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RESEARCH REPORT

Effect of a long-term in-service training program on teachers' beliefs about the role of experiments in physics education

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The basis of this paper concerns a one-and-a-half year in-service training program (*In-service Training for Physics Teachers*; 40 ECTS credits) for physics teachers (Grades 7–12, *n* = 98) designed to enhance both their subject knowledge and pedagogical content knowledge. The role of laboratory experiments in physics education in particular was discussed during lectures, seminars, and through an e-mail list. This discussion centered on the epistemic role of experiments in the teaching of physics. Working in permanent small groups was also central to the training program. Following the active phase of the project, a survey was organized to clarify the teachers' beliefs about the role of experiments. The teachers' descriptions showed that approximately 20% had improved their use of experiments in conjunction with the goals of the *In-service Training for Physics Teachers* program.

Introduction

During the past decade, there has been much discussion of science teachers' beliefs about teaching and learning as well as about the possibility of changing these beliefs through educational reforms and professional development programs. Tobin et al. (1994: 64) summarize the relationships between the teachers' beliefs and reform efforts: 'Many of the reform attempts of the past have ignored the role of teacher beliefs in sustaining the status quo. The studies . . . suggest that teacher beliefs are a critical ingredient in the factors that determine what happens in classrooms'.

Much research has been conducted into teachers' beliefs, although there seems to be no common use or definition of the concept of 'belief' (Tobin et al. 1994: 55). In this study, we identify beliefs with an individual's personal knowledge, which is a compound of the conclusions that an individual draws from experience (Green 1971). Beliefs can also be called one's stable 'subjective knowledge'. Conceptions or conscious beliefs are justified and accepted by an individual and are regarded as high-order beliefs that involve cognitive elements. Some researchers stress the affective (feeling) components of beliefs, considering them as kinds of attitudes. According to Pajares (1992), beliefs form attitudes, which in turn become action agendas. Spontaneous conceptions with strong affective elements are called 'views'. In the literature, the use of the terms belief, conception, view and attitude vary depending on the discipline, perspective and

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researcher (Pajares 1992, Swain et al. 1999, Tobin et al. 1994: 55). By the 'epistemic beliefs of teachers' we mean beliefs about how knowledge can be acquired and justified in science as well as in the physics classroom. For example, when we speak of the epistemic role of experiments in concept formation we mean the formation of meaning through verification/falsification (Franklin 1999). Epistemic beliefs or orientations strongly affect the instructional planning and decisions of teachers and their lessons and models of teaching,[1] as well as their ability and willingness to change established habits and, hence, their efforts to bring about educational reform (Brickhouse 1990, Clark and Peterson 1985, Maor and Taylor 1995, McComas et al. 1989: 26). Berry and Sahlberg (1996) describe how teachers who have the transmission model as their epistemic belief typically adopt the presentation–recitation approach to teaching, while students do routine practical work (cookbook science) or solve simple textbook problems. These activities, however, do not assist students in constructing scientific concepts or meanings (Arons 1997: 345, Stinner 1992). Epistemic beliefs thus affect the way in which the teachers use experiments in a school laboratory, or indeed whether they utilize experiments at all (Hodson 1992, Lumpe et al. 2000). These beliefs also play a key role in cognitive monitoring and in guiding students in interpreting observations (Pajares 1992).

Resistance to change the beliefs of the teachers is one of the reasons for the slow rate of change in physics education (Haney et al. 1996). Various approaches have been suggested (e.g. educational policy, curriculum design and professional development through in-service training and pedagogical study materials) to help change unfavorable teachers' beliefs and to assist the adoption and use of new models of teaching (Fullan 1991: 37, Lazarowitz and Tamir 1994: 121). Educational reforms and improvement in science teaching through in-service training, however, are much more complex tasks than seems at first sight (Fullan 1991). Whether these beliefs can be developed in teacher training by teaching about the nature of physics is a delicate question. It may be more important to introduce and use in teacher education models of teaching designed on the basis of ideas that define how conceptualization should proceed as well as the epistemic role experiments and theory have in this process.

What we describe here is a long-term professional development project, *In-service Training for Physics Teachers* (*ITPT*) project, which is intended to change the classroom practices of teachers, especially the role of experiments within them. To that end, discussions about the epistemic basis of concept formation and its consequences for physics education were combined with planning instruction and exercises. In other words, our purpose was to promote and enhance pedagogical content knowledge (PCK), as defined by Shulman (1987) (quoted in Carlsen 1999) as 'that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding'. PCK comprises curricular knowledge, the knowledge of instructional strategies and representations of subject matter (i.e. knowledge of teaching particular topics), knowledge and beliefs about the purposes of teaching one's subject, and understanding common learning difficulties and students' conceptions (Carlsen 1999: 138). Consequently, teachers' beliefs about the role of experiments in the classroom are seen as an expression of their PCK in this specific domain.

Teachers' opinions concerning the usefulness of various courses in their daily work have been reported by Jauhiainen et al. (2002). In this article, we discuss research designed to establish the effect of this project on the participants' educational and epistemic beliefs, particularly as regards the role of experiments (demonstrations and practical work) in physics education. Our research questions were:

1. What are the teachers' beliefs about the epistemic role of experiments in physics education?
2. What is the effect of a long-term in-service training program on teachers' beliefs concerning the role of experiments in physics education?

The role of experiments in physics education

Demonstrations and practical work in the laboratory have long been accepted as an integral part of learning physics (Wellington 1998: 3–15). It seems natural that, in most reforms of physics education, it has been suggested that learning can be improved through developing study material and experimental models of teaching, as well as ways in which experiments are conducted in the physics classroom, within the framework of constructivist theory (Duit and Confrey 1996: 86–87).

According to researchers and curriculum designers, models of teaching where experiments are essential, are important for: (i) better acquisition of scientific knowledge, (ii) better understanding of the empirical nature of the natural sciences, and (iii) development of different work or process related skills, such as measuring and designing an investigation (for example, Hodson 1996, Millar et al. 1999: 42–47). Students' attitudes and motivation to study science become more positive and conducting experiments in the classroom (Gott and Duggan 1996) enhances personal growth. The importance of practical work is also supported by the desirability of the 'contextuality of learning' (Wilkinson 1999), and by the ability to enhance the role of social interaction as a catalyst for learning (Ford 1999). Practical work is also seen to increase students' autonomy when they are engaged in open-ended problems (Olsen et al. 1996), and by connecting learning with concrete experience. Wellington (1998: 6) categorizes the reasons for experiments into three main areas: knowledge and understanding, skills and processes, and reasons related to attitudes, enjoyment and motivation. While Wellington's summary is mainly based on research conducted before 1990, Swain et al. (1999), for example, report that teachers also emphasize understanding the empirical nature of natural sciences as an important reason for practical work.

Nevertheless, researchers do not always agree on the significance of experimental working methods in physics education (Lazarowitz and Tamir 1994, White 1996). For example, Watson et al. (1995) found that extra time spent on practical work had little impact on student understanding. Hodson (1990) also takes also a critical view of practical work in school science and the often extravagant claims made for it. Achieving understanding and skills or proficiency in the laboratory often proves to be difficult for students. The poor outcomes are suspected to result from the way experiments are conducted. The cognitive demand of the laboratory tends to be low and teachers use experiments mainly as a way to confirm what has already been taught (Lazarowitz and Tamir 1994: 115, 121).

It is also claimed that experiments are valuable when both pupils and teachers have recognized the goals of the experiment (Hodson 1990, 1996).

Gott and Duggan (1995: 25–26) have suggested that teachers should choose experiments so that conceptual and procedural understanding of students could be developed. Conceptual understanding means the understanding of concepts, laws and theories. Procedural understanding, on the contrary, is thinking-behind-doing, and does not mean measuring as such, but the decisions that must be made about what to measure, as well as how often and over what period. Warwick et al. (1999) draw clear distinctions between the concepts of 'process skills' and 'procedural understanding', and, for example, relate the latter to the critical nature of dialog about evidence. Although all types of experiment involve elements of procedural and conceptual understanding, it is useful to classify the major types of experiment. Gott and Duggan (1995: 28) have suggested than these should include those that emphasize application, acquisition or consolidation of conceptual understanding, experiments that emphasize skill acquisition, and the application or synthesis of procedural understanding.

In the *ITPT* project, special attention was paid to the construction of the empirical meanings of concepts through observation and experiment so that prospective participants would find more purposeful ways of utilizing experiments in their teaching, and thus help students develop their conceptual and procedural understanding.

The *ITPT* project

The *ITPT* project was arranged by the Department of Physical Sciences, University of Helsinki, at the request of the National Board of Education for Finland. It was created as part of the national development project 'Finnish Mathematical and Natural Science Awareness, 2002'. The project was run twice (*ITPT I* from 29 July 1996 to 31 December 1997, and *ITPT II* from 6 March 1998 to 31 December 1999), with the acquisition of 40 ECTS credits by each participant. Altogether, 145 + 83 teachers (about 10% of all physics teachers in Finland) of lower and upper secondary school (Grades 7–12) from all over Finland participated in the program. In all the activities, the participant teachers formed permanent local study groups of two or three. For seminars and exercises in contact training, seminar groups of up to 10 study groups were formed.

Training was based on the principles of distance education. The study groups worked at their home sites, supported by home pages consisting of more permanent instructions, reports on progress, and so on (DFCL 1999). This support was available through an e-mail list, personal e-mail discussions and chat sessions, as well as private guidance. During *ITPT I*, for example, 1309 messages, questions, comments or answers related to organizational perspectives, and subject, pedagogical and pedagogical content knowledge topics were submitted to the e-mail list. The detailed analysis of this discussion is described later in this article. As regards contact training, there were approximately four 'in school holiday' sessions of 5–11 days. These sessions were available to all participants as well as were up to four 'week-end' periods of 2.5 days, for two seminar groups at a time. In addition to lectures, exercises, and seminars, substantial time was reserved for private work and group discussion.

Working in small groups had a major role in the *ITPT* project. It was thought that continual collaboration within the permanent study group in planning and performing a given tasks would make the teachers monitor and diagnose their epistemic beliefs and models of teaching more thoroughly. This practice is regarded as necessary for the recognition of one's beliefs, and for recognizing the importance of changing established practices (Loughran 1999, Solomon and Tresman 1999). The exchange of ideas between study groups within the seminar group was also expected to enhance this process.

In the *ITPT* project the role of experiments was discussed in conjunction with the paper by Hodson (1996). The discussion took place in the wider context of the nature of physics as a science, starting from the working idea that individual learning closely resembles the construction of scientific views in history. A framework for the *ITPT* discussions can be analyzed in terms of three processual components. The first is the *scientific process*, which is driven by the desire to understand nature. The second is the *technological process*, driven by the need to modify nature according to human needs. These two components are two basic human interactions with nature, both of which are submitted to the *social process*, or negotiation about meanings, which extends individual cognition into a shared social understanding, and which is necessary to create common concepts. The scientific process is understood as the purely mental element of creating meaning, which includes mental modeling, the formulation of hypotheses and predictions, engagement in thought experiments, and so on. The technological process is understood to include all human activities that manipulate or change nature, and includes, in addition to ordinary technological problem-solving, the design of experiments and the adaptation of our behavior to the conditions of our surroundings. The social process, on the contrary, involves all forms of social interaction necessary for reaching agreement about procedures of advancing the scientific and the technological process, as well as their aims and results. The presence of these three, inseparably intertwined, elements in learning physics was discussed and related to different perspectives or frameworks about teaching and learning including constructivism or social constructivism.

The hierarchical development of science (which now includes technology) runs from observation to interpretation and from experiment to theory. This development leads to an ever-increasing degree of abstraction and complexity of structure and is also the direction then learning takes. Observation and experiments form the basis of learning, where concepts and models are representations of nature as it is observed. Along with its hierarchical development, the process becomes more and more theory-driven (see Hodson 1996), theory representing the 'structure-of-mind' factor of the perception.

The inseparability of observation and the mind in perception is preserved through hierarchical development as the categorical inseparability of experiment and theory. There are no pure observations or pure theory. While every experiment and observation is driven by theory or mental models, every concept and conceptual structure is tied to its empirical meaning. While the process has one direction of propagation, it is driven in every detail by a two-way dynamics in which the mutual roles of inductive and deductive thinking are blended, and cannot be distinguished. Concept formation thus always carries the original basic nature of perception.

In order to promote genuine learning, experiments in school physics should be consciously linked to the concept formation process (Kurki-Suonio 1991). The idea of perception and formation of ordering 'images' is important, much like in the formation of experiential and experimental gestalts (Anderson 1986, Watts 1996) that are based on perception and observations. A classroom experiment should be thoroughly discussed in advance, so that it is understood as questions then are put to nature. Likewise, all experiments should be planned, designed and carried out so that nature is compelled to answer the question. In this way the content dependence of the process (Millar 1994) becomes evident. In the ensuing discussion, it is important to distinguish between the observations and their interpretation and an agreement should be reached on both.

During planning and interpretation, the scientific process dominates, while 'compelling nature' through the design and performance of the experiment requires the technological process to contribute to the social process, which the discussions will activate. The students taking an active role in forming the construction of shared meanings of physical concepts and laws, in collaboration with other students, has been shown to be vital for learning (see Novak 1998: 5–27). There is a significant difference between the processes of learning and science. The teacher can assist the learners in identifying their ideas before an experiment takes place, as well as understanding how to explore them. From the history of science, we know how difficult and slow the development of ideas has been for the scientific community because there is obviously no teacher present within its social process who knows the direction in which to proceed.

One important PCK component is knowing how and why a teacher should guide students in discussing and negotiating about meanings. It extends an individual's learning process through creating shared understanding in small group discussions. Students' activity in the construction of shared meanings with other students regarding physical concepts and laws, is vital for learning (see Novak 1998: 5–27). On the contrary, as emphasized by Wellington (1998: 7), students cannot develop understanding alone through their own observations and other data acquisition processes without a teacher's assistance. The mental element of meaning creation includes creating mental models, the formulation of hypotheses and predictions, and doing thought experiments, all of which are recognized as vital parts of PCK and all of which are recommended for inclusion among the topics of teacher education (Justi and Gilbert 2002). The practical outcomes of these ideas are discussed in two courses that concentrate on PCK, one of which focuses on experiments in a school laboratory.

The *ITPT* project was planned as a whole consisting of four closely connected courses, each with special aims related to PCK. Knowing that teachers tend to teach as they have been taught (Duit and Confrey 1996: 86–87, McDermott et al. 2000, Stein 2001), a variety of models of teaching were used and/or practised as described.

Principles of concept formation

The course 'Principles of Concept Formation' (PCF) (lectures [28 × 90 minutes] in addition to seminars [14 × 90 min]) was the theoretical core of the program. A textbook (Kurki-Suonio and Kurki-Suonio 1994) was expressly written for this course.[2] The nature of physics as a science, particularly the mutual roles of theory and observation in the learning of concepts and conceptual structures, as well as the different ways of approaching knowledge through physics education, was also discussed (see Bunge 1983). The aim of the courses was to enhance teachers' pedagogical content knowledge. The study groups wrote study reports, summaries with questions and comments, in advance of each lecture. The lectures concentrated on the discussion of these reports.

Seminars, on the contrary, were devoted to the application of ideas. Exercises given included analyses of the experimental and theoretical foundations of selected physical concepts, analyses of text-book representations of these processes, analyses of specific everyday environments in respect of physical concepts, and planning teaching sequences. Exercises also included computational problems on specified physical subjects, with subsequent analysis of the relation between problem setting and real situations, as well as the empirical nature of the concepts involved. Each study group discussed the exercises first individually, then together with other groups in the seminars and prepared a written summary.

Experiments in the school laboratory

In the second course, 'Experiments in School Laboratory' (ESL), the 'theory' about the teaching and learning of physics acquired during PCF was applied to the practice of school experiments. The study groups had to plan and implement a set of experiments in 10 specified subject areas. The planning was based on aims related to conceptual understanding, so that each experiment would contribute to the concept attainment process (concept formation) in that area (Bruner et al. 1967: 233). The set would ideally form a consistent whole covering the basic quantities and laws of the area. Moreover, experiments aiming at conceptualization and experimental tests of the validity of concepts would ideally be included, corresponding closely to the 'enquiry practicals' and 'illustrative practicals' described by Gott and Duggan (1995: 21), on both the qualitative and quantitative level (Kurki-Suonio 1991). Learning during the course was thus focused on procedural understanding (e.g. decisions that must be made about what and how to measure, how to present measured data, etc.).

After the approval of a project plan composed by the study group by a lecturer, the experiments (typically five to 10 of them qualitative, and five to 10 quantitative) were conducted as an investigation of their utility in the home schools of the group members. Initially, these tasks were performed at the home sites of the study groups, thereby making use of the resources available. The involvement of their own students and/or trials of the experiments in real classroom situations were recommended. Ultimately, the group had to write a report on the task, including a representation of the experiments themselves, descriptions of their intended use in classroom teaching, and indicate how the experiments helped students learn concepts.

The participants were also encouraged to seek different contexts as starting points (Stinner 1994). Their attention was drawn to the important role of qualitative experiments on the beginning of conceptualization; that is, identification and classifications help students create meaning for concepts (Joyce and Weil 1996: 164–178). They learnt and practised quantitative experiments and how to design and set-up a quantitative experiment. They also learned how to present results in a way that would help students draw conclusions and understand the empirical meanings of concepts (see Arons 1997: 9–11). In addition, the teachers learnt to use different kinds of demonstration equipment, including microcomputer-based laboratory tools.

Activities in the course were supported by lectures in which discussion centered upon possible experiments, available equipment, various experimental techniques, and typical problems. This approach was completely different from that used in normal university laboratory courses, where equipment unavailable in school is used to verify known principles by experiments described in detail in laboratory instructions (see McDermott et al. 2000).

The conceptual and processual structures of school physics

The third course 'The Conceptual and Processual Structures of School Physics' (SSP) (lectures, 28 × 90 minutes), was designed to help participants build up mental images of the conceptual structures they deal with in their classroom teaching. The main areas of school physics were covered, demonstrating how the concepts and conceptual structures of particular subject areas arise from, or are supported by, observational and empirical evidence. How to decide between competing mental models on empirical grounds was also discussed.

The study groups were asked to compose geometric network representations of their ideas concerning the structural relationships between concepts belonging to 12 different topics of wide disparity (mechanics, energy, etc.). Although complete 'artistic freedom' was given in choosing the format of network representation, teachers were asked to consider the basic classification of concepts, and a few basic types of conceptual relationships. Specific attention, for example, had to be paid to the development of the hierarchy of concepts as it arises in the representation of empirical meanings (Väisänen and Kurki-Suonio 2000). This kind of knowledge is particularly important in all planning phases of a physics education, as well as in guiding students' problem-solving (Mestre 2001). 'Diagnostic' versions of each network presentations were first drawn, before the beginning of the lecture's relevant subject area. Towards the end of the course, final versions were developed. The final network representations were also used to assess the SSP course.

The lectures were supported throughout by demonstrations conducted by the teaching assistants of ESL course. To emphasize the ESL-guidance function of the SSP course, the timetables of the two courses' lectures were planned so that the same subject areas were treated as closely in line as possible. The study material supporting both of these courses was based on a series of eight textbooks (Lavonen et al. 1994–1996), written according to the principles already discussed, given to the participants.

History of physics

The fourth course, 'History of Physics' (30 × 90 minutes), concentrated on the historical development of physics as a science and its basic concepts and conceptual structures. The aim was to show the great potential, and even necessity, of utilizing historical knowledge in physics education, pointing out the similarities between the process of learning and the development of science. Each study group had to make a library investigation of a selected historical subject for presentation in a seminar, and each participant was required to write a review of his/her own on some subject treated in the lectures.

Implementation of the study

Six months after the conclusion of *ITPT II*, we conducted a survey to ascertain the extent to which the goals of the project had been realized. Since the aim was to show whether any changes were brought about specifically by the *ITPT* project, we gave identical questionnaire to both an experimental group and a control group. The experimental group consisted of 207 teachers, 139 of whom were from *ITPT I* and 68 of whom were from *ITPT II*. The participants hailed from all over Finland. The control group consisted of the 60 physics teachers who participated in *ITPT III*, starting at the launch of this research.

A web-based questionnaire contained four questions related to the project and several more questions about the background information on the teachers. The teachers were asked:

(A) to enumerate the demonstrations, practical work or experimental investigations conducted during their physics lessons, and to state how these numbers changed during their teaching careers;
(B) to state the three most important reasons for using experiments in physics education;
(C) to describe the most important changes in their use of experimental procedures during their teaching careers; and
(D) to evaluate their skill in organizing practical work and demonstrations on a scale of 'poor', 'satisfactory', 'good', and 'excellent'.

A prototype questionnaire was presented to several teacher trainees. The wording of the questions was modified on the basis of their responses and the final questionnaire was placed on the Internet. The purpose of this research was explained, and the web address of the questionnaire was provided to teachers in an e-mail sent on 29 May 2000. Reminders were sent on 5 June, 20 June and 6 September 2000. A paper version was sent to those teachers who had difficulty responding through the Internet. Finally, a total of $n = 98$ (control, $n = 53$) teachers, of whom 57 (control, 33) or 47% (control, 88%) of the experiment group (control group) were female, answered the questionnaire.

The groups (control group in brackets) had an average of 16–20 (11–15) years of teaching experience, 48% (53%) of the teachers were working at a lower secondary school, and 28% (28%) at an upper secondary school (the others at vocational schools, local administration commissions or as headmasters). Teachers were teaching physics 0–5 (0–5) hours per week on average, mathematics 6–10 (6–10) hours and chemistry 0–5 (0–5) hours. In all 74% (72%) of the teachers had a M.Sc. degree and 23% (19%) held a B.Sc. degree. Their main subject in the M.Sc. or B.Sc. certificate was physics 22% (26%), chemistry 16% (28%), and mathematics 36% (15%).

Two researchers read the responses to the open questions (B) and (C) independently, using the purpose of this study and the research questions as initial guides, and suggested categories for further analysis. They then met to discuss their findings. They subsequently formulated the main categories and subcategories and agreed about statements that were considered typical of each.

Table 1 presents the main categories of reasons for using experiments. The first main category was further divided into three subcategories: 1.1 'general', 1.2 'meaning creation', and 1.3 meaning illustration'. In subcategory 1.1, the statements include only the general idea that experiments help students to learn

Table 1. Main categories of the reasons for using classroom experiments in teaching.

Category	*Description (typical examples)*
1. Students learn concepts	Experiments help students to learn (acquire) new concepts or scientific literacy ('It illustrates and test new law', 'Phenomena are easy to understand through experiments')
2. Students learn skills needed in experiments	Experiments help students to learn skills that are needed in experimental methods (e.g. measurement and graphical presentation of data), and to develop procedural understanding that is needed in planning experiments ('Students learn research skills', 'Before doing they learn planning')
3. Students learn about the nature of physics	Experiments help students learn about the nature of physics, its epistemology and ontology ('It helps to understand how experimental data and theory are linked together')
4. Students learn 'other' skills	Experiments help students learn thinking skills (reasoning, critical thinking, higher-order thinking, problem-solving, and metacognitive skills); social, and communicating skills; and skills needed in self-regulatory or autonomous learning ('It is important to work together', 'Learning is self regulatory', 'Students metacognitve skills are developed within experiments')
5. Experiments allow doing with hands	When students are doing experiments, they have the possibility to do things with their hands. These statements emphasize doing with hands without any clear statements to learning of concepts ('Practical activity is learning by doing', 'Hands-on is best')
6. Learning is linked to context	Through experiments, learning is linked to context, with the aim of making physics more relevant; for example, by including science, technology and society issues in physics courses ('It shows that phenomena belong to everyday life')
7. External motivation	Students enjoy working in the laboratory, or the demonstrations arouse students' interest in studying ('Experiment raises pupils' motivation', 'They become motivated')
8. External authorities	Practical work is emphasized by curriculum, textbooks, colleagues or headmaster ('It is said in the curriculum', 'Textbooks for lower secondary school emphasize experiments')
9. Experiments are not necessary	Teacher's opinion is that experiments are a waste of time, teacher has no equipment or no motivation ('I have no equipment', 'It is always hurry', 'There is no time for demonstrations')

concepts in physics. In subcategories 1.2 and 1.3, it was argued that experiments help students construct and illustrate the meaning of new concepts, representing both the primary direction of the scientific process (Arons 1997). The second subcategory, 1.2 'meaning creation', indicates the basic ideas behind the *ITPT* project, and resembles the category listed by Gott and Duggan (1995: 21) in their summary of types of practical work (experiments). The main aim of 'enquiry practicals' (experiments) is concept acquisition as well as laws or principles. The main difference between our category and the category used by Gott and Duggan is in the nature of the enquiry process itself. The enquiry practicals mainly involve a discovery process on the part of the student, while we emphasize that the process

Table 2. Main categories of the changes in the usage of classroom experiments in teaching.

Category	*Description (examples)*
1. More attention to goals of experiments	Teacher indicates that (s)he thinks more about the goals connected to a certain demonstration/ practical work ('I am now more purpose-oriented when I plan experiments', 'Now I more often use graphical presentation of the data and help student in their concept formation')
2. Emphasis in equipment: (1) simple or (2) MBL tools	Teacher chooses less complex/MBL* equipment that (s)he utilizes in demonstrations/practical work ('I had started to utilize MBL tools in experiments', 'I use simple equipment because too complicated equipment mystify phenomena')
3. More attention to planning of experiments	Teacher indicates that (s)he spent more time or uses more creativity when (s)he plans certain demonstrations/practical work ('Now I do not follow so accurately the textbook, I use my creativity more', 'I plan the demonstration more carefully')
4. Emphasis on students' activity or freedom	Teacher indicates that (s)he tries to activate the student within experiments or (s)he gives more freedom (time for planning) to his/her students through open ended, divergent, approaches to experimentation ('I am looking more independent initiative from the students', 'I use now open-ended problems', 'I have changed cookbook science to open investigations')
5. No changes in experiments	Teacher indicates that there are no changes in his demonstrations or practical work ('I have just thought that I have to do something', 'I think that there are no changes at all')
6. Other changes	A description that does not indicate anything about quality of change in the usage of classroom experiments or indicate change in duration or number of experiment. (Earlier my demonstrations were quantitative but now they are qualitative', 'They are shorter now')

* MBL (microcomputer-based laboratory, in UK data-logging) tools include the hardware and software that are used for collecting data (data acquisition) and using sensors/probes connected to a microcomputer through an interface.

is more acquisition of perception, in which the role of the teacher is important. Moreover, we have already emphasized that, while it is impossible to teach 'theory' through experiments, it is possible to help students understand the empirical meanings of the concepts, laws and principles through teacher-guided experimentation. The practicals typical of our third subcategory, 1.3 'meaning illustration', Gott and Duggan (1995: 21) call illustrative practicals. These experiments demonstrate or provide a particular concept, law or principle that has already been introduced by a teacher, in order to allow the pupils to 'see' the concept in action, and thereby relate the theory more closely to reality.

Table 2 presents the main categories statements describing changes in the use of experiments in physics teaching from responses to the third part (C) of the questionnaire. The first main category was further divided into two subcategories: 1.1 'Goal with the target that experiments help students to construct meanings to new concept', and 1.2 'Other goals'.

Table 3. Main categories of the nature of episodes in e-mail messages.

Category	*Description (examples)*
Irrelevant	Notification of other in-service training, seminar or job, available, discussion about informal meetings, organizing coffee or lunch breaks during the contact training
Organizational	Notification of the timetable of a summer or weekend meeting, or an acceptance, or notification of the tasks or deadline, or students' message about tasks or timetable Problems or success in interaction or collaboration – mainly problems in sending or receiving e-mail messages or taking part in the IRC* session and advice how to solve these problems Others, such as instructions on how to use the PC
Subject knowledge	Discussion, typically questions or answers, about certain subjects or areas of physics (discussion about how a rainbow is born; question and answers about how a voltage supply is working)
Pedagogical knowledge	Discussion, sometimes questions or answers, typically remarks, about certain pedagogical topics (discussion about role of evaluation in learning; discussion about how learning can be guided by making network presentations)
Pedagogical content knowledge	Discussion, sometimes questions or answers, typically remarks, about a certain pedagogical content knowledge topic (questions and answers by teachers and students about how interaction between two wires can be demonstrated in the classroom; discussion about how gas laws can be discussed in the classroom and network presentations used in this discussion)

*Internet relay chat (IRC) provided a way of communicating in real-time in a web page with teachers participating in the ITPT from all over the country.

After identifying the categories all these answers (43 standard pages altogether) were analyzed according to the principles of protocol analysis (Ericsson and Simon 1993, Welch 1999). The answers were then segmented into units and coded according to categories. Responses were sought concerning: (1) the teachers' beliefs, and (2) the effect of the *ITPT* project on beliefs. In particular, since the control group represents the situation before the *ITPT* project, comparison of the groups, in addition to the teachers' own evaluations of the changes, is assumed to provide the information on question (B).

To clarify discussion about the role of experiments during the *ITPT* process, we also analyzed all messages send to our e-mail list during *ITPT I.* During 18 months of training 1309 messages (1165 standard pages of text) were sent. Two researchers read the messages independently, and suggested categories that would describe the nature and dynamics of the discussion. The researchers then met to discuss their findings and formulated the main categories described in table 3. It proved to be appropriate to consider the discussion in three parts: the first 6 months, the middle 6 months and the last 6 months of *ITPT I.* Discussion about the epistemic role of experiments in physics and about how experiments can be completed in the classroom so they will help students to begin discussing the empirical meanings of concepts were typical pedagogical content knowledge topics.

After defining the categories, all e-mail messages were analyzed according to the ideas of protocol analysis (Ericsson and Simon 1993). The messages were first segmented into episodes, and then coded according to the categories presented in table 3. The episodes were selected to facilitate coding each episode in one category. There were 1825 episodes messages in all. The coding of all the data was done by one researcher, while a second researcher coded a randomly selected sample of 10%. The two coders reached a 75% consensus on coding the episodes. Disagreement occurs typically in coding an episode to an organizational or irrelevant category.

Results

From the responses to task (A) we gathered that teachers of both groups present demonstrations on average every second physics lesson, with no difference between the groups ($\chi^2 = 5.3^{ns}$). The numbers of demonstrations by the experiment group before and after the *ITPT* project did not differ either ($\chi^2 = 6.2^{ns}$). Similarly, both groups organized practical work on average every fourth lesson ($\chi^2 = 6.7^{ns}$), and the amount of practical work done by the experiment group before and after the *ITPT* project was equal ($\chi^2 = 1.2^{ns}$).

Table 4 presents the frequencies of the main categories in responses to task (B) concerning the goals of experiments. The frequencies of the subcategories 1.1 'general', 1.2 'meaning creation' and 1.3 'meaning illustration' in the experiment group (control group) were 66.3% (64.1%), 18.4% (17.0%) and 9.2% (17.0%). The differences between the two groups were not statistically significant ($\chi^2 = 1.7^{ns}$).

Table 4. Reasons for experiments.

	Experiment group (n = 98)		*Control group (n = 53)*	
Reason	*Frequency**	*Relative frequency (%)*	*Frequency**	*Relative frequency (%)*
Students learn concepts of physics	92	93.9	52	98.1
External motivation	56	57.1	32	60.4
Experiments allow doing with hands	34	34.7	10	18.9
Students learn about the nature of physics	31	31.6	14	26.4
Students learn skills needed for experiments	26	26.5	9	17.0
Students learn other skills	10	10.2	5	9.4
Learning is linked to context	7	7.1	2	3.8
External authorities	3	3.1	4	7.5
Experiments are not necessary	13	13.3	6	11.3
Missing answer	22	22.4	25	47.2

$\chi^2 = 13.8^{ns}$.

* Sum of the frequencies is 3*n*, because each teacher was asked to give three reasons.

Table 5. Improvements in the usage of experiments.

	Experiment group (n = 98)		*Control group (n = 53)*	
Ways experiments have been improved	*Frequency**	*Relative frequency (%)*	*Frequency**	*Relative frequency (%)*
More attention to goals of experiments	35	24.3	4	6.8
Emphasis on students' activity or freedom	30	20.8	9	15.3
Emphasis on equipment: (1) simple or (2) MBL*	29	20.1	10	16.9
More attention to planning of experiments	20	13.9	5	8.5
Other changes	11	7.6	10	16.9
No changes in experiments	4	2.8	5	8.5
Missing answer	15	10.4	16	27.1

$\chi^2 = 22.8^{***}$.

* Four teachers in the experiment group, and three in the control group, had started to utilize MBL tools.

Table 5 presents the self-evaluation data concerning the changes in the usage of experiments, task (C). There were 24% (9%) of the teachers providing two features, and 12% (2%) providing three features describing the improvement in experiments (control group in brackets). The frequencies of the subcategories 1.1 'Goal with the target that experiments help students to construct meanings to new concept' and 1.2 'Other goals' were 17.3% (0%) and 18.4% (7.5%), respectively.

Responses to task (D) in the questionnaire showed that the experiment group considered their demonstration skills to be 'good' (median) on average, while the control group thought their skills were only 'satisfactory' ($\chi^2 = 6.4^{*}$). The teachers in both groups considered their skills in organizing practical work 'good' (median) on average ($\chi^2 = 0.51^{\text{ns}}$).

Table 6. Nature of of episodes in e-mail messages.

	First 6 months		*Middle 6 months*		*Last 6 months*		
Nature of episodes in e-mail messages	*Student*	*Teacher*	*Student*	*Teacher*	*Student*	*Teacher*	*Total*
Irrelevant	16 (6)	14 (4)	39 (11)	15 (4)	45 (17)	18 (7)	147
Organizational	161 (64)	197 (60)	116 (33)	150 (40)	115 (44)	125 (49)	864
Subject knowledge	18 (7)	21 (6)	104 (30)	86 (23)	36 (14)	37 (15)	302
Pedagogical knowledge	14 (6)	30 (9)	26 (7)	25 (7)	23 (9)	19 (8)	137
Pedagogical content knowledge	42 (17)	67 (20)	65 (19)	103 (27)	44 (17)	54 (21)	375
Total	251	329	350	379	263	253	1825
Total	580		729		516		1825

Note: Proportion of the teachers' and students' (teachers participating ITPT) different episodes in e-mail messages are presented as frequencies *f* (percentages *f*%).

Table 6 presents the frequency and relative frequency of the episodes found in e-mail messages sent during *ITPT I.* This body of data was acquired by qualitative methodology and, was not, therefore, intended for quantitative analysis. Table 6 shows that the next most popular subject after organizational issue was the pedagogical content knowledge, which was also popular in all three phases. The most common topic here was the role of experiments in physics education, with 66–74% depending on the period. Participating teachers both ask questions (19% of episodes in this category) and answer questions from their colleagues (33%), while the most popular way of participating was to spontaneously explain one's own experience of planning and use of experiments. The university teachers who were involved in the *ITPT* project confirm that the proportions of the discussion of subject knowledge, pedagogical knowledge and pedagogical content knowledge was parallel to discussion during the contact training seminars.

Discussion and conclusions

The evaluation showed that the two groups were very similar. Numerically, there was no significant difference in the use of experiments in teaching. The distribution of views on how experiments help students to learn physics (table 4) was statistically similar. The groups agreed about the five most important reasons for experiments: students learn concepts of physics (average 95.4%), experiments arouse external motivation (58.3%), experiments allow hands-on activities (29.1%), students learn about the nature of physics (29.8%), and students learn process skills and enjoy increased procedural understanding (23.2%). Since our third important category, ‘experiments allow hands-on activities’, was typically mentioned by the same teacher, in addition to the first category, ‘students learn concepts of physics’, we selected it as a new category, although the statements also included indefinite mentions of learning. Our findings correlate well with other research. According to the summary by Wellington (1998: 6), the rationale for practical work teachers have typically mentioned often concentrate on three main areas: the cognitive domain, or understanding science; transferable skills, and processes and procedural understanding; and the affective domain or attitudes, motivation and enjoyment.

There are, however, several significant differences that suggest an improved awareness of the goals of classroom experiments, particularly as regards the aims of conceptual understanding within the experimental group. In table 4, categories 1–4 with definite goals display systematically higher frequencies in the experiment group, while the frequencies of missing answers in both tables 3 and 4 are considerably higher in the control group than the experiment group. Following *ITPT,* teachers say that they devote more attention to the goals of classroom experiments. In particular, they tend to use the experiments consciously to help students construct the meanings of new concepts, as well as to help them learn to plan experiments with that aim. This is important, and has of course been emphasized by several researchers. For example, Hodson (1990, 1992, 1996) argues that both pupils and teachers must recognize the goal of experiment in order to extract any benefit. Responses to task (D) in the questionnaire seem to reflect some improvement in confidence performing experiments.

The nature of discussion on the e-mail list during *ITPT I* indicates that teachers were aware of the role of experiments in learning concepts. It also indicates that the teachers were interested in how and what type of experiment best helps students in the physics classroom to learn or create meanings for concepts. Teachers can, therefore, be enabled to think and discuss the role of experiments in the classroom through contact and distance training.

The complementary text additions to table 5 indicate that the teachers in the experiment group are able to specify their goals, and the relevance of experiments to learning better than the teachers in the control group. It also shows that teachers in the experiment group are more aware of the importance of the aims connected to conceptual understanding. The following excerpts show this: 'Nowadays, my demonstrations help students start their learning process from observations', 'I am not doing demonstrations or practical work nowadays just for fun, but because they provide a good basis for discussion', 'At the beginning of my teaching career experiments were just for filling the lecture; now they have clear learning goals', 'Experiments lead students to understand the meaning of the concepts and also help them to understand conformity to law', and 'We spend more time with graphical presentation of the data and discuss the curves'. On the contrary, there might be several other reasons why approximately 40% of the teachers in the control group could not express a classifiable description of the improvement in the experiments they are currently organizing. It is possible that those teachers already had a variety of reasons for experiments, and see no need to make any change. It is also possible they cannot express themselves in their written answers because they lack the vocabulary. On the contrary, the ability of the teachers in the experiment group to express their reasons for using experiments may be that during the *ITPT* project they learned how to express their views.

Although the number of such perceptively specific responses recording an improvement in the use of experiments is small (about 18%), they were found exclusively among the experimental group. Otherwise, teachers give numerous indefinite reasons for using experiments, relating to matters including external motivation and hands-on activity without any obvious relevance to learning physics concepts. This is in accordance with the notion that there are plenty of activities going under the name of practical work that have no real educational value (Hodson 1992).

The internal validity of our study was checked in many ways. The most important measure was the use of two independent researchers (Cook and Campbell 1979: 37–91). Their agreement coefficient rate on the coding of the units was 79.9%. A third independent researcher also analyzed the responses, reading the answers and the definitions of categories to monitor the coverage of the data and independence. Some descriptions of categories were modified following discussion between these three researchers. The agreement coefficient rate on coding between one of the primary coders and the third was 79.0%.

Since it was important to verify that the only effective difference between the nature of the groups was that the control group had not yet been through the *ITPT* project, we collected background information on the important attribute variables: professional position, the major subject in the competence profile of a teacher, and educational background. Chi-square test analysis showed no significant differences between the experimental and the control groups. Furthermore, the lag time between *ITPT II* and launching this study can be regarded as sufficient to ensure that the answers from the experiment group reflect their genuine beliefs, rather than superficial repetition of the *ITPT* phraseology.

Our study thus answers the second research question, concerning the effect of the *ITPT* project. It is more difficult to assess whether the observed beliefs in the answers are representative of Finnish physics teachers in general. Moreover, voluntary attendance at the *ITPT* project may indicate that both the experiment and control groups form a select group. In late 1995, a questionnaire with some related questions about the role of experiments was sent to an unselected group of 52 physics teachers. The preliminary results (Kurki-Suonio 1991) were qualitatively parallel to our results. In this study, physics teaching was regularly supported by experiments. However, the awareness of the teachers about the goals of experiments was obviously lower than in our control group. Motivation, or 'waking them up', was the dominant reason cited. Aims related to conceptual understanding were not mentioned explicitly, although descriptions of the activities in the classroom indicated some efforts in that direction. Such differences from our control group can be partly explained by the time difference between the studies, because the role of experiments in the classroom was thoroughly discussed in national seminars and journals during the years that elapsed in between. The effect of the *ITPT* project is thus difficult to distinguish from the totality of relevant discussion.

Although the changes observed in this investigation are numerically few, and the results of our efforts seem meagre, they do give some hope that sufficiently well-conducted training can change beliefs. In addition, the interaction between participants has not stopped, even though the active period of the project has ended. The e-mail list became a permanent medium for discussions involving the majority of the participants. Typically, 20–50 messages have been sent every month and subjects are being discussed like those during the *ITPT* project. These messages include minimal organizational messages and few irrelevant messages. In addition, a considerable number of the participants, 53 (37%) and 32 (39%) in *ITPT I* and *ITPT II*, respectively, seized the opportunity to continue their studies toward a higher degree in physics education. Ultimately, eight and two of the participants are continuing toward their licentiates or doctorates. We interpret this as a sign of success, and surmise that keeping in contact after the active phase of training is important if permanent effects are desired. On the contrary, it is not clear how much of this is directly related to the questions investigated in this study.

The *ITPT* projects as such will not be repeated, but the experiences are nevertheless important for further development of both in-service and pre-service training of physics teachers. It can be argued, as do Gess-Newsome and Lederman (1995), that the subject matter and pedagogical knowledge of teachers do affect classroom practice (Haney et al. 1996). It has even been suggested that in order to change their practice more permanently, teachers should examine their beliefs about the nature of physics and the role of experiments (see Brickhouse 1990) and would thus need more opportunities to identify their beliefs, as well as to discuss them with their colleagues in small groups (Lumpe et al. 2000).

Our results indicate some success in such areas but, in spite of all such efforts, transfer into reported development of teaching practice remains low. Experiences from the various study groups at the ESL course indicate that real development occurred particularly in those few groups that followed the recommendation to involve their own students, and to try out the experiments in real classroom situations. Further improvement of teacher education could perhaps be achieved by developing direct counseling of teachers in a way that explicitly reflects the existing classroom situations. This challenge is quite close to what de Jong (2000) suggests is essential for PCK. From our experience, we remain convinced that both the physicists and the educationists play an important role in physics teacher education in finding the mechanisms and courses for facilitating transfer and integration across knowledge domains (PCK), both in theory and practice (Gess-Newsome 1999: 83). Furthermore, it might be useful to create an atmosphere in which teachers as well as trainees in pre-service education could observe each other's classroom practices and discuss them, and reflect on and plan physics lessons together. This could take place through peer-coaching models (Joyce and Weil 1996: 399–400). Teachers should be helped to examine their pre-existing knowledge and beliefs, and to be assisted by both physicists and educationists.

Notes

1. In this paper the term 'models of teaching' is used generally for any teaching, learning or instructional method, model, strategy or classroom practice that emphasizes the role of experiments and helps students to acquire new concepts, ways of thinking and related skills (see Joyce and Weil 1996: 7).
2. The book is in Finnish. An English translation of the introduction and the list of contents can be found on the home pages of the program (DFCL 1999).

References

ANDERSON, B. (1986). The experiential gestalt of causation: a common core to pupil's preconceptions in science. *European Journal of Science Education*, 8(2), 155–172.

ARONS, A. (1997). *Teaching Introductory Physics* (New York: John Wiley & Sons).

BERRY, J. and SAHLBERG, P. (1996). Investigating pupils' ideas of learning. *Learning and Instruction*, 6(1), 19–36.

BRICKHOUSE, N. W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education*, 41(3), 53–63.

BRUNER, J., GOODNOW, J. J. and AUSTIN, G. A. (1967). *A Study of Thinking* (New York: Science Editions).

BUNGE, M. (1983). *Epistemology & Methodology II: Understanding the World. Treatise on Basic Philosohy*, Vol. 6 (Dordrecht: D. Reidel).

CARLSEN, W. (1999). Domains of teacher knowledge. In J. Gess-Newsome and N. G. Lederman (eds.) *Examining Pedagogical Content Knowledge* (Dordrecht: Kluwer Academic), 133–144.

CLARK, C. M. and PETERSON, P. L. (1985). Teachers' thought processes. In M. C. Wittrock (Ed.) *Handbook of Research on Teaching* (New York: Macmillan), 255–296.

COOK, T. D. and CAMPBELL, D. T. (1979). *Quasi-Experimentation: Design of Analysis Issues for Field Settings* (Chicago, IL: Rand Mc Nally College Publishing).

DE JONG, O. (2000). The teacher trainer as researcher: exploring the initial pedagogical content concerns of prospective science teachers. *European Journal of Teacher Education*, 23(2), 127–37.

DFCL (1999). Home page of the *In-service Training for Physics Teachers (ITPT)*. Available online: http://didactical.physics.helsinki.fi/dfcl/ (accessed 8 December 2001).

DUIT, R. and CONFREY, J. (1996). Reorganizing the curriculum and teaching to improve learning in science and mathematics. In D. F. Treagust, R. Duit and B. J. Fraser (Eds) *Improving Teaching and Learning in Science and Mathematics* (New York: Teachers College Press, Columbia University), 79–93.

ERICSSON, K. A. and SIMON, H. A. (1993). *Protocol Analysis Verbal Reports as Data* (Cambridge, MA: MIT Press).

FORD, C. E. (1999). Collaborative construction of task activity: coordinating multiple resources in a high school physics lab. *Research on Language and Social Interaction*, 32(4), 369–408.

FRANKLIN, A. (1999). The roles of experiment. *Physics in Perspective*, 1(1), 35–53.

FULLAN, M. (1991). *The New Meaning of Educational Change*, 2nd edn. (London: Cassell).

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome and N. G. Lederman (Eds.) *Examining Pedagogical Content Knowledge* (Dordrecht: Kluwer Academic), 51–94.

Gess-Newsome, J. and Lederman, N. G. (1995). Biology teachers' perceptions of subject matter structure and its relationship to classroom practice. *Journal of Research in Science Teaching*, 32, 301–325.

Gott, R. and Duggan, S. (1995). *Investigative Work in the Science Curriculum* (Buckingham: Open University Press).

Gott, R. and Duggan, S. (1996). Practical work: its role in the understanding of evidence in science. *International Journal of Science Education*, 18(7), 791–806.

Green, T. F. (1971). *The Activities of Teaching* (Tokyo: McGraw-Hill).

Haney, J. J., Czerniak, C. M. and Lumpe, A. T. (1996). Teacher beliefs and intentions regarding the implementation of science education reform strands. *Journal of Research in Science Teaching*, 33, 971–993.

Hodson, D. (1990). A critical look at practical work in school science. *School Science Review*, 71, 33–40.

Hodson, D. (1992). Redefining and reorienting practical work in school science. *School Science Review*, 73, 65–78.

Hodson, D. (1996). Laboratory work as scientific method: three decades of confusion and distortion. *Journal of Curriculum Studies*, 28, 115–135.

Jauhiainen, J., Lavonen, J., Koponen, I. and Kurki-Suonio, K. (2002). Experiences from long-term in-service training for physics teachers in Finland. *Physics Education*, 37, 128–134.

Joyce, B. and Weil, M. (1996). *Models of Teaching*, 5th edn. (Boston, MA: Ally and Bacon).

Justi, R. S. and Gilbert, J. K. (2002). Modelling, teachers' views on the nature of modelling, and implications for the education of modellers. *International Journal of Science Education*, 24(4), 369–387.

Kurki-Suonio, R. (1991). I have been pondering upon the light ray . . . In O. Björkqvist (Ed.) *Quality Aspects of Mathematics and Science Education*. Reports from the Faculty of Education, 5 (Åbo Akademi University), 11–24. Available online: http://didactical.physics.helsinki.fi/dfcl/vanhat/english/98VAASA.htm (accessed 8 December 2001).

Kurki-Suonio, K. and Kurki-Suonio, R. (1994). *Fysiikan merkitykset ja rakenteet* [*The Meanings and Structures of Physics*] (Helsinki: Limes ry).

Lavonen, J., Kurki-Suonio, K. and Hakulinen, H. (1994–1996). *Galilei 1–8*. Text-book series for the Finnish upper secondary school (Porvoo: Weilin + Göös).

Lazarowitz, R. and Tamir, P. (1994). Research on using laboratory instruction in science. In D. L. Gabel (Ed.) *Handbook of Science Teaching and Learning* (New York: Macmillan), 94–128.

Loughran, J. (1999). Professional development for teachers: a growing concern. *Journal of In-service Education*, 25(2), 261–273.

Lumpe, A. T., Haney, J. J. and Czerniak, C. M. (2000). Assessing teachers' beliefs about their science teaching context. *Journal of Research in Science Teaching*, 37(3), 275–292.

Maor, D. and Taylor, P. C. (1995). Teacher epistemology and scientific inquiry in computerised classroom environments. *Journal of Research in Science Teaching*, 32(8), 839–854.

McComas, W., Clough, M. P. and Almazroa, H. (1989). The role and character of nature of science in science education. In W. McComas (Ed.) *The Nature of Science in Science Education: Rationales and Strategies* (Dordrecht: Kluwer Academic), 26.

McDermott, L. C., Shaffer, P. S. and Constantinou, C. P. (2000). Preparing teachers to teach physics and physical science by inquiry. *Physics Education*, 35(6), 411–416.

Mestre, J. P. (2001). Implications of research on learning for the education of prospective science and physics teachers. *Physics Education*, 36(1), 44–51.

Millar, R. (1994). What is 'scientific method' and can it be taugh? In R. Levison (Ed.) *Teaching Science* (London: Routledge), 164–177.

Millar, R., Le Maréchal, J.-F. and Tiberghien, A. (1999). 'Mapping' the domain: varieties of practical work. In J. Leach and A. C. Paulsen (Eds) *Practical Work in Science Education* (Roskilde: Roskilde University Press), 33–59.

Novak, J. D. (1998). Theoretical and empirical foundations of human constructivism. In J.J Mintzes, J.H Wandersee and J. D. Novak (Eds) *Teaching Science for Understanding: A Human Constructivistic View* (San Diego, CA: Academic Press), 5–27.

OLSEN, T. P., HEWSON, P. W. and LYONS, L. (1996). Preordained science and student autonomy: the nature of laboratory task in physics classroom. *International Journal of Science Education*, 18(7), 775–789.

PAJARES, M. F. (1992). Teachers' beliefs and educational research: cleaning up a messy construct. *Review of Educational Research*, 62, 307–332.

SHULMAN, L. S. (1987). Knowledge and teaching: foundations of the new reform. *Harvard Educational Review*, 57, 1–22.

SOLOMON, J. and TRESMAN, S. (1999). A model for continued professional development: knowledge, belief and action. *Journal of In-service Education*, 25(2), 307–319

STEIN, F. M. (2001). Re-preparing the secondary physics teacher. *Physics Education*, 36(1), 52–57.

STINNER, A. (1992). Science textbooks and science teaching: from logic to evidence. *Science Education*, 76(1), 1–16

STINNER, A. (1994). Providing a contextual base and a theoretical structure to guide the teaching of high school physics. *Physics Education*, 29, 375–381.

SWAIN, J., MONK, M. and JOHNSON, S. (1999). A comparative study of attitudes to the aims of practical work in science education in Egypt, Korea and the UK. *International Journal of Science Education*, 21(12), 1311–1324.

TOBIN, K., TIPPINS, D. J. and GALLARD, A. J. (1994). Research on instructional strategies for teaching science. In D. L. Gabel (Ed.) *Handbook of Research on Science Teaching and Learning* (New York: Macmillan), 45–93.

WARWICK, P., LINFIELD, R. S. and STEPHENSON, P. (1999). A comparision of primary pupils' ability to express procedural understanding in science through speech and writing. *International Journal of Science Education*, 21(8), 823–838.

WATSON, J. R., PRIETO, T. and DILLON, J. (1995). The effects of practical work on students' understanding of combustion. *Journal of Research in Science Teaching*, 32, 487–502.

WATTS, M. (1996). An explanatory gestalt of essence: students' conceptions of the 'natural' in physical phenomena. *International Journal of Science Education*, 18(8), 939–954.

WELCH, M. (1999). Analyzing the tacit strategies of novice designers. *Research in Science & Technological Education*, 17(1), 19–35.

WELLINGTON, J. (1998). Practical work in science. In J. Wellington (Ed.) *Practical Work in School Science: Which Way Now?* (London: Routledge), 3–15.

WHITE, T. (1996). The link between the laboratory and learning. *International Journal of Science Education*, 18(7), 761–774.

WILKINSON, J. W. (1999). The contextual approach to teaching physics. *Australian Science Teachers Journal*, 45(4), 43–51.

VÄISÄNEN, J. and KURKI-SUONIO, K. (2000). The use of concept maps in the physcs teacher education. In L. Aho and J. Viiri (Eds) Undervisning i naturvetenskap ur kultur-, teknologi- och milijöprspektiv. *Rapport från det sjätte nordiska forskarsymposiet om undervisning I nsturvetenskap I skolan* [*The Sixth Nordic Research Symposium on Science Education at School*] (Joensuu: Joensuu universitet).