CHAPTER 38

Teacher Professional Development in Science

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Professional development for science teachers is of considerable current importance. This is an era in which, around the world, a new vision of learner-centered instruction is being developed. This grows out of a major, extended research enterprise over the past quarter-century. The focus of attention on what learners know and can do when they enter classrooms, and how this influences the instruction that they receive, has led to significant advances in our understanding of student learning and the implications this has for teaching. In parallel with these reforms, there has been a major push to develop new curricula and to identify explicit standards that together represent significant changes in what it is that students are expected to learn and do. A third circumstance of considerable importance is the increasing recognition of the systemic nature of the educational enterprise, arising in part from the difficulties experienced by reformers who sought to introduce new curricula and new teaching approaches. Aligning different components of educational systems is not a straightforward matter and has led to the investment of large amounts of resources for systemic reform. A notable example in the United States is the large number of Systemic Initiatives funded by the National Science Foundation (NSF) throughout the last decade of the twentieth century (see Chapter 30, this volume): a considerable portion of their budgets funded teacher professional development activities. Another circumstance that has considerable implications for teacher professional development is the growth of more extensive testing of students at all levels. Most, if not all, states in the United States have instituted their own proficiency tests and use these to judge the quality of schools and teachers. Furthermore, the No Child Left Behind legislation in the United States extended these testing requirements throughout the country. In part, these initiatives have been driven by international studies, such as the Third International Mathematics and Science Study and the Programme for International Student Assessment, that have raised issues of national performance. In a number of countries, the perception of inadequate performance has been a driving force for reform.

There are several arguments to be made to support the idea that responses to these national and international circumstances should necessarily, if not exclusively, focus on practicing teachers and their professional development. The first argument addresses the question, why focus on teachers? There is currently a broad consensus that teachers play a central, key role in any model of educational improvement. We are long past the era of so-called teacher-proof curricula. We have also tried, and found wanting, the assumption that teachers could be replaced by computers. Much of this recognition has come from recent research into the nature of a teacher's practice and expertise. What teachers do is not a formulaic following of rules, but nuanced, professional practice in which teachers constantly make important decisions and judgments in how they interact with their students to facilitate their learning. What this means is that if teachers are not involved, educational reform will not happen.

A second argument addresses the question, why not put our efforts into initial teacher education? If the teaching profession as a whole has to change its practices, this cannot happen solely through the introduction of new teachers into the profession. There are several reasons for this. If a teacher's effective teaching life is 25 to 30 years, the proportion of new teachers entering the profession each year is a small subset of the total teaching force. In other words, it will take a long time to change the teaching force if this is the sole means by which it is done. It is also the case that new teachers enter the profession without much power. Their veteran colleagues have experience and expertise that they do not have, and the likelihood that new teachers will be able to teach in different ways and perhaps influence their colleagues is small.

A related argument is that it is an optimistic assumption that all teacher preparation institutions will certify teachers who are fully capable of teaching in ways that are consistent with current reforms. Another argument is that internationally there are many countries where the current teaching force is poorly qualified. This may be due to a lack of resources for teacher education, or the country may have only recently moved to expand its education to all children, thereby creating the need to produce many teachers very rapidly. Under the circumstances, it is clear that the quality of new teachers will be severely compromised.

A final argument addresses the question, why focus on teacher professional development for practicing teachers? This is necessary because in the current climate of reform, teachers' practices, even when they were highly effective at an earlier stage, may be in need of reconsideration and updating. In other words, as the educational context changes, teachers' existing practices and beliefs may not be well matched with the revised demands of new reform efforts.

The focus, then, of this chapter is teacher professional development in science. First, I identify the meaning of teacher professional development in science as used in this chapter, followed by several comments on the specific boundaries of the term as it is adopted in this chapter. Then, I consider some general comments on the difficulty of doing research in this area. Next, I outline three different perspectives on teacher professional development in science; these focus respectively, though not exclusively, on the various aspects of teachers' personal, social, and professional development; what it is that teacher professional developers attend to and do; and the enactment of teachers' professional development in their classrooms. Then, I review specific studies that connect professional development activities on the one hand with the teacher participants in these activities, and on the other hand with learning outcomes of students in the classrooms of teacher participants. The chapter concludes with a discussion of issues raised by the review.

DIMENSIONS OF TEACHER PROFESSIONAL DEVELOPMENT IN SCIENCE

What is teacher professional development in science? First, it is about teachers and their teaching activities involving curriculum, instruction, and assessment; about their students and their learning; and about the educational system in which they practice. Second, it is about teachers being professionals who have an extensive knowledge base of conceptions, beliefs, and practices that they bring to bear on the unique complexities of their daily work lives, a knowledge base that is shared within a professional community. Third, it is about teachers as adult learners who have an interest in and control over the continuing development of their professional practice throughout their working lives, a process that is greatly facilitated by working in community with their peers. Finally, it is about science and the epistemologies, methodologies, and bodies of knowledge about the natural world that give scientific disciplines their distinctive character.

What are the boundaries of teacher professional development in science as used in this chapter? Focusing first on professional development, an obvious answer would be to include only professional development activities themselves and the teachers who participate in them. An alternative viewpoint is to recognize that the ultimate purpose in providing professional development is the improvement of student learning. This, then, leads to the conclusion that the connection between professional development activities themselves and student learning should also be included. The problem with such a perspective is that this connection is lengthy and complicated; it is also difficult to separate it out from many other issues. Increasingly, however, professional developers are being called upon to evaluate their programs in terms of student learning. For these reasons it is necessary to expand the domain of professional development from a tidy, focused, coherent perspective on professional development activities and participants to include the complex, intertwined connection to student learning.

I have included only those research studies that focus on practicing teachers, as distinct from those involved in initial teacher education. Studies of prospective teachers involved in initial teacher education are examined elsewhere in this volume (see Chapter 37). Although this is a convenient division that reflects the reality that initial teacher education and inservice teacher professional development are most commonly different enterprises, it cuts through the important principle that teacher learning should be a continuum, something that happens across the whole professional life of a teacher (Feiman-Nemser, 2001). Although the emphasis and intensity of teacher learning change as teachers move from initial certification to their first teaching positions, there are important common features across these two phases that need to be preserved.

Next, I included only those studies that explicitly described a professional development program. This means that I excluded studies that only consider teacher learning and, possibly, its outcomes in teaching and student learning, or that consider teachers who are their own professional developers. In identifying this limitation it is necessary to recognize, but reject, a possible implication of the distinction this makes between programs and teachers, that is, that programs and the professional developers who run them are active providers, and the teachers who are participants in these programs are passive recipients. On the contrary, it is of the utmost importance to recognize that the focus of any professional development program is the teacher, and that it is teachers themselves who are responsible for their own professional development (Kennedy, 1999; Shapiro & Last, 2002; Wilson & Berne, 1999). Any activity should have the purpose of supporting teachers in taking responsibility for their own learning, in making the topics of teacher professional development their own, and in being active learners.

Finally, included studies needed to have an explicit focus on teachers of science. This requirement arises from the nature of this volume. It also has the practical effect of limiting the number of studies to be reviewed. It goes without saying that the specific character of science is an essential ingredient of student learning, of teacher practice, of teachers' professional development, and thus of programs designed to facilitate these outcomes. That being said, it is also the case that there are many aspects of professional development that are shared across disciplinary contexts, and thus there is much to be learned from literature that makes no reference to the subject matter of science. While not explicitly addressing this literature might be regarded as a significant limitation of this chapter, its influence is apparent, however, in many of the studies included.

Research on Teacher Professional Development in Science

What can be said about the nature of research on teacher professional development in science? The short answer is that it is complicated and difficult, because the object of study—teacher professional development in science—is itself inherently complex, consisting as it does of a number of interrelated components. Therefore it is necessary for research to focus on the nature of relationships between these components, while it concurrently explores each of these components in its own right.

Conceptually, research in this area is very difficult. Although the immediate focus is on the professional development activity itself and the teachers who participate in it, the ultimate purpose of professional development is the improvement of student learning. The pathways of influence of professional development from the original activity to student learning proceed through the intervening variables of teacher learning and classroom enactment. These pathways are complicated, not only by the time it takes for teachers to clarify their learning from professional development activities and translate this into effective curriculum and instruction, but also by everything else that is happening concurrently in the lives of students, teachers, schools, and the community; teacher learning in professional development activities, teachers teaching in classrooms, and student learning are not isolated from the educational and social environments of schools and communities.

There are also practical difficulties in conducting research in this area. Because of the number of components involved, the length of time it takes for teaching practice to mature, and the amount of detail and intensive research techniques required to provide understanding of what is happening at each stage of the process, the cost of effective research on and evaluation of teacher professional development can be substantial. Inevitably there is a trade-off between the costs of the evaluation and the value of the information that is obtained. A valuable approach adopted by the NSF in the United States has been to contract with one organization, Horizon Research, Inc., to develop a set of evaluation instruments that can be used across many projects that NSF has funded to reform the teaching of mathematics and science (Weiss, 1999).

A final comment is that, as always, there is a close relationship between research into a topic and evaluation of that topic, even though they are inherently different activities. This is particularly so because of the complexity of teacher professional development. Thus, in this chapter clear distinctions are not made between research and evaluation, and in some cases these terms will be used interchangeably.

Perspectives on Teacher Professional Development in Science

It is necessary to recognize two essential focal points when considering teacher professional development in science. One essential focus is on the *people* who are experiencing professional development—teachers of science—and the processes through which they are going. This is encapsulated in the language that teachers use—they talk about developing professionally. The question that arises from this focal point is: How do teachers develop professionally? The second essential focus is on the *programs* that have an explicit purpose of providing professional development to teachers. In most cases this means that one or more persons can be identified as professional developers whose purpose is to plan and implement activities for science teachers that are designed to further their professional development. Professional developers, likewise, use characteristic language: they talk about the professional development they are providing. The question that arises from this second focal point is: What is it that good professional developers do? As previously argued, however, it is necessary to follow the influence of programs into teachers' classrooms. Thus a third question to consider is: What is the relationship between teachers and professional development programs? These questions were addressed respectively in three studies that specifically considered the teaching of science, all of which produced theoretical frameworks that conceptualize these essential focal points.

How Do Teachers Develop Professionally?

This question was addressed in a three-year research project, the Learning in Science Project (Teacher Development), in New Zealand (Bell & Gilbert, 1996). In the project, teachers of science learned about and implemented teaching approaches designed with students' thinking and ideas in mind. During this time they experienced development of different kinds that were interwoven with each other. Bell and Gilbert modeled this in terms of personal, professional, and social development, and argued that, if development is to happen, teacher development programs must address all three of these components. In the project, a total of 48 teachers of science, both elementary and secondary, participated in four teacher development programs. Each program consisted of two-hour weekly after-school meetings over one or two school terms. In the meetings teachers shared their experiences of implementing new teaching activities that explicitly took account of students' thinking. The researchers collected multiple forms of data. In addition to that obtained in program meetings, the data included interviews, surveys, and classroom observations. Bell and Gilbert's model of teacher development is detailed in the following paragraphs.

In the initial phase, *Personal Development* involves teachers coming to realize that some *aspects of their practice are problematic*. This could be a slow process, starting with an inarticulate awareness that requires time to take shape. It could also be sparked by a specific event that crystallizes dissatisfaction. This realization then becomes the spur for teachers to seek ways to address the problem. There are, of course, many cases in which teachers get involved with programs even though they do not see their practice as problematic (e.g., a department chair has recommended attendance). Bell and Gilbert (1996) suggested that no progress happens without this phase of personal development. However, they pointed out that this is more likely to happen if teachers feel that overall their teaching is competent, with only a limited aspect being problematic. Related to this is *Social Development*, in which teachers become *aware of their professional isolation* from their peers and recognize that this, too, is problematic. This, then, helps to create a willingness to find ways of discussing their practice with others. A key element of this is the need to be able to trust that their peers will be supportive colleagues who offer critique in a nonjudgmental fashion. These developments support the initial phase of their *Professional Development* in which teachers are *prepared to try out new activities* in their classrooms. In doing so, they take on the role of teacher-as-learner, in which they become aware of the process of change and development; this is seen as a positive progression, the anticipated outcomes of which are better student learning and feeling better about themselves as teachers.

In the next phase, *Personal Development* involves *coping with the restraints inherent in teaching*. When new teaching activities and approaches are introduced, particularly if these give students more opportunities for input, the personal concerns include fear of losing control and not knowing when and how to intervene, uncertainty of the demands on their knowledge of the subject, worries about covering the curriculum and meeting assessment requirements, and concerns about dealing with students, parents, and others who may object to these changes. In this phase, *Social Development* involves teachers coming to *see the value of collaborating with their colleagues*. As trust in each other grows, teachers become more ready to share their experiences with each other, listen openly to their colleagues' suggestions and critiques, and offer their own ideas about ways to address questions, problems, and concerns. In the process, their own self-confidence and ability to reflect critically on their own practice grows. In effect, their collaboration involves their "renegotiating and reconstructing their shared knowledge about *what it means to be a teacher of science*" (Bell & Gilbert, 1996, p. 26, emphasis added). Their *Professional Development* in this phase manifests itself in *developing a more coherent practice*. Their conceptions of teaching science become more articulated, more nuanced, and more reflective. Their classroom practice becomes more flexible, more responsive, and more able to accommodate changes in appropriate ways. More importantly, they see the need to integrate their conceptions with their practice and thus to reconstruct what it means to be a teacher of science.

In the final phase in Bell and Gilbert's (1996) model of teacher development, *Personal Development* entails teachers *feeling more empowered* with respect to their own development. They come to trust that what they are doing will produce the outcomes they hope for, and that students will not let them down when they hand over control. Feelings of empowerment also extend to interactions with their colleagues: teachers feel good about contributing ideas and volunteering their time and energy. In this phase, *Social Development* takes place as teachers begin to initiate activities and relationships with their colleagues, thereby *fostering collaborative ways of working*. Closely related is the *Professional Development* they experience by seeking out or *initiating different development opportunities* beyond the programs in which they are involved.

The scenario outlined in the previous paragraphs is a plausible narrative of how the various phases of the three forms of development might be interwoven with each other. There is a progression through these phases as teachers initially see themselves as competent professionals who nevertheless have room for growth in some aspects of their practice. Next, as they learn new ideas, approaches, and activities, and become more self-aware, they reconstruct aspects of the practice, and they develop a new sense of being a teacher of science within their collegial group. A natural outcome of this development is that they feel empowered to take the initiative with respect to all three types of development. Bell and Gilbert (1996), however, emphasized that their model of teacher development is not a stage model. In other words, there are no requirements that teachers complete one phase before proceeding to the next, or that they have to go through each phase in their developmental journey.

What Is It That Good Professional Developers Do?

This question was addressed by the professional development team of the National Institute for Science Education in the United States. The team explored the nature of professional development practice through a process of collaborative reflection over the period of a year with five accomplished professional developers in science and mathematics (Loucks-Horsley, Hewson, Love, & Stiles, 1998). Rather than thinking of their practice as the refinement and use of models of professional development that others could easily adopt, these professional developers felt that their practice was more complex. Instead, it combined components of different models in programs that were changing over time and tailored to the particular circumstances in which they were working. In other words, they agreed that the practice of professional development is a process of design. On the one hand, professional developers have a set of purposes that they want to achieve. On the other hand, they are working in a particular context, with a particular group of teachers, in a set of circumstances that are unique to this particular project. The process of design requires that purposes be matched with context. Although this inevitably will require compromises, the intent is that these decisions will be made in order to maximize desirable outcomes. These reflections were summarized, albeit greatly simplified, in the form of a framework for the design of teacher professional development in science and mathematics. The specific components of the most recent version of the design framework for professional development in science and mathematics (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003) are elaborated in the following paragraphs.

The design framework has several major elements. First, there is a generic *planning process*, the steps of which are likely to be familiar to readers. These steps start with a commitment to a vision and a set of standards, and an analysis of student learning data; move on to the setting of goals, the planning and doing, or implementing, of professional development; and conclude with evaluation. Second, there are a series of *inputs* into the steps of the planning process. These inputs represent the knowledge and expertise about professional development that developers bring to the process of designing programs. They include *knowledge and beliefs* about all aspects of the process and participants of professional development, knowledge of the specific *context* in which the specific project will be implemented, knowledge and awareness of the range of *critical issues* that any professional development project needs to address, and a knowledge of the range of possible *strategies* that can be used within a professional development project to achieve its particular purposes. Third, these inputs are most salient for different steps of the planning process. For example, knowledge and beliefs will strongly influence the step at which professional developers commit to a vision of professional development, whereas it is only at the planning step that professional developers will be making decisions about which strategies to use. This is not to say, of course, that these inputs will be exclusively considered at these different steps. Rather, once inputs have entered the planning process, they will be considered in subsequent steps. Finally, there is feedback from the reflective evaluation of the project not only to the process of the project, thereby leading to improvements in the design itself, but also to the various inputs into the process that are as a result extended, deepened, and enriched. In other words, this is a dynamic framework.

The first of the four inputs into the professional development design process are the *knowledge and beliefs* that professional developers hold. There are five major knowledge bases that all professional developers are likely to consider when they are designing any professional development project. Of course, it is not the case that this will lead to identical designs. On the contrary, the outcome of the design will be strongly influenced by the specific content of these knowledge bases, and this will change as different theoretical orientations are adopted and further research with respect to each is carried out. The first two concern the principal players at the heart of an educational system and the activities that they are involved in. Thus, professional developers use knowledge of *learners and learning* on the one hand, and *teachers and teaching* on the other, in the design process. The third knowledge base concerns the substance, the content of what is being taught; in this handbook the focus is on the *nature of science*. The final two knowledge bases are directly related to the process of professional development itself: the *nature of professional development* and the *change process*. Current thinking in the field with respect to these five knowledge bases is considered in detail in Loucks-Horsley et al. (2003, Chapter 2).

The second of the four inputs into the professional development design process is the set of *context* factors influencing professional development. If design is the process of marrying theory with reality, and the knowledge and beliefs that professional developers bring with them are theory, then the reality of the particular project to be designed is rooted in the local context. Thus professional developers need to know the teachers that they will be working with and their learning needs, and these teachers' students, the standards they are expected to achieve, and what they currently know. They also need to know what the local curriculum is, the forms of instruction that teachers use, their assessment practices, and the learning environment in their classrooms. Professional developers will also need to know about the larger context in which these teachers' classrooms are situated. What is the organizational structure and culture in the school? Who are the leaders and what support do they give to education reform? What are the local, state, and national policies that influence education in the school? What resources are available to schools and teachers? What history of professional development is there in the school, district, or state? Who are the parents of the students in the school, and what is the nature of the community and its commitment to education? A detailed consideration of these context factors is contained in Loucks-Horsley et al. (2003, Chapter 3).

A third major input into the process of designing professional development is that of the *critical issues* that any professional development project will face. Although these may not be front and center for all projects, professional developers ignore them at their peril. First, there is the need to find *time* for professional development, either within the existing structures, or by influencing policies and practices to create more time. Next is the question of ensuring *equity*. In societies that are increasingly diverse, and needing a greater array of scientific expertise, specific attention needs to be given to ensuring access for all to science education. Another critical issue is the building of a *professional culture* for teachers that recognizes that teachers should be lifelong learners. Closely related to this is the issue of developing *leadership*, particularly with respect to ensuring an environment that facilitates teachers' transforming professional development experiences into classroom practice. A related critical issue is the need to build capacity for *sustainability*. A major failing of much professional development is the lack of sustainability: when a project ends, teachers and schools return to the status quo. Even if a project is successful in sustaining itself, however, another critical issue is *scaling up*. Will the new professional practice only be maintained or will it grow? A final critical issue is that of garnering *public support*. Professional developers need not only to build awareness of science initiatives in schools, but also to engage the public in supporting these initiatives. These critical issues are discussed in depth in Loucks-Horsley et al. (2003, Chapter 4).

The final major input into professional development design is that of *strategies* for professional learning. Even though Loucks-Horsley et al. (2003) documented a large number of potential strategies, they pointed out that strategies are the means of achieving ends that should already have been specified, rather than ends in themselves. It is for this reason that the design process should be quite advanced before suitable strategies are chosen. Any one project is likely to employ a number of different strategies to achieve its various purposes. One set of strategies focuses on the processes of *aligning and implementing curriculum*. When new curriculum materials are available, this is an obvious choice. Another set of strategies looks at a different part of classroom experience by *examining teaching and learning*. Teachers might focus on their own practice through action research, or on their students' thinking and work. A third set of strategies focuses on ways of teachers' *immersion* in the science content that they teach, either through inquiry and problem-solving in science, or by spending time in the world of scientists. A fourth set of strategies focuses on *teaching* itself through strategies such as coaching, mentoring, and demonstration lessons. Another set of strategies focuses more on the ways in which teachers *collaborate* with one another than on the content of their collaborations. Examples of these are partnerships with scientists, professional networks, and study groups. A final set of strategies includes the *vehicles and mechanisms* that professional developers use in their projects: developing professional developers, technologies for professional development, and various structures such as workshops, institutes, courses, and seminars. Strategies for professional learning are considered in detail in Loucks-Horsley et al. (2003, Chapter 5).

What Is the Relationship Between Teachers and Professional Development Programs?

Fishman, Marx, Best, and Tal (2003) explored the relationship between professional development programs and science teachers' practice and developed a model of teacher learning from professional development. In common with Loucks-Horsley et al. (2003), they viewed professional development as a process of design, in which professional developers consider a broad array of issues in order to design all the activities that constitute an effective professional development program. In considering professional development practice, they specifically focused on the issues that professional developers have control over, or "*design elements*," and categorize these in four ways that have much in common with the design framework proposed by Loucks-Horsley et al. (2003). Content is the first design element; this refers to the learning outcomes for teachers who participate in professional development. This might be pedagogical knowledge (e.g., assessment knowledge) or subject matter knowledge. The second design element is strategy, used much as Loucks-Horsley et al. (2003) did. The third design element is sites: these are the settings in which teacher learning happens. This element pays attention to aspects of context, format, and place. Media are the final design element. This pays attention to the means through which professional development might be carried out (e.g., video, computers, face-to-face interactions).

Fishman et al. (2003) focused explicitly on teacher practice as an outcome of professional development programs, going beyond Loucks-Horsley et al. (2003) in the process. For them, the primary criterion for deciding program effectiveness was teacher learning: the *knowledge, beliefs, and attitudes* that teachers acquire as a result of participating in *professional development activities*. However, they did not stop with teacher learning. Rather, they adopted from Richardson (1996) the viewpoint that one has to consider teachers' knowledge, beliefs, and attitudes as an interactive entity with their classroom *enactment* in which each influences the other. Thus, they saw a need to consider how teachers' knowledge, beliefs, and attitudes are enacted in classroom settings, and how enactment influences student learning, as evidenced in *student performance*. They also recognized a reciprocal, interactive relation in which student learning influences teacher learning, mediated through enactment. A final node in the framework is *curriculum*, about which they made two arguments. On the one hand, they saw curriculum influencing, and being involved in, professional development activities. On the other hand they argued that curriculum materials themselves may be educative.

This framework is valuable in the emphasis that it gives to tracking the influence of teacher learning, through its enactment in the classroom, and on to student learning. This emphasis gives explicit attention to various aspects that need to be considered in evaluating teacher professional development. Their illustration of this point in terms of a project that they evaluate is considered elsewhere in this review.

Summary

The three frameworks provide perspectives on teacher professional development in science that are complementary of each other. Together, they illuminate the many different components of the complex enterprise of professional development. Professional development programs have the goal of facilitating changes toward more effective teacher practices that ultimately are intended to improve students' science learning. Bell and Gilbert's (1996) model of teacher development focused on the teacher participants in professional programs and the interrelated strands of their personal, social, and professional development. Loucks-Horsley et al. (2003) highlighted the need for professional developers to pay explicit attention to a range of knowledge bases, to the wide variety of strategies for professional development, to the context of their particular programs, and to critical issues that arise for any program as they design their programs. Finally, Fishman et al. (2003) stressed the importance of being explicit about the connections between program, teacher practice, and student learning.

RESEARCH STUDIES

While there are considerable numbers of research studies that focus on individual components of these frameworks of programs, teachers and their practice, and students, and many that consider the relationship between classroom practice and student performance, the number of studies that consider the effect of programs on other components of these frameworks, with specific reference to science, was considerably smaller. The only previous review of professional development that explicitly considered professional development in science (and mathematics) was that conducted by Kennedy (1999). She included studies if they considered benefits to students. Four of the 10 studies included in Kennedy's review focused on science.

One other review, by Wilson and Berne (1999), discussed a small number of professional development projects. Their criteria for inclusion required that projects also conducted research, thought about both the content and process of professional development, and conceptualized professional teaching knowledge in terms of knowledge of subject matter, of individual students, of cultural differences across groups, of learning, and of pedagogy. Only one of these studied the teaching of science.

One reason why there are so few studies of professional development in science is likely to be the complexity of what is being studied. Consider the question of how student learning is related to professional development activity. The first link is between the professional development activities, for which some relevant variables are their nature, content, and extent, and the teachers who participate in them. Next, the outcomes from teachers' engagement in these activities will be mediated by their knowledge, beliefs, attitudes, and skills, as well as by the contexts in which they work. These outcomes could include learning further knowledge and skills, and developing different beliefs and attitudes; they could lead to the planning and implementation of revised curriculum and instruction that through reflection become more coherent. The next link, then, is between teachers, their professional practice, and their students' participation in classroom activities. Finally, as with teachers, students' learning outcomes are mediated by their knowledge, beliefs, attitudes, and skills, as well as by the contexts of school, home, and community. In other words, the connection is complex and involved. This conclusion is supported by Guskey's (2000) identification of five levels of professional development evaluation: participants' reaction, participants' learning, organizational support and change, participants' use of new knowledge and skills, and student learning outcomes.

Before considering studies in some detail, it is useful to address who should be considered as professional developers. Professional developers are people who are likely to play different but complementary roles, depending on their primary places of employment. Boyd, Banilower, Pasley, and Weiss (2003) identified a broad array of people who served as professional development providers for U.S. Local Systemic Change projects funded by the NSF. Their data demonstrated that teachers can be professional developers, as can their colleagues, heads of departments in schools, curriculum specialists in the school or in the district, staff development personnel in the district, personnel drawn from independent educational organizations, and/or people employed at tertiary-level institutions such as colleges or universities. Within this range, teachers released full-time from their teaching assignments constituted the largest group. Although teachers can be, and often are, their own personal professional developers, articles that focus on teachers' own self-study and development are not considered in this chapter, since this important group of studies is considered elsewhere in this volume (see Chapter 34). For the purposes of this chapter, a professional developer will be regarded as someone who is concerned with the professional development of others.

All of the research studies reviewed include descriptions of professional development programs with teachers of science. These studies are grouped in two ways. First, there are those that only consider the influence of these programs on the teachers who were participants in them. Second, there are those that include student outcomes from classes taught by teachers who participated in professional development programs. Within each group, studies are ordered, depending on the size of the study in terms of teacher participants: case studies of one or two teachers, studies of coherent groups of teachers, and large-scale samples of teachers.

Professional Development and Teachers of Science

The first three studies reviewed are case studies of one or two teachers. This allowed the researchers to spend extended periods of time with each teacher and thus to consider in some depth a variety of aspects of the teachers themselves, the professional development activities they were engaged in, and their enactment of ideas and approaches considered in these activities. Because of the concentrated nature of the research, the data-gathering methods produced loosely structured, thick descriptions, and these were analyzed with qualitative techniques.

Appleton and Asoko (1996) presented a case study of an elementary teacher in the United Kingdom who taught a science unit in which he sought to implement his understanding of a constructivist view of learning. The teacher, Robert, taught the unit for nearly a year (10 months) after attending an inservice program whose primary focus was a constructivist view of learning and its implications for instruction.

The program consisted of four blocks of five days each over a period of 10 weeks. Teachers in the program learned key principles of learning and were given examples of teaching approaches derived from these principles. They also had opportunities within the program to plan lessons using these approaches and were encouraged to try them out in their classrooms between the blocks. Robert had been enthusiastic about the ideas in the program and had reported success in using them in his classroom. In the period between the end of the program and the case study, Robert had had no formal support in putting these ideas into practice. The case study itself took place over a three-week period, during which Robert implemented a science topic he had planned on his own in a class of 10-year-olds. While he maintained overall control of the unit, one researcher was a participant observer in the classroom and provided some support for the teacher, both in helping out in small groups and making suggestions about the teaching of the unit. Data sources included observational field notes, audiotapes of teacher talk and pupil discussion, interviews with Robert, and samples of pupils' work. Analysis showed that Robert implemented some of the principles of constructivist learning more effectively than others. Although he provided an encouraging classroom atmosphere that facilitated his being able to elicit pupils' prior knowledge, he was not able to articulate clearly defined conceptual goals for the unit (focusing more on classroom process than content), he did not consistently use teaching strategies that challenged pupils to develop new ideas, and he provided no opportunities for pupils to use new ideas in different contexts. The researchers noted that Robert held prior beliefs about teaching and learning that facilitated his assimilation of some of the principles, while hampering the assimilation of other principles. They concluded that Robert would have benefited from inservice programs that modeled the principles they are teaching more effectively and that provided regular ongoing support, since teacher change is difficult and incremental, particularly if it involves a teacher's core beliefs about teaching and learning.

Rosebery and Puttick (1998) presented a case study of a single science teacher in the United States involved in an intensive professional development project that extended for nearly two years. The project advocated a view that both learning science and practicing science teaching are socially and historically constituted sense-making practices. Consistent with this viewpoint was a perspective that, even for the most experienced teachers, their daily teaching would always involve challenges, dilemmas, and uncertainties. The teacher, Liz, was videotaped while she learned science in workshops and taught science in her sixth-grade classroom, and was interviewed about both her learning and her teaching. During the project, data were gathered as Liz taught the same unit twice and planned the way she would teach it a third time. The extensive, detailed data gathering demonstrated a strong connection between key aspects of her science learning and her classroom practice. Specifically, Liz valued the opportunities she had to explore her ideas in an environment that supported her struggle to learn, while challenging her thinking, and sought to construct her elementary science practice along similar lines. Critical colleagues and a set of resources (e.g., videotape) to facilitate reflection on both her science learning and her teaching of science were essential features in her journey toward teaching in ways that she had experienced as a science learner.

Hand and Prain (2002) detailed an extended case study of two science teachers' participation in an ongoing inservice program in Australia to develop pedagogical practices to support writing-to-learn strategies. The inservice program was set up in response to the concerns of "a group of science teachers about the role of language in science . . . to generate strategies to diversify the types of writing used for learning science in each class" (p. 745). Eight junior secondary science teachers participated in the program. The article reported on two of these teachers, Alan and Chris, who were most open to innovation. The program's goal was to facilitate reflection on teachers' changing concerns arising from ongoing classroom practice, through an equal partnership between researchers and teachers. Although teacher ownership of the program remained high throughout the four-year time frame of the study, at times teachers assumed a cognitive apprenticeship role when researchers introduced and modeled different approaches in regular inservice sessions. Data sources included audiotapes of these inservice sessions, field notes of classroom observations, and interviews with teachers. Analysis of the data identified three issues that were central to the two teachers' concerns. The first issue was assessment, with teachers primarily seeing writing in science as an excellent assessment technique. Initially, they saw it as summative, but in time realized its many formative uses. The second issue was planning and setup of writing tasks in order to incorporate them into normal classroom practice. More specifically, they needed to develop strategies that supported students completing and, in time, planning writing tasks. The final issue concerned their changing roles as classroom teachers. They came to see that they needed to move from being a "wisdom-giver" (Hand & Prain, p. 750) to being a facilitator if students were to maximize the benefits they gained from writing-to-learn tasks. Critical features of this professional development experience were its long-term support for the teachers and the balance between the teachers' ownership and apprenticeship roles.

These studies understandably have strong similarities in their data-gathering and data-analysis techniques. They are, however, quite different from one another in the design of the professional development programs; there were differences with respect to the explicit content focus of the programs, the strategies that were used (examining teaching and learning, and immersion in inquiry), the extent to which teachers had input into the programs, and whether programmatic professional development overlapped with teacher enactment. The specifics of each program understandably carried through quite directly into the teachers' classrooms. Of particular interest is the considerable difference between the first study, where Robert's teaching was observed nearly a year after formal professional development activity concluded, and the latter two, in which teachers' implementation of different teaching approaches was interspersed with continuing interactions with professional developers and peers. On the one hand, Robert only adopted aspects that he could assimilate to his core beliefs about teaching (which he did not examine). On the other hand, there is evidence that the teachers in the other two studies became more aware of, and in some cases reconsidered, their core beliefs about teaching, as enacted in their classrooms.

The next two studies focus on larger groups of teachers who participated in a single professional development program. Briscoe and Peters (1997) in the United States explored how collaboration among elementary teachers from several schools, and with university researchers, supported them as they attempted change in their practices. Twenty-four teachers (mostly volunteers, with some specifically recruited) participated in a three-week summer workshop (four hours a day, four days a week) on problem-centered learning in science. The agenda implemented in the workshop was negotiated between teachers and researchers. During the following semester, a researcher visited each teacher twice a month to observe him or her teaching science, and once a month all teachers and researchers held a day-long meeting. Data sources included initial structured interviews with teachers, field notes of classroom observations, transcripts of discussions, and collections of artifacts created by each teacher, representing respectively the implementation of problem-centered activities and the nature of teaching and learning. Analysis of the data showed that, as a result of the professional development, many teachers were thinking about changing their practices. Doing so was, however, difficult. Case studies of six teachers showed that having someone with whom to brainstorm ideas and discuss successes and failures was key to their learning both content and pedagogical knowledge, and sustaining their commitment to and enthusiasm for problem-centered learning.

Luft and Pizzini (1998) reported on a program designed to teach a structured model of problem solving in science (the Search-Solve-Create-Share (SSCS) model). Thirteen elementary teachers in the United States, all volunteers, attended a four-day workshop on the model, including information on the model, being a student in a model cycle, and planning implementation. During the following school year, they were encouraged to implement the model in their classrooms, to observe an experienced teacher demonstrating the model (up to four times), and to repeat the implementation. Seven of the teachers completed all of these phases and were the focus of the study. All implementations were observed by a researcher, and the teachers' use of the problem-solving model was assessed with a specially designed instrument, the SSCS Implementation Assessment Instrument, which focused on key categories of the problem-solving model, such as learning group performance, student participation, and the teacher's role in supporting a student-centered classroom. The level of SSCS implementation on each category before and after observing demonstration lessons was compared. Of eight categories, there were significant increases in three (time in groups, group cohesiveness, and active participation) at the 0.05 level, and two (teacher role and students generating problems and action plans) at the 0.10 level.

These two studies have strong similarities with the first group of studies with respect to similar, intensive data-gathering procedures and the differences in program structures and strategies. In both studies, program support structures and classroom implementation overlapped to provide the opportunity for the reflective cycles that are an essential part of effective teacher enactment (Fishman et al., 2003). Although to varying degrees, both studies stressed the value of collegial interaction in supporting this process. Finally, in both studies there was evidence that there were changes in teachers' classroom practices toward those advocated in the programs, though not as extensively as the professional developers had hoped for. A reasonable conclusion is that it is still an open question whether these changes will be embedded in teachers' continuing practice.

The final group of studies connecting professional development programs and teachers involved large numbers of teachers who participated in a broad range of different programs. Supovitz and Turner (2000) examined the relationship between professional development and teaching practice and classroom culture. The data were gathered, by means of a survey, from teachers in the United States involved with the Local Systemic Change initiative of the NSF. The survey was completed by nearly 3500 K–8 teachers in 24 diverse localities around the country, who had received varying amounts of professional development, ranging from none to more than 160 hours. The professional development was assumed to be of high quality, with characteristics such as immersion in inquiry, intensive and sustained, embedded in classroom realities, focused on teachers' subject matter knowledge, consistent with standards for professional development, and connected to other aspects of school reform. These teachers reported on the extent and nature of the professional development they received, their teaching practices in science classrooms, and their classroom and school culture. Analysis showed that there was a strong relationship between the extent of teachers' professional development on the one hand, and their self-reported adoption of reform-oriented teaching practices (e.g., "design or implement their own investigation") and classroom culture of investigation (e.g., "encourage students to explain concepts to one another") on the other hand. The level of teachers' content preparation was also a strong influence on their teaching practice and classroom culture.

Garet, Porter, Desimone, Birman, and Yoon (2001) researched the effects of different characteristics of professional development on teacher outcomes in the United States. These characteristics, or structural features, included form of activity, duration (contact hours), and degree of collective participation, these being identified as elements of "best practice" in the professional development literature. Teacher outcomes focused on teacher knowledge and skills, and change in classroom teaching practice. These outcomes were determined by a survey of a national probability sample of teachers of science and mathematics who were involved in professional development provided through state and local institutions using national Eisenhower funding. The study showed that there were significant positive effects on teachers' self-reported increases in knowledge and skills and changes in classroom practices by core features from professional development activities. Mediating between structural features of professional development and teacher outcomes were content knowledge, active learning (observing and being observed; planning for classroom implementation; reviewing student work; and presenting, leading, and writing), and coherence of the professional development programs (being integrated into the daily life of the school).

Because of the large numbers of teachers involved, these studies differ from those previously discussed in this section in several ways. The sampling techniques together with the large numbers sampled provide assurances that the samples studied are representative of the whole population and the results can thus be generalized. The necessary use of surveys to gather information from teachers means, however, that the data gathered about classroom enactment, in particular, are qualitatively quite different. Data on teaching practices come from teacher self-reports in terms of categories provided by the researchers rather than from classroom observations.

Professional Development, Teaching, and Students' Science Learning

The first four studies reviewed below focus on relatively small, coherent groups of teachers and their students. The groups, all with fewer than 20 teachers, were coherent because within each group teachers participated in the same professional development program, and, in the first two of these studies, the teachers taught in the same school.

Parke and Coble (1997) conducted a study in the United States that connected professional development, teachers' instruction, and student achievement. Professional development sessions for middle school science teachers were built around a strategy of curriculum development. Prior to focusing on curriculum, however, teachers were introduced to research on teaching and learning, as well as reform goals and standards, and, through dialogue, articulated their personal beliefs about teaching, learning, and assessment. They also worked to align their curriculum with the demands and constraints of their school and community environments through conversations with peers, administrators, and parents, and explored the implications of their revised curricula for assessment. Data were gathered in the same school from 19 teachers who participated in the project, and 11 control teachers who did not, and from 205 project students and 120 control students. Teachers were individually interviewed about their teaching practices and their perceptions of student attitudes toward learning science, and students were surveyed about their teachers' teaching practices and their attitudes toward science. Analysis of these data indicated statistically significant differences with respect to the frequency of in-class experiments and student collaboration (both higher for project teachers), and students' attitudes toward science class (more positive in project classrooms). There were, however, no significant differences between project and control classroom students on a state-mandated science test that emphasized factual information recall. The test was developed in 1960 and thus predated current reform efforts.

Barak and Pearlman-Avnion (1999) reported on a two-year case study of a junior high school in Israel aiming to integrate the teaching of science and technology. The primary mechanism for achieving this was intensive and extended professional development for the school's eight science teachers and three technology teachers. Information on implementation of an integrated unit was gained from interviews with professional development providers, administrators, and teachers; from school visits; and from an achievement test and an attitude questionnaire (specifically designed for the study) at the end of the first year to assess pupil performance on a science-technology project. Geared to the quite different backgrounds of science teachers and technology teachers, the professional development opportunities were intensive in nature and extended over time. First, teachers were released for half a day each week throughout the school year to attend inservice courses offered by higher education institutions to improve relevant content knowledge of science for technology teachers, and vice versa, based on instructional materials specially prepared for integrating science and technology. Second, teachers attended individual, nonevaluative tutoring sessions about once every two weeks that focused on class activities, pupil achievement, and relationships with administrators and different subject area teachers. A key factor in the first-year implementation was the reluctance and, in one or two cases, the refusal of science teachers to teach the technical aspects of science-technology projects (e.g., combining the physics of sound with designing and constructing an audio amplifier). It should be noted that pupil achievement scores were noticeably higher on technology items. The authors concluded that a more realistic professional development goal was to develop awareness of the different field of study rather than expect teachers to teach both science and technology.

Fishman et al. (2003) illustrated their approach to linking teacher and student learning with professional development previously discussed in this chapter, in their report on a study with eight middle school science teachers in a large urban school district in the United States. The study was guided by their iterative model for evaluation of professional development that specifies that the design of professional development should be based on evidence of students' performance with respect to particular content standards. The implementation of the professional development should be evaluated by teachers who, in turn, enact ideas explored in the professional development. This enactment should be observed and student performance evaluated. This should then lead to redesign of the professional development, leading to a reiteration of the same cycle. In the study, the professional development was redesigned after an initial lack of student success on map reading and watershed concepts. Conducted in four Saturday workshops of six hours' duration held once a month, the professional development activities used strategies of curriculum review, peer information exchanges, and the examination of student work and consisted of an overview of the unit, modeling of a particular activity from the unit, and practice with a software tool used for building student understanding of watersheds. Teachers reported that their confidence in being able to support student learning had increased as a result of these workshops. Observations of their teaching showed that they used several strategies developed in the workshop. An evaluation of student learning, in this case with 755 students, showed that there was a statistically significant improvement in responses to water quality test items from the previous year.

A statewide NSF-funded systemic initiative (SSI) in the United States was the context for a study connecting professional development and student learning (Kahle, Meece, & Scantlebury, 2000). Ohio's SSI focused on middle school science and mathematics in urban districts through intensive teacher professional development activities. Teachers attended six-week summer institutes with six follow-up seminars throughout the course of the subsequent year. The institutes addressed teachers' lack of content knowledge and modeled inquiry teaching in science and mathematics, with a particular emphasis on standards-based teaching practices such as cooperative groups, open-ended questioning, extended inquiry, and problem-solving. Kahle et al.'s (2000) study was based on a subset of the data gathered in this project.[1] These data, gathered in two ways from students, included student achievement tests, prepared by the SSI from National Assessment of Educational Progress public-release items, and student questionnaires. The latter had subscales on student attitudes, standards-based teaching strategies used by their teachers, parents' involvement in science homework, and peers' participation in science activities. The data reported were gathered in eight middle schools, in each of which teachers who had participated in the SSI's professional development program were matched with one or more teachers teaching similar classes who had not. The data reported in this study were gathered in the science classrooms of eight SSI teachers and 10 non-SSI teachers. Analysis showed that there was a positive relationship between the SSI's standards-based professional development and students' science achievement and attitudes, especially for boys. This relationship was mediated by the reported use of standards-based teaching practices that were positively related with teachers' participation in the SSI's professional development.

1. At least 30 percent of the students in all schools in this study were minorities. The data reported were for African American students. Although this was a significant aspect of the published study, the ethnicity of students is not considered further in this chapter.

It is instructive to compare how the three components—professional development, teaching practice, and student outcomes—played out across these studies. First, the professional development provided to teachers in each of these studies had several commendable characteristics. In each case, professional development included intensive sessions where teachers had opportunities to build knowledge of new approaches and explore implications for teaching, followed by opportunities to teach using these approaches that were interspersed with follow-up—reflective sessions to talk through aspects of their implementation in the specific circumstances of their classrooms. Different professional development strategies were used, some in combination with each other; these included aligning and implementing curriculum, immersion experiences, and examining teaching and learning (Loucks-Horsley et al., 2003). Data on classroom teaching strategies were gathered in different ways, including classroom observations, interviews with teachers about their teaching, and student surveys of teaching strategies. The inclusion of students in these studies provided a further opportunity to gather data about teaching that was not provided by the teacher. Next, these studies reported different ways of gathering student achievement data, varying from the proximal to the distal. In two studies, tests were prepared by the researchers themselves, in one study tests specifically targeted to the purposes of the study were constructed from available national test banks (Kahle et al., 2000), and in another study (Parke & Coble, 1997), an independent, statewide assessment test was used. Finally, there were variations in how closely the relationships among these three components were followed, flowing in part from the data-gathering methods employed. The study by Fishman et al. (2003) is noteworthy in this respect. Guided by an iterative model for the evaluation of professional development, the authors were able to track the influence of professional development explicitly and directly through teachers' enactment to student performance on tests specifically designed for the study.

One large-scale study reported connections among types of professional development, classroom activities, and student achievement. Huffman, Thomas, and Lawrenz (2003) conducted an external evaluation of a large-scale, statewide professional development project in science and mathematics in the southern United States.[2] The professional development provided by the state was extensive and diverse, consisting of coordinated workshops in the summer, with extended follow-up through the school year. It utilized all five general categories of professional development strategies proposed by Loucks-Horsley et al. (1998). Across all of the sites at which the project was implemented, there were many opportunities for teachers to engage in long-term, intensive professional development. Because the teachers were free to decide in which opportunities they would engage, there were variations in the type and duration of professional development. The authors surveyed 94 eighth-grade science teachers about, first, the type and duration of professional development they had experienced, and, second, the type and frequency of use of standards-based instructional methods they used. Student achievement was measured with the existing state achievement test, "part of a criterion-referenced state assessment system designed to measure student achievement of the state standards" (Huffman et al., p. 381). The test included multiple-choice and short-answer

2. Only the science results are reported in this chapter.

questions and a comprehensive scientific inquiry task. Regression analyses were conducted with the independent variable being the type and duration of professional development. The dependent variables used were, first, the reported frequency of use of standards-based instructional methods, and, second, class mean scores on the state achievement test. The professional development strategies of curriculum development and examining practice were the only ones predictive of the use of standards-based instructional methods. Finally, there were no significant statistical relationships between any of the professional development strategies and students' achievement scores.

DISCUSSION

The frameworks for considering teacher professional development in science adopted in this chapter include programs that provide professional development to teachers of science, the people—teachers—who participate in these programs, the classroom practices that emanate from this participation, and the people—students—who are the participants in these practices. Research studies reviewed in this chapter explicitly addressed professional development programs for teachers of science. Some were primarily concerned with the effect of these programs on teacher practice, and others sought to connect student performance to programs through classroom practice.

How has research been conducted on programs, teachers, classroom practice, and students in the studies reviewed in this chapter? First, the research on programs is largely descriptive. In most studies these descriptions focus on project design, including its purpose, the pattern and duration of professional development activities, the professional development strategies used in these activities, the focus of these activities (science content, teaching strategies, etc.), and the teachers who participate in these activities. In only a few cases were data gathered during program activities and from participants, and in only one case was the research focused on program activities themselves (Fishman et al., 2003). The intent, for the most part, was to treat the programs as contextual constraints on the professional development of the teachers. Second, the research on teachers is both descriptive and evaluative, rooted, as it is, in a large, growing body of literature on teachers of science and other disciplines that detail what teachers know and believe, how they teach, and how they learn to teach. Thus it uses the same variety of data-gathering procedures used in the larger literature, including surveys, interviews, and observations of teaching and, in a few studies, participation in program sessions. It is no surprise, therefore, that these studies provide a much clearer picture of the teachers and their teaching, than they do of their learning as a result of their participation in professional development programs. A few studies, such as that of Rosebery and Puttick (1998), paid close attention to teacher learning within professional development programs. Others, such as Parke and Coble (1997) and the large-scale studies, relied on implicit assumptions about how and what teachers learned as a result of the programs in which they participated. Finally, the research on students largely focused on student outcomes, as measured by scores on achievement tests. The tests used in these studies varied with respect to their proximity to program, from those specifically designed within the context of the study, such as Barak and Pearlman-Avnion (1999), to those that used existing, distal measures such as state tests, such as Huffman et al. (2003).

How have the ideas in the theoretical frameworks considered in this chapter been addressed in the studies that have been reviewed? First, consider the model of teacher development outlined in terms of three different components—personal, social, and professional—by Bell and Gilbert (1996). Although none of the studies reviewed used this framework, the case studies that gathered detailed data from teachers provided an opportunity to consider teacher development in these terms. For the most part, these teachers engaged in the first two phases of personal development: they implicitly accepted aspects of their teaching as problematic as they were dealing with aspects of the restraints of their classrooms and schools, with some rethinking their core beliefs about teaching. Barak and Pearlman-Avnion (1999) provided a counterexample that strengthens the importance of personal development: some science teachers saw no need for the professional development program provided (to integrate science and technology) and refused to change their practice. In terms of professional development, most teachers in these studies tried out new activities and were engaged in developing their classroom practice. There was also social development through their expressions of seeing the value of collaborative ways of working. Of interest, however, is that there was little evidence presented to decide whether any of these teachers moved into the third phases of development: feeling personally empowered and initiating other activities and collaborative ways of working.

Second, consider the professional development design framework outlined by Loucks-Horsley et al. (2003). Derived from a consideration of the practice of professional developers, the framework considers the process of design as being informed by knowledge and beliefs about various aspects of professional development, the context in which professional development occurs, various critical issues that all professional developers need to consider, and a catalog of professional development strategies. Only one study (Huffman et al., 2003) explicitly used any components of this framework, categorizing strategies of professional development across a broad array of professional development programs. Few studies explicitly considered the knowledge and beliefs underlying professional development. Other studies, to varying degrees, considered some aspects of the framework—case studies generally included context and some discussion of critical issues, and most studies gave some indication of the professional development strategies used, such as Luft's and Pizzini's (1998) consideration of demonstration classrooms. No studies, however, used the framework in a systematic fashion in planning, or in formative or summative assessments of professional development programs.

Finally, consider the emphasis on enactment as an interactive entity involving teachers, their classroom practice, and student performance provided by Fishman et al. (2003). Only a few studies considered these interactions in the larger context of professional development programs. One obvious reason is the difficulty of keeping a detailed focus on the different components of enactment as an interactive entity; across the studies that attempted to do so, classroom practice and student assessment were components that were addressed in a distant or indirect fashion. Another reason is that, although there are persistent calls to assess the effectiveness of professional development programs in terms of student achievement, there are other more proximal goals that professional developers might like to achieve, such as finding ways to reduce the out-of-class workload of teachers.

Kennedy's (1999) review of professional development in science and mathematics concluded that, based on evidence of benefits to students, the content of professional development (what to teach and how students learn it) is more important than its form and structure (its duration, whether it is interspersed with teaching, whether it advocates prescriptive or discretionary approaches). Kennedy also concluded that it was important to treat teachers as professionals. The studies reviewed in this chapter do not support Kennedy's conclusion that the content of professional development is more important than form and structure. On the contrary, the various case studies demonstrate that without continuing support during the critical phases of planning, implementing, and reflecting on instruction, teachers are unlikely to make major changes in their teaching, particularly if these changes require reconsideration of their core beliefs about science, teaching, learning, instruction, and/or assessment. Content is still important: the studies reviewed here largely included it in ways similar to the most effective studies in Kennedy's review. The conclusion about the importance of treating teachers as professionals is also relevant; it is a reminder that the role of program structure is facilitative and not causative. Teachers themselves are responsible for changing their practice and, in the process, empowering themselves. In this regard, the questions that Bobrowsky, Marx, and Fishman (2001) posed about whether participants in professional development programs are volunteers or not, and how to design effective professional development for non-volunteers who may need it most are clearly relevant.

Because of the complexity of professional development programs and their effects on teachers and students, it is not surprising that the variations across the studies reviewed in this chapter are extensive; with a finite amount of resources to devote to studies of these issues, trade-offs are necessary. Consider the number of participants in a study. By limiting the study to one or a few teachers, it is possible to focus in depth on a broad array of factors that influence a teacher's learning, practice, and influence on students. Although this leads to a rich, nuanced description of a teacher and a deep understanding of the complexities of his or her world, it does not provide pictures of the breadth, extent, and variation of teachers' professional development experiences across schools, districts, regions, or nations. In studies with large numbers of teachers, choices need to be made to limit the number of issues to focus on, and to choose efficient methods of data-gathering. For example, in order to reach over 3,500 teachers, Supovitz and Turner (2000) used teacher self-reports for information about their professional development experiences and their teaching practices, rather than data gathered by independent observers. Trade-offs also need to be made with respect to the components that are studied. Deciding to include programs, teachers and their practices, and student outcomes in a single study requires other limitations. For example, Parke and Coble (1997) relied on a state-mandated science test, developed some 30 years prior to their study, for information on student achievement. In contrast, Fishman et al. (2003) designed the achievement tests used in their study, but limited the study to a tightly constrained content area and a few teachers. In other words, in studying teacher professional development in science, trade-offs are inevitable. This means that it is essential that there be a broad array of different methods and data that complement one another in providing an overall picture of the field. While the studies reviewed in this chapter illustrate the diversity of possible approaches, they also illustrate that many more studies are needed to paint a coherent picture of the field.

CONCLUDING REMARKS

The complexity of teacher professional development in science points to its systemic nature and suggests that research consider not only the people involved in professional development, but also the systems in which these programs are embedded. A metaphor that provides some insight into this issue is that of pathways. In considering professional development programs, it is necessary to consider not only the outcomes that the programs seek to achieve but also the means, the processes, the pathways by which those outcomes will be achieved. It is seldom that outcomes are ignored; much more frequently, however, it is only when desired outcomes are not achieved that the pathways by which they might be achieved are considered. However, the likelihood of programs being successful is greatly enhanced if the pathways are explicitly included in the program design. The pathway metaphor itself is valuable because it suggests several important issues. First, it draws attention to the starting point, the endpoint, and the various ways by which they might be connected. Without knowing where one starts from, and identifying reasonable connections between various points along the way, the possibility exists of finding oneself on the wrong side of a chasm to be bridged that requires more resources than are available. Next, the pathway metaphor suggests the need to pay careful attention to the journey and the resources that are likely to be available along the way. In other ways it is necessary to understand the system components that facilitate progress along the pathway. Finally, the idea of a pathway draws attention to the time that will be needed to complete the journey. It does not happen instantaneously; specifying milestones along the way reminds us that this is the case.

Thinking systemically also highlights a particular aspect of the relationship between people and systems. Frequently, what makes sense to individual participants is at odds with what makes sense at the organizational level. If a system and the people who work within it are to work effectively, there are different conditions that need to be met. On the one hand, at an individual level, each person needs to believe that she or he is an important part of the enterprise, that his or her contributions are valued and respected, and that she or he has a measure of autonomy in carrying out his or her responsibilities. This means that each person needs to develop an understanding of the many facets of his or her job and become committed to the belief that it is fair, equitable, and worthwhile. The organization needs to be responsive to the needs and ideas of its members, and to be trusting of their abilities. In other words, each person needs to be able to take ownership of the position to which she or he is appointed, and the work that this entails. On the other hand, at an organizational level, if the system itself is to operate effectively, there needs to be coherency in its vision, a concerted working together to achieve common goals, and a lack of different groups working at cross purposes to one another. This requires leadership to create a vision, set goals to be achieved, and developing strategies for reaching those goals. One of the key strategies needs to be the effective communication of the vision to all participants in the system. Individuals, then, can come to see that their efforts are responsive to, contributing to, and fitting in with an overall vision.

Bringing a system together such that what makes sense for the participants is coherent with what makes sense for the system does not happen of its own accord. There need to be strategies in place that allow reconciliation of these different perspectives to occur as a normal part of the functioning of the system, whether it be a classroom, a school district, or teacher professional development.

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