogia didaktika erialal |
| 1994–1995 | Tallinna Pedagoogika Ülikool, põhikooli bioloogia- ja geograafiaõpetaja |
| 1969–1974 | Tartu Ülikool, keemik, keemia ja füüsika pedagoog |
| 1964–1969 | Tartu Pedagoogiline Kool, algklasside õpetaja |

## Teenistuskäik

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|---|---|
| 2008–... | Tartu Ülikool, Loodus- ja tehnoloogiateaduskond; teadur (0.50) |
| 2008–... | Tartu Mart Reiniku Gümnaasium, keemiaõpetaja (0.3) |
| 1992–2008 | Tartu Veeriku Kool, keemia ja bioloogia õpetaja |
| 1985–1992 | Tartu Ülikool Arstiteaduskond, vanemlaborant, teadur |
| 1977–1985 | Füüsika Instituut, keemik-tehnoloog |
| 1974–1977 | Kuressaare Õhtukeskkool, keemia õpetaja |

## Teadustegevus

Teadustegevuse põhisuunad on seotud õpilaste uurimuslike oskuste arendamise võimalustega ja õpetajate avatud uurimusliku õppe läbiviimise kompetentsuse kujundamisega.

# DISSERTATIONES PEDAGOGICAE SCIENTIARUM UNIVERSITATIS TARTUENSIS

1. **Miia Rannikmäe.** Operationalisation of Scientific and Technological Literacy in the Teaching of Science. Tartu, 2001.
2. **Margus Pedaste.** Problem solving in web-based learning environment. Tartu, 2006.