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Professional Development and Reform in Science Education: The Role of Teachers' Practical Knowledge

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Abstract: In this article, professional development in the context of the current reforms in science education is discussed from the perspective of developing teachers' practical knowledge. It is argued that reform efforts in the past have often been unsuccessful because they failed to take teachers' existing knowledge, beliefs, and attitudes into account. Teachers' practical knowledge is conceptualized as action-oriented and person-bound. As it is constructed by teachers in the context of their work, practical knowledge integrates experiential knowledge, formal knowledge, and personal beliefs. To capture this complex type of knowledge, multimethod designs are necessary. On the basis of a literature review, it is concluded that long-term professional development programs are needed to achieve lasting changes in teachers' practical knowledge. In particular, the following strategies are potentially powerful: (a) learning in networks, (b) peer coaching, (c) collaborative action research, and (d) the use of cases. In any case, it is recommended that teachers' practical knowledge be investigated at the start of a reform project, and that changes in this knowledge be monitored throughout the project. In that way, the reform project may benefit from teachers' expertise. Moreover, this makes it possible to adjust the reform so as to enhance the chances of a successful implementation. © 2001 John Wiley & Sons, Inc. J Res Sci Teach 38: 137–158, 2001

Introduction

The idea that teachers are the most influential factor in educational change is not controversial (cf. Duffee & Aikenhead, 1992). However, the crucial role of teachers in efforts to reform or innovate the curriculum may be assessed from quite different perspectives. In a traditional top-down approach, the lack of success of many innovative projects is attributed to the failure of teachers to implement the innovation in a way corresponding to the intentions of the developers. In this approach, the curriculum developers are assumed to know how the curriculum has to be changed and how teachers have to adapt their teaching practice, that is, change their classroom behavior.

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This top-down approach has been criticized, for example, by Tobin and Dawson (1992). Instead of blaming teachers for the relative lack of success of many curriculum reform efforts, they suggest that curriculum developers have often failed to take into account the teachers, students, and the culture in which the new curriculum is to be embedded (cf. Wallace & Louden, 1992). In particular, teachers' beliefs are deemed important. In their influential review of research on teacher thinking, Clark and Peterson (1986) warned that "teachers' belief systems can be ignored only at the innovators' peril." To understand the role of teachers with respect to educational reform, it has been suggested that their beliefs and views (Tobin & McRobbie, 1996), or their practical knowledge (Duffee & Aikenhead, 1992) be analyzed. Practical knowledge consists of teachers' knowledge and beliefs about their own teaching practice, and is mainly the result of their teaching experience. This practical knowledge perspective is the central issue of this article, in which we address the question "What can we learn from research on teachers' practical knowledge in order to increase the success of reform in science education?" After all, as it is directly related to the teachers' behavior in classrooms (Verloop, 1992), their personal practical knowledge will exert a major influence on the way teachers respond to educational change.

Reform in Science Education

In many nations around the globe, science education is currently going through a process of change. Other articles in this series will describe the current reform from a historical perspective, and will highlight various aspects of the content of this reform (see also Bybee & DeBoer, 1994). It appears that the reform efforts in different countries share some important characteristics, which are apparently related to dissatisfaction with how science is traditionally taught. Although studies like TIMSS have revealed substantial differences in science education across countries (e.g., Stigler, Gallimore, & Hiebert, 2000), in general, an emphasis seems to exist on lectures to convey science content, and technical training for acquiring practical skills. Science is usually presented as a rigid body of facts, theories, and rules to be memorized and practiced, rather than a way of knowing about natural phenomena. To an increasing extent this approach has become the subject of criticism among policy makers, teachers, educators, and researchers. First, this traditional approach has been related to the decreasing popularity of science among students, apparent from the declining numbers of students choosing science subjects as a specialization. Second, research on students' conceptions of scientific topics has convincingly demonstrated that students exposed to this approach often end up with a poor understanding of scientific concepts. Moreover, it is felt that science education in its traditional form has become outmoded, in that it does not adequately prepare future citizens to understand science and technology issues in a rapidly evolving society (Millar & Osborne, 1998). Finally, it has been argued that the culture of "school science" may restrict the professional development of science teachers (Munby, Cunningham, & Lock, 2000).

In an attempt to change this situation, a series of influential publications in the United States (Rutherford & Ahlgren, 1989; AAAS, 1993; NRC, 1996) have advocated a nation-wide reform of science education, with the following aims:

- To achieve scientific literacy as the central goal of science education ('Science for all Americans'). In this respect, it is considered particularly important to focus on students' understanding of the nature of science, for instance, by studying the history and the philosophy of science (AAAS, 1993).
- To achieve science standards for all students, implying both excellence and equity (NRC, 1996).

- To design science education to reflect the premise that science is an active process, so that both "hands-on" as well as "minds-on" activities should constitute the core of the educational process.
- To focus on inquiry as a central element of the curriculum, to promote students to actively develop their understanding of scientific concepts, along with reasoning and thinking skills.

Similar goals can be found in articles and reports documenting reform efforts in other countries, for instance, the implementation of 'Science, Technology and Society' in Canada (Aikenhead & Ryan, 1992), or a new science curriculum in Australia (Curriculum Corporation, 1994). Also, a recent report about the future of science education in the United Kingdom, called 'Beyond 2000,' contains recommendations with a similar direction (Millar & Osborne, 1998). In accordance with the 'Beyond 2000' report, a new GCE syllabus has been introduced, called 'Science for Public understanding' (NEAB, 1998). This new syllabus aims to increase students' (1) understanding of everyday science, (2) confidence in reading and discussing media reports of issues concerning science and technology, and (3) appreciation of the impact of science on how we think and act.

In the Netherlands the national curriculum traditionally only contained physics, chemistry, and biology as separate subjects. With the exception of local, small-scale projects, there is no experience with an integrated approach to science teaching. As of 1998, however, such an approach has been implemented in the national curriculum through the introduction of 'Public Understanding of Science' as a new, separate subject, alongside the traditional disciplines of physics, chemistry, and biology (De Vos & Reiding, 1999). As with 'Science for Public understanding' (NEAB, 1998), this new subject has three main objectives: (1) to introduce *every* student to major scientific concepts (i.e., life, matter, biosphere, solar system and the universe), (2) to demonstrate the complex interactions between science, technology, and society, and (3) to make students aware of the ways in which scientific knowledge is produced and developed, that is, to promote students' understanding of the nature of science. At the same time, the curriculum of the traditional subjects has been changed to promote active learning activities by the students, especially through inquiry, and, in general, to promote students' critical thinking abilities. To facilitate these changes, in particular to reduce the amount of content which needs to be covered, some topics have been removed from the curricula (e.g., the concept of entropy was removed from the chemistry curriculum).

From a teaching perspective, the reform efforts described above share some implications for teaching science:

- Instead of transmitting content knowledge in a rigid manner, the emphasis in teaching will be on designing situations and a variety of activities which enable students to learn actively. In this respect, the teacher needs to investigate what the students already know, identify possible misconceptions, and then design an appropriate educational setting. In any case, teachers need to be able to respond to situations in their classroom they might not have anticipated (Kennedy, 1998).
- Consequently, the number of topics in the curriculum will probably have to decrease. For teachers this implies the acceptance of the idea that "less is better," and resisting "the temptation to include too much" (Millar & Osborne, 1998, p. 17).
- In general, a shift toward *reflection on science* rather than focusing solely on the content of scientific ideas is implied. Teachers will thus be asked to pay more attention to aspects of science they usually ignore, or do not feel very comfortable with, like the history and philosophy of science, or the relation between science and societal issues.

- Teachers will be confronted with the challenge of teaching science in a way which appeals to *all* students, both from a cognitive and an affective perspective, and not just students with high abilities or high motivation for science.
- A shift toward the teaching of inquiry skills, which is definitely more complex than the traditional training of practical skills.

Before discussing these changes from the perspective of professional development activities, we will first address the literature on educational change and teachers' cognitions in a more general way.

Implementation of the Reform

The question how to involve teachers in curriculum reform efforts so that the chances of a successful innovation are enhanced has, of course, been asked in earlier innovations. For science education, in particular, "ever since the birth of the science curricular reform movement in the late 1950s, a large portion of science teacher education has been connected in some way to attempts to introduce curricular change" (Anderson & Mitchener, 1994, p. 36). Traditionally, this process consisted roughly of the following steps:

1. The core elements of the innovation were defined by curriculum developers or policy makers.
2. A description was made of the teaching behavior expected of teachers who would loyally implement the innovation, or of the skills teachers should acquire.
3. A series of training sessions or supervision activities were designed, aimed at developing the desired teaching behavior (cf. Joyce & Showers, 1980). In particular, "single shot interventions," like inservice workshops, were used to achieve this aim.
4. Usually, the implementation was not adopted by the teachers in the manner intended, or initially observed changes in the teachers' behavior did not persist.
5. The preceding four steps were repeated, but in a modified manner, or after the innovation itself had been redefined.

Of course, not every reform effort in the past followed this scheme. There have been many attempts to improve on this outline (cf. Sparks & Loucks-Horsley, 1990), but on the whole it can be concluded that the role of teachers in the context of curriculum change usually has been perceived as 'executing' the innovative ideas of others (policy makers, curriculum designers, researchers, and the like). Recently, Ball and Cohen (1999) have argued that the role of the government should be limited to establishing a framework for reforms (e.g., by setting standards and providing useful tools, like curricular materials). The reform of actual practice, however, should be in the hands of the professional sector.

In the recent literature, there is a growing consensus that educational reform efforts are doomed to fail if the emphasis is on developing specific teaching skills, unless the teachers' cognitions, including their beliefs, intentions, and attitudes, are taken into account (Haney, Czerniak, & Lumpe, 1996). Reforms call for radical changes in teachers' knowledge and beliefs about subject matter, teaching, children, and learning. Therefore, the implementation of reforms can be seen as essentially a matter of teacher learning (Ball & Cohen, 1999). However, many authors have pointed out that teachers' ideas about subject matter, teaching, and learning do not change easily nor rapidly. There are various reasons why teachers' cognitions are usually stable and why innovative ideas are not easily applied in their teaching practice. First, teachers do not tend to risk changing their own practice which is rooted in practical knowledge built up over the course of their careers. Over the years, this knowledge has proven workable in a satisfying way. From a constructivist point of view, there is thus no need for teachers to change their conceptions (Posner, Strike, Hewson, & Gertzog, 1982). Rather, teachers tend to change their practice in a tinkering manner, picking up new materials and techniques here and there, and incorporating these in their existing practice (Thompson & Zeuli, 1999). Second, although experience contributes to an increase in the extent of a teacher's practical knowledge, at the same time, the variety within this knowledge decreases. This phenomenon is known as knowledge concentration: people gradually "feel more at home" in an area that becomes smaller (Bereiter & Scardamalia, 1993). Consequently, it becomes more and more difficult for someone to move into an area of experience he or she is not familiar with. For these two reasons, innovators often tend to consider teachers' practical knowledge conservative (cf. Tom & Valli, 1990). However, as it is the expression of what teachers really know and do, it is a relevant source for innovators when implementing educational changes.

In order to understand the role of teachers' practical knowledge in the context of educational reform, a more detailed discussion of the nature of practical knowledge seems appropriate. The next section presents a review of the research on this subject, addressing the various elements of practical knowledge and their mutual relationships, how it develops, and the research approaches that may be used to investigate practical knowledge and changes herein.

Research on Teachers' Practical Knowledge

In the past decade, the interest in teachers' practical knowledge (Carter, 1990) or craft knowledge (Grimmett & MacKinnon, 1992) has increased. This increase was influenced by a growing dissatisfaction with research which focused exclusively on teacher behavior. In particular, the results of process–product research have been criticized. By process–product research we refer to a tradition in research on teaching that was inspired by, among others, the work of Gage (1978). Its main characteristic is the search for "effective" variables in teaching behavior, that is, teacher behaviors that correspond positively to pupil achievement scores. After the correlational relationship is established, the next step typically consists of determining the exact influence of that particular variable in an experimental–control group study (Rosenshine & Stevens, 1986). Doyle (1990) has argued that the focus in process–product research on indicators of effectiveness has led to a depersonalized, context-free, and mechanistic view of teaching, in which the complexity of the teaching enterprise is not acknowledged. The underlying knowledge claim was that research could prescribe what teachers had to know and how they should act in the classroom. However, it has also been argued that, to understand the complex process of teaching, it is necessary to understand the knowledge teachers build and use "in action" (cf. Schön, 1983). In what has been labeled a "cognitive change" (Clark & Peterson, 1986), the focus in research has shifted toward the cognitions or thoughts that underlie a teacher's actions. Within this perspective, the concept of practical knowledge refers to the integrated set of knowledge, conceptions, beliefs, and values teachers develop in the context of the teaching situation. Based on the view that research cannot control practice, and prescribe what practitioners have to know and do, research on teachers' practical knowledge can be seen as a result of the criticism on process–product research, and the knowledge claim that belongs to that vision. By acknowledging the complex and context-specific nature of teaching, this research will hopefully empower teachers and enhance the status of teaching as a profession (Doyle, 1990).

The Nature of Teachers' Practical Knowledge

It is generally agreed that a teacher's practical knowledge guides his or her actions in practice (Lantz & Kass, 1987; Brickhouse, 1990; Verloop, 1992). Consequently, practical knowledge can be seen as the core of a teacher's professionality. The most important features of practical knowledge are described below:

1. It is *action-oriented* knowledge, acquired without direct help from others (Johnston, 1992). It is the accumulated wisdom of teachers on the basis of their experiences, which they can immediately use in their own teaching practice (Carter, 1990; Beijaard & Verloop, 1996).
2. It is *person- and context-bound*. It allows teachers to achieve the goals they personally value (Johnston, 1992). In addition, practical knowledge is affected by teachers' concerns about their own teaching context. Thus, practical knowledge is situation-specific, as it is adapted to a context which includes the students, the coursebooks and other learning materials, the curriculum, the school culture, and so on. This context may also vary considerably across countries (Stigler, Gallimore, & Hiebert, 2000). Also, the teachers' disciplinary background appears to play an important role in this respect. Especially in secondary and higher education, a teacher's professional identity formation is strongly determined by the subject he or she teaches (Sikes et al., 1991).
3. It is, to a great extent, implicit or *tacit* knowledge. Teachers are not used to articulating their practical knowledge: they are more in a "doing" environment, than in a "knowing" environment (Clandinin, 1986; Eraut, 1994). Consequently, developing a shared knowledge base seems to be more problematic for teachers than for professionals in other fields.
4. It is *integrated* knowledge: scientific or formal knowledge, everyday knowledge, including norms and values, as well as experiential knowledge are part of practical knowledge (Handal & Lauvas, 1987). The process of knowledge integration is guided by experiences which play a key role in the development or change of teachers' practical knowledge. Through this process, practical knowledge encompasses elements of formal knowledge, adapted to the teaching context. Such elements may be derived from the teacher's prior formal education, as well as from inservice schooling activities (Beijaard & Verloop, 1996). However, researchers still only minimally understand how teachers integrate knowledge from different sources into the conceptual frameworks that guide their actions in practice (Eraut, 1994).
5. In building practical knowledge, teachers' *beliefs* play a very important role. As part of practical knowledge, both beliefs and knowledge are closely interwoven, but the nature of beliefs make them the filter through which new knowledge is interpreted and, subsequently, integrated in conceptual frameworks (Pajares, 1992). Beliefs, therefore, play a central role in organizing knowledge and defining behavior (Richardson, 1996). Beliefs may refer to pedagogical values as well as to teaching a specific subject or issue. Such beliefs are influenced by, among other things, a teacher's biography, for instance, by their own teachers, by raising their own children or by their disciplinary background.

One implication from the above description concerns the importance of the subject teachers teach in their practical knowledge. In this respect, it is relevant to discuss the concept of pedagogical content knowledge (PCK), which has been introduced as an element of the knowledge base for teaching (Shulman, 1986). PCK has been described as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8). It refers to a transformation of the subject matter knowledge, used by teachers in the communication process with learners. PCK consists of two key elements: knowledge of instructional strategies incorporating representations of subject matter, and understanding of specific learning difficulties and student conceptions with respect to that subject matter (Van Driel, Verloop, & De Vos, 1998). As PCK refers to *particular topics* it is to be discerned from the knowledge of pedagogy, of educational purposes, and of learner characteristics in a general sense. Moreover, because PCK concerns the *teaching* of particular topics, it may turn out to differ considerably from subject matter knowledge per se. Finally, PCK is developed through an integrative process rooted in classroom practice implying that prospective or beginning teachers usually have little or no PCK at their disposal. In light of our conceptualization of practical knowledge presented earlier in this article, it follows that PCK may be perceived as a central element within teachers' practical knowledge (cf. Cochran, DeRuiter, & King, 1993).

In recent years, research in the domains discussed above has significantly promoted our understanding of the content of teachers' knowledge and beliefs, and of the relations between the elements that form teachers' cognitions. However, at this time it is not possible to characterize research on teachers' practical knowledge unequivocally. A wide range of research has already been done on teachers' practical knowledge, on teachers from different disciplinary backgrounds and countries, focusing on different aspects of a teacher's work, such as student learning, teaching of specific subject matter, collaboration with colleagues, school culture, and educational change. To understand the scope of the research on practical knowledge, we will now discuss the rationale and methodological approaches used by different investigators.

Research Rationale and Methodological Approaches

Most research on teachers' practical knowledge takes place within the hermeneutic or interpretative scientific research tradition. The studies within this tradition are usually small-scale and in-depth. Many researchers embed their studies in a narrative research approach. The underlying assumption is that narratives are not only crucial for providing insight into what teachers think and do, they also help teachers to make sense of what they think and do. Narrative research can be seen as a means of understanding teachers' culture from within (Cortazzi, 1993), by making use of personal materials such as life story, conversation, and personal writing (Connelly & Clandinin, 1990; Elbaz-Luwisch, 1997; for an example of a study in science teaching, see Osborne, 1998). The ways researchers structure their studies differ considerably. Some focus on the teacher's story applying a very loose way of collecting data, sometimes without any advance theoretical structuring of the study, whereas other researchers determine in advance which aspects of practical knowledge they want to investigate and, subsequently, use more structured methods of data collection. This is not the place to discuss and assess the various types of research on teachers' practical knowledge in detail. However, we consider it problematic if researchers merely let teachers 'talk' without interpreting their stories in terms of similarities and differences between them. We agree with Tom and Valli (1990) that such research merely leads to a collection of idiosyncratic teacher narratives, without any reference to scientific theory.

From our point of view, research on practical knowledge should aim to identify common patterns in the practical knowledge of individual teachers, and in the development of this knowledge. As a result, research in this domain can lead to the establishment of a body of knowledge which constitutes an addition to existing scientific knowledge bases for teaching (Verloop, 1992). This body of knowledge may function as a "framework for helping prospective and experienced teachers develop their repertoire of responses, understandings, and magical tricks'' (Grimmett & MacKinnon, 1992, p. 441). Thus, codifying practical knowledge can help to bridge the gap between the theory and practice of teaching. For example, the results of such research may be used as case material in teacher education, and as an important source for prospective teachers to reflect upon.

To achieve this aim, various instruments and procedures have been developed to investigate teachers' knowledge and beliefs in a valid and reliable manner. In her review of methods for investigating teachers' cognitions, Kagan (1990) is rather critical of research designs in which only one method or instrument is applied. She argues that such designs are problematic, because the complexity of a teacher's practical knowledge cannot be captured by a single instrument. Instead, Kagan suggests applying multimethod designs, which focus on specific, well-defined aspects of teachers' knowledge and beliefs (e.g., PCK of particular topics). For instance, adequate designs may include Likert-type questionnaires, in combination with interviews and experimental tasks (cf. Peterson, Fennema, Carpenter & Loef, 1989), or structured interviews, combined with teachers' logs, transcripts of actual lessons, and stimulated recall (cf. Smith & Neale, 1989). Kagan recommends the use of techniques that ''yield qualitative, molar descriptions'' and concludes that ''the use of multimethod approaches appears to be superior, not simply because they allow triangulation of data but because they are more likely to capture the complex, multifaceted aspects of teaching and learning'' (Kagan, 1990, p. 459).

A recent example of a study in which these suggestions have been applied, is found in Meijer (1999). To capture experienced teachers' practical knowledge about teaching reading comprehension in secondary education, Meijer used three instruments: (a) a semi-structured interview to elicit ideas about all possible aspects of teaching reading comprehension, (b) concept mapping, in which teachers organized and explained concepts that they viewed as important in this domain, and (c) stimulated recall interviews, in which teachers explicated what they were thinking in response to the videotape of a lesson they had just given. In a triangulation procedure, the data obtained with these instruments were combined to develop a comprehensive view of teachers' practical knowledge in the specific area of reading comprehension. It was concluded that this approach had been fruitful, as the combination of data from different sources had led to the identification of three types of practical knowledge, which could be described in detail (Meijer, 1999, p. 107).

All of the methods described so far can be used to capture teachers' practical knowledge at one point in time, or in a particular period. Obviously, in the context of curriculum reform, it is often relevant to monitor changes in teachers' practical knowledge. On the basis of her review, Kagan (1990) concludes that techniques to measure short-term changes in teachers' beliefs often suffer from a lack of ecological validity. She suggests that this may be due to short-term conceptual change being ''superficial and ultimately transient'' (Kagan, 1990, p. 459). A technique that has been applied frequently to investigate changes in teachers' practical knowledge, is the repeated use of concept mapping. Although Kagan is critical about how this method has been applied in many studies, she recommends the use of free-style concept maps at specific points in time, in combination with additional data sources (e.g., lesson plans, stimulated recall, or written self-evaluations). When these data sources are triangulated, an increase in the complexity of the concept maps may be indicative of an increased understanding of the topic under consideration.

A relatively new technique for investigating practical knowledge about relevant experiences and events throughout a teacher's career, is the so-called story-line method (Gergen, 1988). Beijaard et al. (1999) applied this technique in three different studies, focusing on teachers' subjective evaluation of experiences and events which pertain to a particular aspect of teaching (e.g., their interaction with students) for a period of time (e.g., the number of years they work as a teacher). By drawing a story line, teachers describe their evaluation of the aspect under consideration, on a scale from positive to negative as a function of time. Next, they are asked to clarify, in writing or orally, the high(est) and low(est) points in their story lines. Beijaard et al. concluded that the story-line method can be used efficiently and satisfactorily if certain conditions are met (e.g., addressing a limited number of aspects of teaching, drawing story lines from the present to the past). In particular, the authors value the fact that this method enables teachers to evaluate and interpret crucial experiences themselves, as an alternative to methods in which this evaluation is done by the researcher.

Science Teachers' Practical Knowledge

In this section, the attention is shifted toward science teachers' practical knowledge. For this purpose, we have selected studies in which science teachers' knowledge and beliefs are explicitly related to their classroom practice. It should be noted, however, that the expression "practical knowledge" is not used by all the scholars whose work is discussed below. From studies of *experienced* science teachers' cognitions it follows that these teachers have developed a conceptual framework in which knowledge and beliefs about science, subject matter, teaching and learning, and students are integrated in a coherent manner. Moreover, their teaching behavior usually seems consistent with this framework (Brickhouse, 1990). Individual teachers, however, may have developed quite different frameworks or "functional paradigms," even when they teach the same curriculum (Lantz & Kass, 1987). Tobin and McRobbie (1996) have identified four "cultural myths" which guide the classroom practice of experienced science teachers. Among other things, these myths concern the belief that teaching in a transmissive mode is more effective than the use of innovative teaching approaches, in which the emphasis is on facilitating and guiding student understanding, and the feeling that the mandated curriculum dominates classroom practice. From an innovative point of view, these myths are to be considered as impediments to change. For *beginning and prospective* science teachers a different picture emerges. The practical knowledge of these teachers often consists of elements which are not integrated. As a result, these teachers often seem to experience conflicts between their personal beliefs about science and science teaching on the one hand, and their own actual classroom practice on the other hand (Roberts & Chastko, 1990; Brickhouse & Bodner, 1992; Powell, 1994; Simmons et al., 1999).

Below, studies on specific aspects of science teachers' practical knowledge are discussed. This concerns studies on knowledge and beliefs about the teaching and learning of science, and about the nature of science. Next, studies on science teachers' beliefs about reform in science education are addressed. Finally, research on science teachers' PCK is discussed.

Practical Knowledge of the Teaching and Learning of Science, and the Nature of Science

Many studies on specific aspects of science teachers' practical knowledge have focused on views about the teaching and learning of science. These studies were usually conducted in the context of the implementation of constructivist teaching approaches. Some of these studies focused on the effects of inservice or preservice programs on teachers' views of teaching and learning science (e.g., Constable & Long, 1991; Hand & Treagust, 1994; Porlán Ariza & García Gómez, 1992), sometimes in connection with views on teaching science to students from various cultures (Southerland & Gess-Newsome, 1999). From the perspective of practical knowledge, studies focusing on the actual implementation of constructivist approaches in classroom practice are particularly interesting. These studies have revealed that although teachers may express cognitions about the teaching and learning of science which are consistent with constructivist ideas, their actual classroom behavior may be more or less 'traditional' (Briscoe, 1991; Johnston, 1991; Mellado, 1998). However, some studies reported changes in both teachers' cognitions and their classroom practice in the direction of constructivist ideas. These changes seemed to take place on the conditions that sufficient time, resources, and on-going professional support are available (Appleton & Asoko, 1996; Glasson & Lalik, 1993; Tobin, 1993; Radford, 1998). Hewson, Tabachnick, Zeichner, and Lemberger (1999) concluded, on the basis of a series of studies of prospective biology teachers, that specific courses within a teacher education program may substantially promote teachers' adoption of constructivist views. To help teachers to put these constructivist ideas into practice, a close cooperation between schools and universities is necessary. Adams and Krockover (1999) also reported positive outcomes in a 3-year case study of a beginning secondary biology teacher, in which a specific observation rubric was used to stimulate a constructivist teaching style.

Another strand of research on science teachers' practical knowledge is devoted to cognitions about the nature of science (Lederman, 1992). As understanding of the nature of science is a central goal of many current reform efforts, teachers' cognitions in this domain are, of course, crucial. In general, however, these studies amount to the conclusion that, irrespective of their academic background, science teachers possess limited knowledge of the history and philosophy of science (Gallagher, 1991; King, 1991) and, as a consequence, hold inadequate or naive conceptions of the nature of science (Abd-El-Khalick & BouJaoude, 1997). For example, many teachers appear to hold positivist views, believing that the substantive content of science is fixed and unchangeable rather than tentative. Moreover, it has been repeatedly found that teachers' conceptions of the nature of science "do not necessarily influence classroom practice" (Lederman, 1999, p. 927). In a review of teacher education progams aimed at improving science teachers' conceptions of the nature of science, Abd-El-Khalick and Lederman (1999) concluded that explicitness and reflectiveness with respect to the nature of science are the most important features of programs that appeared successful in facilitating teachers to develop conceptions of the nature of science that are consistent with those advocated by current reforms, and to translate these conceptions into an appropriate classroom approach.

Beliefs about Reform in Science Education

Given the importance of teachers' beliefs with respect to their teaching behaviors, several scholars have investigated teachers' beliefs about science education reform. The identification of teachers' beliefs is considered to be critical to the reform process. Lumpe, Haney, and Czerniak (2000) concluded that, in particular, teachers' capability beliefs in combination with their beliefs about their science teaching context are "the more precise agents of change" (Lumpe et al., 2000, p. 288). Cronin-Jones (1991) identified four categories of beliefs, which strongly influenced curriculum implementation. These categories concerned the teacher's own role, the way students learn, the abilities of particular groups of students, and the relative importance of content topics. When implementing a new curriculum, teachers appeared to adapt this curriculum according to their own context and beliefs.

Yerrick, Parke, and Nugent (1997) investigated the beliefs and knowledge of a group of experienced science teachers ($n = 8$) during a 2-week summer course, intended to prepare teachers to implement an inquiry-oriented science curriculum. The authors reported that teachers "began to use different ways of speaking about students and content (. . .) without changing fundamental views of science and teaching" (Yerrick et al., 1997, p. 14). Rather than accusing these teachers of conservatism, the authors discussed the "real dilemmas" which teachers encountered when they attempted to change their classroom practice. The authors concluded by expressing the desire to continue to collaborate with teachers, and ‘‘to continue to listen to the impact of reform in the classroom setting and then use what we hear to make shifts in staff development design’’ (Yerrick et al., 1997, p. 156).

Several studies have been carried out in the context of projects of local systemic science education reform. In a study aimed at assessing the impact of such a program, Levitt (2000) found that experienced teachers espoused certain non-traditional beliefs about teaching and learning of science. These beliefs concerned the use of hands-on activities, discourse and collaboration, and inquiry approaches. Similar results were obtained by Haney et al. (1996). In Levitt’s study, it was also found that teachers’ practices began to align with these beliefs. However, the change in teachers’ beliefs was deemed ‘‘not yet strong enough.’’ Levitt concluded that continuing professional development activities are necessary to sustain and elaborate the changes in teachers’ beliefs and practices. Haney et al. (1996) suggested that such activities should be organized at a local level in a concrete and project-like manner.

Whigham, Andre, and Yang (2000) investigated the beliefs of science and mathematics teachers with respect to teaching activities that were either consistent or inconsistent with the national standards for science or mathematics education (cf. NRC, 1996). They found that teachers expressed a higher degree of belief in, and greater classroom use of, standards-consistent activities than standards-inconsistent activities. At the same time, however, many teachers, especially secondary science teachers, also expressed a strong commitment toward standards-inconsistent activities. For instance, most teachers believed that they should focus on student understanding, whereas they also believed that the curriculum should focus on student acquisition of information. These apparently inconsistent belief systems were explained by the authors in terms of science teachers struggling with the tension of pursuing science topics in depth, as required by the standards, versus pressure to ‘‘get through’’ the breadth of the provided curriculum materials. They suggested that teachers might benefit from inservice training, aimed at conceptual change instruction on the standards.

Science Teachers’ PCK

A distinct group of studies concerns science teachers’ PCK. Some of these have emphasized the importance of teachers’ understanding of subject matter, which appears to function as a prerequisite before the development of PCK can take place. Smith and Neale (1989), for example, studied the effects of an inservice workshop for elementary teachers, and concluded that this program had been successful in terms of promoting teachers’ knowledge of specific contents, but not with respect to the development of PCK. The authors concluded that unless teachers have acquired a ‘‘deeply principled conceptual knowledge of the content,’’ the development of PCK is unlikely to occur (Smith & Neale, 1989, p. 17). From studies of experienced science teachers who taught topics outside their area of certification, it appeared that their general pedagogical knowledge provided them with a framework for teaching. The teachers in these studies quickly learned the new content as well as adequate content-specific instructional strategies. Sanders, Borko, and Lockard (1993) concluded that teachers integrated content knowledge and PCK in their pedagogical knowledge frameworks. In other words, it appears that both general pedagogical knowledge and subject matter knowledge can form a basis on which teachers build the development of their PCK.

The most important factor in the development of PCK is, obviously, teaching experience. For instance, Clermont, Borko, and Krajcik (1994) found that experienced chemistry teachers possessed a greater repertoire of representations and strategies of a particular topic than novices when they used chemical demonstrations as an instructional strategy. Moreover, experienced teachers were able to use certain demonstrations for various purposes, and were more successful in relating their demonstrations to specific learning difficulties of students. However, experienced science teachers' PCK may differ considerably, even when their subject matter knowledge is similar and when they teach the same curriculum. These differences are reflected by different representations and instructional strategies used in the classroom. A lack of teaching experience explains why prospective or novice science teachers usually express little to no PCK (e.g., Lederman, Gess-Newsome, & Latz, 1994). Teacher training programs are not always very successful in promoting the development of science teachers' PCK (e.g., Adams & Krockover, 1997).

Discussion and Implications

In summarizing the results of research on science teachers' practical knowledge, we may conclude that experienced science teachers, as opposed to beginning teachers, have developed an integrated set of knowledge and beliefs, which is usually consistent with how they act in practice. Factors such as the mandated (national) curriculum, and the school culture seem to determine, to a large extent, the content of their practical knowledge. Consequently, in the context of curricular change, several problems may occur. First, teachers may not possess adequate knowledge of the new content (e.g., the nature or philosophy of science) or pedagogy (e.g., conceptual change teaching) to be implemented. Second, teachers' beliefs with respect to the new content or pedagogy may differ from the intentions of the innovation. For that matter, it seems that ''traditional'' staff development programs, such as short-term intensive workshops can be successful in upgrading teachers' content knowledge, and in their acceptance of the ideas behind an innovation.

However, when teachers are asked to put an innovation into practice, problems are reported in all studies. For instance, inconsistencies often occur between teachers' expressed beliefs and their behavior in the classroom. It seems that long-term staff development programs are needed to actually change experienced teachers' practical knowledge. Given the nature of practical knowledge as integrated knowledge which guides teachers' practical actions, this is not surprising. From this perspective, an innovation implies not simply adding new information to existing knowledge frameworks; in fact, teachers need to restructure their knowledge and beliefs, and, on the basis of teaching experiences, integrate the new information in their practical knowledge. In the following section, types of staff development programs are discussed which have the potential to stimulate this complex process.

Reform and Professional Development Focusing on Teachers' Practical Knowledge

We perceive staff development or professionalization as a permanent process, aimed at extending and updating the professional knowledge and beliefs of teachers in the context of their work. With respect to reform efforts, we agree with Wallace and Louden (1992) that the focus ''should be on facilitating the growth of the knowledge teachers have and use'' (p. 518). In other words, the implementation or ''scaling up'' of a reform is ''a process of learning rather than a process of design and engineering'' (Thompson & Zeuli, 1999, p. 371). From research, it has become clear that there is not one 'ideal' way to organize staff development in the context of a reform project. Rather, multiple strategies are necessary to promote changes in teachers' knowledge and beliefs. These strategies may include: access to innovative classroom materials, opportunities to practice new ways of teaching, reflection on practical experiences, possibilities to discuss elements of the reform with others (peers, coaches, supervisors), a supportive environment, and so on (Haney et al., 1996). Below we will discuss some strategies aimed at changing teachers' existing practical knowledge (for a more detailed description of these strategies, see Beijaard, Verloop, Wubbels & Feiman-Nemser, 2000). The elements shared by these strategies include: (a) an explicit focus on teachers' knowledge and beliefs, throughout all stages of the reform, (b) collegial cooperation or exchange between teachers, and (c) sufficient time for changes to occur, from at least one semester to several academic years.

Learning and Professional Development in Networks

In the last decade, collegial learning in school networks has emerged as a way to promote professional development (Huberman, 1995). It is generally agreed that the natural resistance to change and innovation, particularly by experienced teachers, can be reduced by learning in networks. Such networks are more or less formalized structures in which participants from different schools aim to achieve previously formulated objectives for a particular period of time. In networks, participants systematically learn from and with each other as colleagues. In other words, networking is characterized by "horizontal learning" as opposed to "vertical learning," that is, learning conducted by an external expert. Empirical research on this kind of teacher learning is beginning to appear (e.g., Galesloot, Koetsier & Wubbels, 1997; Ryan, 1999). This research has shown that learning in networks may be particularly effective when teachers share similar school tasks, but have different experiences performing these tasks in their own schools. Specific results of learning in networks could refer to a growth in teachers' confidence in the value of their own practical knowledge for other teachers, and an increase in willingness to experiment with ideas from colleagues in their own classrooms. In this respect, it seems that external conditions, such as available time, need to be related to internal or personal conditions (e.g., one's expectations of a network and prior experiences) so as to create an environment of willingness to learn and to experiment.

It is important for future research to focus not only on how and what teachers learn in networks, but also on the requirements and conditions that have to be met to establish well-functioning horizontal learning in a network as a relatively new structure in continuing education. For instance, conversations about practice in network settings are not necessarily productive. Thus we need to know what it is that can make such conversations useful.

Peer Coaching

Horizontal learning takes place not only in networks, but in other settings as well; for example, through peer coaching. Peer coaching can be seen as a process of cooperation between two or more colleagues in which they exchange ideas, attempt to implement these ideas, reflect on their own teaching practice, and so on. Peer coaching requires interaction on an equal basis. Moreover, a strict separation from performance evaluation must be guaranteed. Being a coach for a colleague calls for a systematic approach agreed upon by all participants. This concerns, for example, the way feedback is given on a lesson observed by the coach. A teacher acting as a coach contributes not only to the professional development of a colleague, but to his or her own professional growth as well (Bergen, 1996; Philips & Glickman, 1991). In general, collegial coaching can be considered a rather simple strategy. In reality, it may have a great impact on how teachers function in schools: most teachers are "professionals in isolation," and are not used to talking about their work (Clandinin, 1986). Peer coaching, therefore, also implies that certain working conditions are met and implemented by school leaders, so that it becomes part of the school culture.

Collaborative Action Research

Collaborative action research projects can be designed as a specific form of staff development in the context of the implementation of an innovation. Although there are many variations of action research, the aim is always to yield practical, applicable results, for either personal, professional or political purposes (Noffke, 1997). Action research can have various theoretical orientations (e.g., technical, practical or emancipatory), and can imply different types of reflection (e.g., autobiographical or collaborative; Rearick & Feldman, 1999). Common features of collaborative action research include control or ownership of the specific questions or problems teachers want to explore and the actions they carry out (e.g., developing materials, gathering information, and collecting data), in combination with group activities, such as sharing experiences and discussing or evaluating results (Cohen & Manion, 1994). The group, which may be supported or facilitated by educators or university-based researchers, constitutes a context in which the activities of individual teachers are embedded. In the case of the implementation of an innovation, the group may have a common goal, but each individual teacher is stimulated to explore this goal according to his or her own context, teaching situations, individual beliefs, and so on.

Feldman (1996) applied this approach in a group of eight physics teachers during a 3-year project. Activities included anecdote telling as a tool for teachers to share their knowledge, trying out new ideas about teaching and learning in the classroom, and systematic inquiry. Feldman concluded that since these activities were closely connected to the normal practice of the participants, they have the potential to be embedded in the practice of other science teachers, leading to the enhancement of this practice. Bencze and Hodson (1999) arrived at similar conclusions after an action research project in which two teachers and a researcher/educator cooperated in the design and implementation of more authentic science for Grade 7 classrooms. In addition to other results, the project led to changes in the teachers' views about science and science teaching.

Lynch (1997) studied the effects of a collaborative project on a group of 25 beginning science teachers who were preparing for the science education reform advocated by AAAS (1993) and NRC (1996). The project consisted of a series of 3-hour-long seminars. During these seminars the intentions of the reform were discussed in relation to the participants' ideas and beliefs. Next, teachers developed their own criteria, as a tool to make sense of the reform. Finally, teams of three teachers were formed, who designed 10-day teaching units. Although these units were not actually taught, the project apparently helped the teachers to make sense of, and appreciate, the goals of the reform. In particular, the teachers' criteria appeared to be a useful tool, which they used afterward to review the goals of the reform, and specific teaching materials. Lynch concluded that developing these criteria contributed to the development of the teachers' PCK.

Parke and Coble (1997) have taken the collaborative action research approach a step further by involving teachers in curriculum development activities, which became a vehicle for professional development. Parke and Coble designed an approach in which teachers communicated continuously with colleagues as well as university staff. The development of curriculum materials was preceded by a dialogue about the reform goals. Next, in the organization of the curriculum development activities, attention was given, in particular, to the alignment of the curriculum materials teachers developed with the personal beliefs they articulated, and the school environment in which the curriculum was to be implemented. On the basis of a study involving science teachers from seven schools, Parke and Coble concluded that their approach "supported teachers to become architects for change through building upon their current conceptions instead of attempting to remediate them" (Parke & Coble, 1997, p. 785).

The Use of Cases

The use of cases as a tool to promote the development of professional knowledge of teachers has been advocated by Shulman (1986). Cases are short narratives, usually written in first-person, describing authentic or realistic classroom situations. Most cases concern problematic situations, for instance, illustrating typical problems that can occur during the teaching of specific issues. Darling-Hammond and Snyder (2000) described several professional development contexts in which cases were used. They also wrote about problems which may occur when using cases, for instance, (1) a case writer's or case user's limited knowledge or frame of reference for an adequate analysis of the nature of the issue addressed in the case, and (2) a case writer's or case user's lack of ability to generalize from the single instance represented in the case to a well-grounded set of principles for interpretation of practice. Darling-Hammond and Snyder described examples of cases, in which these problems were avoided.

In a review of the *Mathematics Case Methods Project*, Barnett (1998) concluded that teacher-authored cases can be a powerful tool to discuss content-related, pedagogical and philosophical issues in groups of teachers and university-based facilitators. Among other things, this approach appeared to stimulate (1) teachers' own understanding of mathematics, (2) the use of a student perspective as a source of feedback, and (3) a critical examination of alternative views. The latter results are relevant in particular for the development of PCK. Essential to the case-based approach was the goal to have teachers expose different ways of looking at things, rather than to impose specific views upon them.

In the field of science education, some scholars have reported that the use of vignettes which focus on content-specific teaching approaches, or on students' reasoning and misconceptions concerning a specific topic, may contribute to the development of PCK (Loughran, Gunstone, Berry, Milroy, & Mulhall, 2000; Veal, 1998). For instance, when teachers analyzed students' reasoning in such vignettes in relation to their own teaching experiences and discussed their analyses with their peers, they were stimulated to develop representations and instructional strategies with respect to the specific topics under consideration (Geddis, 1993; Van Driel et al., 1998).

Concluding Remarks

From the research discussed in this article, it follows that the practical knowledge of experienced teachers consists of an integrated set of beliefs and knowledge, which is often implicit. The research literature does not suggest, however, that this practical knowledge cannot be changed. Various methods may be applied to change teachers' practical knowledge in the course of a reform project. Preferably, a combination of methods should be used in this respect. In any case, professional development activities and reform should be linked firmly throughout all stages of any reform project.

An essential characteristic of the strategies described in the last section is that a teacher's practice and his or her personal knowledge of this practice constitute the starting point for change. Consequently, one needs to investigate the practical knowledge of the teachers involved, including their beliefs, attitudes and concerns, at the start of a reform project (cf. Haney et al., 1996). Rather than recommending a few specific techniques, we suggest the use of multimethod designs (cf. Kagan, 1990). Obviously, the teachers' existing practical knowledge should not be considered as the norm per se. In attempts to change this knowledge, however, one should realize that the role of a teacher's practical knowledge in the context of educational reform is complex and multifaceted:

- When teachers' actual cognitions are deemed incompatible with specific ideas behind educational reform, one may attempt to create cognitive dissonance among teachers (Ball & Cohen, 1999; Thompson & Zeuli, 1999). For this purpose, strategies may be used which are similar to those in the conceptual change literature (e.g., Posner et al., 1982). Next, teachers may alter their conceptions when alternatives are in reach, which are vivid, concrete, and detailed enough to become plausible and attractive (Feiman-Nemser & Remillard, 1996).
- Some of the teachers' cognitions can be used as a source of inspiration in the design of the reform, in particular when teachers with rich expertise (cf. "wisdom of practice"; Shulman, 1987) are identified. For instance, this may occur in the context of developing curriculum materials.
- Occasionally, when a large gap is identified between innovative ideas and the practical knowledge of a vast number of teachers, one may arrive at the conclusion that the reform needs to be redefined, for instance, at a lower level of ambitions. In other words, an investigation of teachers' practical knowledge may reveal what can be achieved within the reform project.

In the course of a reform project, it is necessary to monitor the practical knowledge of the teachers to investigate the progress of the reform. Moreover, this makes it possible to adjust the project so as to enhance the chances of successful implementation.

The apparent success of some of the approaches discussed in the last section (e.g., Lynch, 1997; Park & Coble, 1997) supports our view that teachers should be involved substantially in all phases of a reform effort. Partnerships between teachers, educators, researchers, and administrators are necessary to facilitate such approaches. Moreover, time is needed, because the approaches we advocate here are not likely to bring about change in teaching practice rapidly, but rather they should lead to authentic change (cf. Thompson & Zeuli, 1999). Future research on the effectiveness of approaches like these may contribute to the design of successful reform projects in science education, in close conjunction with strategies for professional development.

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