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Developing Science Pedagogical Content Knowledge Through Mentoring Elementary Teachers

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Abstract Elementary teachers are typically hesitant to teach science. While a limited knowledge of science content is a reason for this, limited science pedagogical content knowledge (PCK) has emerged as another reason in recent research. This study constitutes two case studies of a professional development program for elementary teachers involving mentoring by a university professor. The mentor took the role of a critical friend in joint planning and teaching of science. The study examines the nature of the mentoring relationship and reports the type of teacher learning that occurred, with a particular focus on the teachers' development of science PCK.

Keywords Elementary science · Professional development · Science · PCK · Mentoring

Introduction

Research over several decades in Australia and other countries has consistently shown that many elementary school teachers are hesitant to teach science (e.g., Appleton and Symington 1996; Goodrum et al. 2001). This has largely been attributed to the teachers' low self-confidence in teaching science (Watters and Ginns 1997), which has also been described in terms of Bandura's (1977) notion of self-efficacy. Low self-efficacy and lack of self-confidence tend to arise from the teachers' limited knowledge of science subject matter, school contextual factors,

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such as limited resources for teaching science, and perceived priorities in elementary schooling afforded to other subjects compared to science (Appleton and Kindt 1997; Ginns and Watters 1994; Goodrum et al. 2001). Given that self-efficacy varies between teachers, the teaching of elementary science can consequently vary considerably, even within the one school. The minority of teachers who feel fairly confident with science seem to teach it regularly and attempt to use teaching strategies consistent with recent science curricula (Goodrum et al. 2001). Those lacking confidence tend to engage in avoidance behavior, such as not teaching science at all or teaching a version of science that more closely resembles such subjects as language and social studies (Appleton 2003; Harlen and Holroyd 1997).

As mentioned earlier, teachers' knowledge of science subject matter has been identified as one of the contributing causes of teachers' low self-confidence in teaching science. However, this is just one aspect of teacher knowledge. In an earlier study (Appleton 2003), I explored how another form of teacher knowledge related to science content knowledge, science pedagogical content knowledge (PCK) seems to also play a role in elementary teachers' teaching of science. This study draws upon two research and development projects from a series spanning 6 years (see Appendix for further detail) and examines professional development that enhances elementary school teachers' science PCK.

Theoretical Framework

The theoretical framework for this study draws upon two fields. Those fields are teacher knowledge, in particular, science PCK; the other field is teacher professional development.

Science Pedagogical Content Knowledge

Twenty years ago, Shulman (1986, 1987) suggested that there are seven knowledge bases required for teaching. Three that are relevant to this study are (a) content knowledge, (b) knowledge of general pedagogy, and (c) pedagogical content knowledge (PCK). Content knowledge is related to the discipline and includes subject matter knowledge and ways of working in the disciple. General pedagogy constitutes the common strategies and procedures used in teaching. Shulman suggested, however, that PCK was different from both content knowledge and knowledge of general pedagogy: he thought that it consists of such knowledge as how to represent subject matter to students, ideas about student conceptions, and understandings of specific learning difficulties students may have (van Driel et al. 1998). That is, it is knowledge of how to teach specific content in specific contexts—a form of knowledge in action (Mellado et al. 1998). Emphasizing that PCK is a different form of teacher knowledge, Magnusson et al. (1999) stated that PCK is the "result of a *transformation* of knowledge from other domains" (p. 96, emphasis in original).

A number of researchers have further explored the nature of PCK. Grossman (1990), for instance, suggested there were four central components contributing to pedagogical content knowledge development: (a) knowledge and beliefs about purpose, (b) knowledge of students' conceptions, (c) curricular knowledge, and (d) knowledge of instructional strategies. Taking a somewhat different perspective, Magnusson et al. (1999) saw science PCK as including (a) teacher's orientation to teaching science, (b) knowledge of science curricula, (c) knowledge of assessment, (d) knowledge of scientific literacy, (e) knowledge of students' understanding of science, and (f) knowledge of instructional strategies. Cochran et al. (1993) took a constructivist perspective, proposing the different idea of pedagogical content knowing (PCKg). They suggested that there were four components of PCKg: (a) knowledge of students, (b) knowledge of environmental contexts, (c) knowledge of pedagogy, and (c) knowledge of subject matter. The different contributing forms of teacher knowledge identified in these studies have a number of similarities, although there are some differences in wording and theoretical orientation. Commonalities include knowledge of subject matter, knowledge of students and possible misconceptions, knowledge of curricula, and knowledge of general pedagogy.

Gess-Newsome (1999) identified two different epistemological views of science PCK: an integrative view and a transformative view. In the former, science PCK is not seen as a separate area of teacher knowledge, but, rather, an experiential application of other forms of knowledge, such as science content knowledge. In the latter, other forms of teacher knowledge are seen as being transformed and combined through experience into a new form of knowledge: science PCK. This view is inherent in the work of Shulman (1986, 1987), Grossman (1990), Magnusson et al. (1999), and Cochran et al. (1993) and has been adopted in this study. A detailed explanation of the view of science PCK used in this study is outlined by Appleton (2006).

The development of PCK has also been subject to research. Grossman (1990), for instance, thought that contributing sources to PCK are classroom observation during times as a student, as well as preservice teacher education; studies in science; teacher education programs; and personal classroom experience. Recommendations from trusted colleagues (Appleton and Kindt 1999) have also been found to contribute. Morine-Dershimer and Kent (1999) also highlighted the role of personal beliefs and perceptions of teaching and learning in developing and shaping science PCK (see also Magnusson et al. 1999), as these determine how experiences are viewed and understood.

My research into the development of PCK in elementary teachers (Appleton 2006) and other reports of PCK development in elementary teachers (e.g., Smith 1999; Smith and Neale 1991) led me to consider that PCK and PCK development for elementary school teachers may differ from that of secondary school teachers. For instance, in work with secondary physics teachers, Bell et al. (1998) proposed a hierarchy of PCK "types," suggesting different levels of generality. They identified a broad base of science PCK, specific discipline PCK (e.g., physics), and specific topic PCK (e.g., electric circuits). They saw specific discipline PCK as emerging from repeated experiences of teaching specific topic PCK. My research suggests that elementary school teachers work with PCK in different ways. They usually start with the idea that science should be activity based and work from specific activity ideas (Appleton 2006). That is, they tend to work with specific topic PCK, but would rarely have the opportunity to develop specific discipline PCK because few develop a science discipline specialization. Another difference is that secondary school teachers tend to develop specific discipline PCK in their own discipline specialty. However, in common with elementary teachers, they may find their PCK for teaching a different science discipline limited or nonexistent. For instance, Chan (1998) reported that scientists with doctorates in physics hold common misconceptions about selected biology topics; hence, highly qualified secondary teachers in one science discipline will not necessarily have the science content knowledge enabling them to develop effective PCK for other disciplines. Not surprisingly, the majority of elementary school teachers tend to have limited knowledge in both science content knowledge and in science PCK, given that few elementary school teachers are science discipline specialists. For instance, in my own institution, the majority of preservice elementary teachers have chosen humanities specializations and, consequently, have limited science content knowledge (Appleton 1991; Goodrum et al. 2001) and limited science PCK. Hence, studies that consistently reveal problems with elementary science education are a reflection of the science knowledge held by elementary school teachers.

In summary, science PCK is a form of teacher knowledge transformed from other forms of teacher knowledge (Magnusson et al. 1999). It has inherently close links to other forms of teacher knowledge, such as the teacher's science content knowledge, and is developed through the teacher's own experiences and science teaching practices, as well as the recommendations from colleagues' experiences. In developing science PCK, teachers draw on a range of other forms of teacher knowledge, such as knowledge of curriculum, context, general pedagogy, and students (see Appleton 2006 for a full discussion of my views of science PCK).

Teacher Professional Development

Teacher professional development in Australia has typically followed a top-down model (Anderson 2000), where the professional development is initiated and controlled by the education system central office and where groups of teachers attend lectures, workshop sessions, or both conducted by a visiting expert. Surveys have shown that these are not highly effective (e.g., Anderson 2000), and the teaching of elementary science remains in a perilous state (Goodrum et al. 2001). The professional development literature in science education indicates that the classroom teacher is the key to effective professional development (Klapper et al. 1994). Long-term programs of workshops that include external expertise and groups of teachers' sharing of experiences in trialing new teaching practices have had some success (e.g., Bell and Gilbert 1996; Hardy and Kirkwood 1991). However, these require a significant commitment by teachers for out-of-hours attendance at workshops.

In contrast to the top-down model of professional development, Bell and Gilbert (1996) described science professional development that was transformative, that is, it resulted in meaningful, personal, and lasting changes in science teaching practice. Transformative teacher change in elementary science, according to Bell and Gilbert, involves teacher-development in each of three areas: social (developing collaborative ways of relating to other teachers), professional (developing ideas and actions), and personal (attending to feelings). Such teacher change can be viewed as teachers learning new knowledge or developing new perspectives in each area. Addressing each of these areas requires long-term support for teachers (Bell and Gilbert 1996). This notion of professional development was the guiding model for the professional development used in this study.

According to Peers et al. (2003), long-term, sustained, one-to-one support is one way of helping teachers effect lasting change in the three areas identified by Bell and Gilbert in 1996. In a case study very similar to those reported here, Peers et al. concluded that "Andrew's success was facilitated by a credible mentor, who provided the stimulus and support for change" (p. 104). Peers et al. report was published toward the end of the data collection period for this study, and their use of the term "mentoring" aligned closely with my reflections about my role in the series of projects in which I had been engaged (see Appendix). Further, there is increased support for mentoring programs within the first 5 years of teaching, and these are also seen as crucial to teacher retention. For instance, award-winning science teachers reiterated to the U.S. House Committee on Science (National Science Foundation 2003) the need for mentoring programs beyond the first year of teaching. However, most reports of teacher mentoring in the literature refer to preservice teacher education or novice teacher induction (e.g., Cunningham 2002; Monsour 2003), rather than inservice professional development. This literature was consequently not helpful in understanding the professional development associated with my series of projects.

Mentoring has been a feature in the literature associated with other fields of study, such as business. Kochan (2002a) recently published an overview of mentoring across a number of contexts and fields of study. While this literature did not inform the development of the professional development program reported here, it was subsequently explored when it became clear that a key component of the program was mentoring and, so, is discussed later in this report.

This paper adds to the science professional development literature by demonstrating, in line with findings by Bell and Gilbert (1996) and Peers et al. (2003), that elementary teachers need considerable support in developing their knowledge base, which I have shown includes science PCK, when learning how to implement new ideas and change their science teaching practices. It further demonstrates that mentoring can play a significant role in supporting teachers and clarifies the nature of the mentoring role that enhances lasting teacher change. As a consequence, I have come to the conclusion that one-to-one, in-class mentoring of elementary teachers can be an alternative, critical component of professional development in science (see also Appendix).

Summary

Elementary teacher learning in science requires a focus on at least three interrelated aspects of teacher knowledge (Shulman 1986, 1987): content knowledge, curriculum knowledge, and pedagogical content knowledge. There may also need to be a focus on pedagogical knowledge, assessment, or both, depending on the teacher's expertise and experience. It most likely will also involve reconsideration of orientations to teaching and learning (Magnusson et al. 1999) and a focus on self-confidence in teaching science (Appleton 1995). Given the complexity and interrelatedness of these knowledge areas, in-class mentoring in a cooperative teaching framework with mentors who are acknowledged experts in these areas of knowledge potentially provides a meaningful, situated learning context (McInerney and McInerney 2002; Wertsch 1985) for elementary teachers.

The Context of the Study

In 1999, a new outcomes-based science curriculum was introduced into Queensland elementary schools (Queensland School Curriculum Council 1999). This presented a considerable challenge to teachers, as it was the first science curriculum change for almost 20 years and shifted the emphasis from hands-on science using process skills to constructivist-based pedagogy developing understanding. Those teachers who already taught science tended to follow the recommended thrust from the old curriculum and tried to engage children in hands-on activities. When confronted with the new curriculum, they did not know how to proceed. Further, as indicated earlier and revealed in recent studies (e.g., Goodrum et al. 2001), many teachers had habituated into science-avoidance practices, such as not teaching science or dealing with science topics during language or social studies (Appleton 2003). Some of these were prompted by the introduction of the curriculum to reevaluate their teaching of science, but they did not know how to change their practice.

Purpose of the Study

Since the introduction of the new curriculum, I have been working with groups of teachers to help them become familiar with the new curriculum and adapt their teaching of science to an outcomes framework (Appleton and Harrison 2001). My role has been varied, including provision of curriculum familiarization sessions, explaining outcomes-based education, showing teachers how to plan from outcomes, and providing on-going support to teachers as they plan and implement science units of work. It is my role in providing this support that was the focus of this study. As my involvement with teachers developed, it became evident that the role I was playing was consistent with that described in the mentoring literature. It was this mentoring that was a critical component in helping the teachers with both the new curriculum and in changing their practice. The purpose of the study, therefore, was to conduct a post hoc analysis to identify what I was doing as a mentor that was of value to teachers and, consequently, to infer what the characteristics of a mentor might be. Specific questions were as follows:

1. What aspects of mentoring (i.e., the roles assumed by the mentor) were of value to the elementary teachers in effecting change to their science teaching practices?

2. What characteristics of a mentor were important when providing assistance to the elementary teachers?

Methodology

This study constitutes a report of case studies (Yin 1994) of two teachers extracted from two consecutive projects in a series. A number of the teachers I have worked with agreed to participate in a series of research projects (see Appendix). Most of these teachers were trying to engage with science teaching and were interested in improving their practice. The projects on which this report is based arose from requests by two elementary schools for professional development help in science. Colleagues and I worked with those teachers in the schools willing to participate (the majority), but asked for two volunteers from each school or a small school group to help in the research component. The potential sample of teachers for this study, therefore, had a built-in bias attributable to the teachers' willingness to have their science teaching closely scrutinized by a high-status expert university professor (see also Peers et al. 2003)—a risky behavior unlikely to be adopted by a teacher avoiding science. Two of the participating volunteer teachers are used as post hoc data sources for this report. This purposive sample for the two case studies was chosen because they were among those teachers who demonstrated considerable, lasting change in their science teaching practices and provided rich data about the professional development mentoring.

Both teachers had been teaching elementary school for more than 10 years. The first teacher, Sonya, was a grade-one teacher at an outer-suburban church school in a regional city in Queensland. The school had one teacher per grade and a nonteaching principal. Sonya sometimes taught science using hands-on activities, and at other times she used work sheets and books. The second teacher, Chelsea, had a multigrade (one through three) class in a small rural public school. She taught science regularly, preferably using hands-on activities. Neither knew how to work from outcomes or how to help children develop understandings—their use of hands-on activities tended to be limited to providing the experience for the children. They both claimed to have little confidence in teaching science and put it toward the bottom of their preferred subjects.

My role as researcher was a participant observer in the classroom. I also provided professional development opportunities for the teachers and direct classroom assistance as a critical friend and helper. That is, as discussed later, I was a mentor to the teachers. Data sources included tape-recorded interviews with the teachers; extensive field notes of lessons; planning documents; and, in Chelsea's case, some videotaped lessons. Since I played the dual role of mentor and researcher, I included my reflections and perceptions of what was going on as part of the field notes. Where possible, the final interviews were conducted by a colleague to provide an independent data source and to satisfy the evaluation requirements of the funding body. Visits were subsequently made to the teachers' classrooms several months later to check whether any changes in practice were being maintained.

I acknowledge the potential difficulties associated with conducting research into teachers' practice where I have also been heavily involved in those teachers' classrooms providing professional development support. While the two case studies reported here have been chosen because they typify the data collected in a number of classrooms, they are also consistent with what has happened with nine other teachers (e.g., Koch and Appleton 2007). Further, a few other case studies have shown that, when the conditions for mentoring are not met, outcomes can be much more limited (e.g., Prinsen 2001).

Data Analysis

The data were analyzed for evidence regarding the roles that I played as mentor and the extent that these influenced the teaching practices of the teachers. From these roles and their consequences, tentative characteristics of a mentor have been identified.

Case descriptions for each of the participating teachers were constructed from the various data sources, including the teachers' own conclusions and reflections about the professional development (Yin 1994). The descriptions were in the form of narratives telling the story of events and changes in practice that occurred over time. The narrative had dual perspectives: mine, as mentor and researcher, and the teachers'. The research questions provided a framework for identifying events and statements that were related to the success (or otherwise) of the professional development in terms of the mentoring that occurred (see Yin 1994). Analysis was, therefore, a process of identifying the components of the narratives that revealed a change in practice—whether or not it related to mentoring—and what contributed to bringing about the change. As it transpired, all changes in practice were directly attributable to the mentoring. The data reported here are extracts from the case narratives.

Results

One of the difficulties in identifying the role that I played as mentor is the extent to which my perceptions of my role aligned with those of the teachers. I, therefore, describe my own perceptions of what I did, and then I outline the teachers' comments about their own teaching behavior and what influenced them to change it. Their perceptions of their teaching behavior have been compared with my classroom observations to ensure consistency.

My Perceptions of the Professional Development Support

The professional development that the teachers were involved in followed a similar sequence for each school. A 2-day orientation workshop to the science curriculum was held with the teachers from the school, with particular focus on its new features—outcomes, working scientifically, and constructivist-based pedagogy, such as identifying children's existing ideas, scaffolding learning, and using such challenges as discrepant events. Planning a unit of work based on outcomes from the curriculum was then modeled with the teachers co-constructing the plan, working through sample activities, and touching on science background knowledge as appropriate. That is, the workshops touched on different aspects of teacher knowledge, including curriculum, assessment, the nature of science, views of science teaching and learning, science content, and knowledge of students.

I then worked with each teacher individually, cooperatively planning the next science unit that they would teach. The topic for the science unit was from the teacher's normal schedule, so they had control over what was planned. Plans extended over a 6- to 8-week period. When they implemented the plan, I worked with the teachers during the scheduled science lessons. In these planning and implementation phases, aspects of science PCK (as well as other areas of teacher knowledge) were exposed and shared.

Frequently the science would spill over into other times and subjects when I could not attend. Each visit I checked with the teachers as to what the focus of the next lesson would be, and we discussed any adaptations to the plan that needed to be made. During lessons, I assumed the role of a second teacher, helping out when needed, sometimes sitting in the corner, and sometimes working with individual children. At prearranged times (when the teacher was unsure of the content or how to teach something), or when the teacher gave a "help" glance, I stepped in and took over for a segment before handing back the lesson to the teacher. When prearranged, I would occasionally take the whole lesson, with the teacher as helper. On a few occasions, I also provided some resources. With Sonya, I repeated the mentoring phase for a second unit of work, but withdrew more, visiting less frequently and taking a minor classroom role.

My main role in working with the teachers was to show them how I would teach science myself by modeling my own practice; but, at the same time, I tried to ensure that they had ownership of the unit and felt that it was suitable for them and their class. That is, the unit was one that they planned and taught, with my teaching involvement being negotiated, incidental, and by invitation. For instance, when the teacher lacked confidence to take a particular lesson or lesson segment, she invited me to take that part; or, when I thought the teacher was attempting something inappropriate or was heading in a nonproductive direction, I made alternative suggestions without being critical of her ideas. When asked, I explained my thinking.

Key aspects of my support for the teachers (through mentoring), therefore, included cooperative planning from outcomes so that we had a clear idea of what we wanted the children to learn. Our planning included identifying and selecting suitable learning experiences for the children; sequencing these so they formed an effective scaffold for the children's learning; showing how to give the children ownership of the work; asking probing questions to identify their existing and developing ideas; suggesting explanations, analogies, and models that might help the children reach a desired understanding; challenging children's misconceptions and conclusions; and assessing the children's learning.

Examples of Specific Instances of Mentoring

Grade 1, Sonya: Example 1. Sonya planned a unit on Earth and Beyond, focusing on landforms and features of the sky. She wished to include looking at near and far objects to compare their apparent size, as she was concerned that they understand that the moon and sun were much bigger than they appeared. She had some activity ideas about placing objects at various distances on the oval and gauging their apparent size, but could not think how to apply this to the moon and sun. I suggested an illusion box—a sealed shoebox painted black inside with a peep hole at one end and a picture of the moon midway, illuminated by a hidden torch bulb. Sonya liked the idea, but was uncertain about how to do it. She wanted the children to make this and asked me to take the lesson.

Example 2. Prior to the lesson's being taught on the school sports oval, the children had been explaining to me about the different landforms that they had learned and were constructing and labeling three-dimensional landscapes. It became apparent that at least a third of the children did not understand a valley. As the class walked down to the oval to look at a ball placed at different distances, Sonya pointed to a distant mountain range "V," saying that there was a valley. I noticed that there was a mounded earth drain next to the path and showed the children the valley formed between the mounded sides. I explained how this was too small to be a real valley; but, if we were in a plane, it would look like that.

Grades 1–3, Chelsea: Example 3. Chelsea had begun her unit on "Minibeasts" and had worked with the children to construct a terrarium containing grass sods and some creatures they had found. A black pupae case was in the sod. The children thought it was an egg. I asked a series of questions, exploring what they knew of eggs, insect life cycles, and how they could tell if it was really an egg. They decided to keep it and see if anything "hatched" out of it. I mentioned to Chelsea the need to focus on insect life cycles to avoid a misconception developing.

Example 4. Chelsea followed this up with an exploration of the school grounds to find creatures and the habitat they were living in. She had, in the meantime, discussed ideas with a colleague, John Hunt, about the children devising a trap for a creature (technology); and this was intended partially as an entry to an activity sequence. However, she also wanted the children to work intensively with an insect to work out its life cycle, but did not know which one to choose, how to get enough of them, or how to go about it. Several years before, she had kept silkworms and wanted to replicate the success of that unit; but it was the wrong season for silkworms. In the playground, the children had found some case moths[1] living on the leaves of a tree. As there were large numbers of them on several trees, I suggested that Chelsea use these. She could readily give a case moth to each child for a lesson, during which they could study it closely. The case moths could then be returned to their habitat, but one or two could remain in the class terrarium for ongoing study. This would give the children a focus when gathering information

[1] The case moth is the larval (caterpillar) stage in the life cycles of a number of species belonging to the insect family, Psychidae. The caterpillar spins a silk cocoon to which it attaches leaves or twigs, forming both a camouflage and protective case. A brief summary is available online at http://home.bluepin.net.au/yallaroo/Case_moths.htm (retrieved 14 April, 2005).

about insect life cycles by looking in books and the like. I also suggested that she follow up with more limited investigations of some of the other creatures the children had found (e.g., scale insects on leaves that the children thought were eggs). This launched Chelsea into a whole new exciting direction.

Example 5. After the case moth investigation, Chelsea was looking for an activity that would both help the children synthesize the work and lead to an effective assessment strategy. I emailed her the following suggestion:

> I had an idea for a culminating activity prior to final assessment: a story-telling and constructing activity. It could just be story-telling, or it could have the added component of making a book, as well (lot more work). Don't feel obliged to take the idea up—only if you like it and are comfortable with it.
> Work as a whole class. Tell a fictionalized story of Kate the Case Moth Caterpillar, building in what has been found out. The children could fill in important bits. For example:
> Kate wriggled out of the egg case. There was dim light coming through the silk case where the eggs had laid hidden. She saw a brighter patch and wriggled toward it. Not that she could see like you and me—she could only make out light and dark places.
> (This could be one picture. As the story is told, make an outline sketch of essential parts—the egg case, Kate, and a hole. The children could be involved in doing bits too.)
> She perched on the edge of the opening in the case and felt a gentle breeze blowing in her face. Perfect! She busily spun (have children say what) a tiny silken thread, letting it flow out with the breeze. Before long, she was flying through the air, carried along by her silken thread just like someone with a parachute.
> (Another picture of Kate at the opening, with a thread.)
> Kate came to a gentle stop. Her thread had caught on the (have children say what) leaf of a tree. She quickly wriggled onto the underside of the leaf so she could hide from any birds looking for a tasty caterpillar meal. She was hungry, so hungry! She tasted the leaf to see if was good to eat. Yummy!! She was in her new home.
> (Another picture).
> Then she could start spinning her case and cut out bits of leaf to stick onto it. And so on. Have to watch the mating bit I suppose!

Chelsea adapted this suggestion to include an assessment exercise. After the story telling, each of the children was given his or her own booklet of the story with incomplete sections. They were asked to draw the various parts of the story (several weeks earlier I had had a conversation with Chelsea about using drawings as a window into children's understandings). As they completed their drawings, she conferenced with the children, exploring their understanding of the life cycle and specific aspects about the case moth.

The Teachers' Perceptions

Each of the teacher's perceptions about the changes to their practice and what contributed to those changes are outlined below. Their views were triangulated with classroom observations and field notes. The statements address both research questions.

Sonya's Comments About Changes in her Practice and My Mentoring: Sonya's own words convey best her perceptions, so I have avoided summarizing them. She believed that she had made several major shifts in her science teaching. She described the following changes to her practice, for which I have provided a descriptive label.

> *Outcomes and Constructivism*. I feel that I have moved along a bit, and I can take on board an outcomes approach better that I could before. I used to get all caught up in the activities and my actually keeping track of the activities so closely that I wasn't allowing the children the freedom to explore an area or concept and run with it. So I have found having this more constructivist approach has allowed the children to learn more and find their feet with concepts that are probably further that what we expected.…It allowed them to explore things with a greater depth.…The old way I used to do it, I had my objectives clearly in mind and then I would be more evaluating my teaching than what they had actually learned and what they were demonstrating to me that they now know. (Sonya, postinterview)
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> *Children Thinking for Themselves*. [T]hat part appealed to me where it said students learn best when they participate in a number of activities that give opportunities for them to work things out for themselves. I think the kids have done that. We posed questions, and they have answered them and given good reasons a certain thing happens. For example, "Why can you see the moon in the daytime?" "Because it is always there. It is just [that] we've moved from night to day." Remember the day we looked out at the clouds, and we were talking about the colors, and they all had ideas why the clouds were different colors [at] different times of the day. (Sonya, postinterview)
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> *Flexible Planning*. They are things that probably, in the way I used to teach, wouldn't allow for that because it would be too straight down the line.…That was the way we were taught to teach. You actually had it clear in your mind how something would eventuate. That was, you had your objectives and your learning techniques, and you evaluated that, and you were mostly evaluating yourself, and you gave something that was probably a very narrow assessment tool that would say, "Yes I'm a pretty good teacher, aren't I, because I can teach that." But this way there is probably a wealth of knowledge [where] the main idea was to see if [the children] had reached that outcome, what they learned, and what they know and what they can do. (Sonya, postinterview)
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> *Metacognition*. And the kids reflecting on their learning too. I've always been keen on that metacognitive awareness. I think this kind of planning and teaching supports metacognition better than I've seen in other styles of teaching. And the parents have been very keen to let me know how much their children now know, that they seem very switched on by their learning.…You know, it's kind of putting teaching back into a big learning perspective. To start a child's learning career like that is a good way to be. (Sonya, postinterview)

Sonya attributed these changes to specific roles that I had played.

Modeling Teaching. [Ken] assisted greatly in the delivery of the lessons, because a few times I'd say, "Oh that sounds a bit curly.[2]" And he'd say, "Well, I'll be around then. Would you like me to give a hand with that?" So it was really good, because where I may not have even tried it or attempted it, having him there to just, you know, with one sentence to have this powerful lesson and the activities heading in this direction because of one sentence, you know? It was good for him to model. So I guess he became a role model for the way I could approach that learning for the children, or teaching. (Sonya, postinterview)

Expert Help. [H]aving [Ken] around gave me confidence to trial things that were of a hands-on nature that maybe I didn't quite understand, like making a circuit and the illusion box. So I was willing to call on somebody else to be the expert to come in and help.

And that expertise, having that knowledge that [I lack available]. I'm not big on science in terms of my [education]. So having someone who you can pick their brains was really handy, good. (Sonya, postinterview)

Support in Making Changes. You know, there was this great kind of awareness thing. I know through things that Ken's said, it's still been a long journey for me to arrive at where I am now. (Sonya, postinterview)

Building a Relationship. [I]t's all about developing a relationship and having that rapport going, too. I mean, Ken often sat here, and there'd be birthday cakes [in the staff room]—he just sort of became part of what we are here. And he was very welcome, and I think he felt welcome, too. So he was touching base with us fairly often, and he'd say, "Do you need a hand here?" And he didn't mind bringing out resources, just offering help where we sort of needed it, I guess, which is a bit intuitive, isn't it? So that's a gift, rather than something that you plan. (Sonya, postinterview)

Flexibility. [Ken] sort of fitted in well with our program. (Sonya, postinterview)

Chelsea's Comments About Changes in Her Practice and My Mentoring: Chelsea also felt that she had made personal changes to her science teaching practices that were directly attributable to my involvement.

Hands-on Science. [This unit] was much more hands on than my normal [science teaching]. Probably my normal lesson on something like that would have been much more book orientated, computer orientated. But we were out in the paddock looking at these [creatures], and it was because we were out looking and we found so many of them that we decided to actually do that study [of case moths]. So it was much, much more hands on than we've ever done before.…I never thought I could actually get things [resources] from around the schoolyard. I think it made us look at our own back yard much more closely. (Chelsea, postinterview)

Less Controlling. If I'd have done a lesson on case moths, say, before…I would have given the kids the answers, straight away. I'd have done the research myself, made sure I knew about it before I did something with the kids, and as we went I would have told them [the information at] each stage of what we were doing.

[2] Difficult.

I wouldn't have been asking them to make inferences, and [having] them coming up with ideas. Especially, I wouldn't have let them have the wrong answer with something scientific. What we've been able to do is let them come, sometimes, with the wrong answer—although sometimes I haven't known if it's the right or wrong answer. My knowledge myself was a bit limited.…But even when we knew they weren't right, we didn't put them right straight away. We let them think about what they were doing, and they came up with the right answer in their own time. That really helped their thinking. (Chelsea, postinterview)

Depth of Learning. [What has surprised me about the children's learning is] the depth of what we've gone into—it's beyond [what I would normally do]. Normally with my [poor] knowledge of science and my [low] confidence in science, I wouldn't have gone into such depth, and their learning wouldn't have been so deep. I've had some of them go home and tell their parents that they're experts on moths. Another one went home and said, "I know everything there is to know about minibeasts. Ask me something." And their confidence in the area is just incredible, even the ones who don't have a total understanding. (Chelsea, postinterview)

Changes in Assessment. Talking to [Jonathon] now, his understanding is so much more advanced, it really is.…Actually I was a bit surprised today and a bit shocked with Robert. I thought he understood the life cycle of the case moth, but he actually said that the moth emerged from the egg.

I now know how to [transfer images from the digital camera to the computer] and to get from taking photographs of our case moths to using them in the books for the children's assessment. (Chelsea, postinterview)

Planning Based on Children's Learning Progress. I think after we're done, at the end of this lesson, it might be good to look at other butterflies and moths just to, it is time now to set them straight, if they're still getting the wrong idea about the life cycle. (Chelsea, postinterview)

Transfer to Other Subjects. [This way of teaching is] spilling into the other things in my room. So even the literacy block to a degree—we're continuing doing our insect study in the literacy block. (Chelsea, postinterview)

Improved Self-Confidence in Science. Doing [science] this [way], I'm not worried about not having the knowledge. I don't mind exploring with the children. You asked if I'm comfortable doing that kind of thing. I'm very comfortable with my class, but wasn't so comfortable about looking for things I knew nothing about in science. It would fall flat, but now I realize I don't have to have all the answers—just to be able to do some of the research and get the children to help me. So that was really, really beneficial. I think I'll try that again in any aspect of science that I do—not having to know the answers beforehand. (Chelsea, postinterview)

Regarding self-confidence, Chelsea developed sufficient confidence to telephone an entomologist at the Queensland Museum and then the Department of Primary Industries in an attempt to find out more about her case moths. The fact that they were mostly unknown to the entomologists surprised her and led her to the confidence-boosting realization that her classes' work was new science.

Chelsea highlighted some specific aspects of my, and a colleague's, mentoring that particularly helped her.

> *Modeling Teaching*. [I]t's mainly been [Ken's] visits out here, rather than [formal inservice sessions at] the university….[H]aving [Ken in my classroom] every week, helping me build up the children's learning, that was fantastic….[And him] guiding me into the types of questions that we should be asking the children. That probing of the questioning, that really extended my knowledge and gave me a science [understanding]. (Chelsea, postinterview)
>
> *Expert Help*. [A colleague] came [to the school at the beginning of the unit and] helped me with Inspirations [computer planning software] and gave me some ideas of what I could do for my first lesson.
>
> *Interviewer*: Was [the first activity where you got the children to draw animal homes to find out their existing ideas] something that you would have normally done?
>
> *Chelsea*: No. I hadn't thought of that before, that was an excellent idea….[I found out] what they knew about the insects and their homes. It showed me where they were coming from. It showed me the ones who had some ideas about what insects did, to those who hadn't a clue. That was a good start [to the unit, finding out] that prior knowledge. (Chelsea, postinterview)
>
> [When the children were drawing their insects,] [Ken] suggested getting the magnifying glasses out and having the children look at the insects and see how they really were and not just how they imagine them. (Chelsea, postinterview)

Children Thinking for Themselves and Support in Making Changes:

> *Interviewer*: Is there something that pushed you toward [helping the children with their thinking] that you can put your finger on?
>
> *Chelsea*: [Ken]. The way [Ken was] questioning the children. [He] often stopped me from telling them the whole picture, from giving them the whole picture. [He] encouraged me to give them a bit at a time and let them discover by themselves. That and the fact that we went out looking for things [creatures]. (Chelsea, postinterview)

Discussion

The results above reveal different aspects of the mentoring that were effective for the teachers.

Roles Assumed by the Mentor

These aspects are summarized below as roles assumed at different times by the mentor, in answer to research Question 1. The mentor

- was an expert in the classroom who bridged the confidence gap for the teachers—their success led to increased self-confidence in teaching science;

- provided support for the teacher when venturing into risky teaching behavior, so there was an increased incentive to take risks;
- was at times a classroom helper—another pair of hands in the classroom when things became busy;
- presented alternative views of teaching and learning for the teacher to consider;
- challenged the teachers' current science teaching practices and extended their thinking about how to help children learn; and
- was a source of expert knowledge for the teacher in
  - curriculum (particularly the new curriculum and working from outcomes),
  - science content,
  - science PCK,
  - general pedagogy, and
  - assessment.

Together, these roles adopted by the mentor facilitated real and lasting changes in the teachers' practice. For instance, when I visited Sonya's classroom 2 years after her professional development involvement, she was still engaging her pupils in exciting hands-on, minds-on science based on the new outcomes curriculum.

According to the teachers, the more formal orientation sessions did little to influence their teaching, whereas the regular classroom support had a significant impact on helping them review and change their science teaching practice. This is not to say that the orientation sessions were of no value, as they provided a context for the subsequent classroom support. However, from the teachers' perspective, the mentor's multiple roles adopted in the classroom were more helpful.

Sonya's point about the mentor being flexible and fitting easily into the school and classroom routine is also important. A degree of flexibility by both teacher and mentor were necessary to work around school, class, and university schedules. The regular weekly, sometimes twice-weekly, contact was also important to the teachers. Further, for a mentor to help teachers successfully, a level of trust must be built between them. This can only be established by professional time together. Both Sonya and Chelsea mentioned their initial nervousness about having a high-profile university professor in their classroom, and their slight reservations about the "classroom currency" of the professor (reflecting the common perception of professors' being "ivory-tower" people). It took a few lessons working together before their nervousness and reservations were dispelled. It is, therefore, essential that the mentor be classroom current and possesses considerable interpersonal skills to negotiate a way into the school and classroom and have an ongoing welcome.

By trial and error in these and other teachers' classrooms, I have found that the mentor's behavior in the classroom is also important. The mentor needs to be a critical friend and helper to the teacher and should always defer to the teacher's decisions about what to do and how to do it. In practice, once trust is established, the relationship becomes a true partnership with genuine cooperative teaching; but I have always been careful to acknowledge that I was working in the teacher's classroom. Although I was helping the teacher, I was also a disruption to the normal routine and operation of the class.

Mentoring as a Means of Extending Science PCK

Many of the above roles have a common focus and highlight how, during the mentoring process, I was frequently acting as a source of science PCK for the teachers. While the teachers expressed reservations about their limited science content knowledge on occasions, what they were really referring to was how to make the science content (that they admittedly were uncertain of) relevant and available to the children.[3] I drew upon a range of different aspects of my own science PCK, including activity ideas; pedagogy to enhance children's thinking; "scientific" explanations of phenomena appropriate to the children; examples, analogies, and models that help children reach understanding of complex ideas; ideas for children's recording of data; and questioning and similar interactions with children. My explanations of why I was doing some of these things exposed my beliefs about the teaching and learning of science and about the nature of science.

These are all elements that contribute to the development of science PCK. As the teachers observed my science PCK in practice, they assimilated aspects of it into their own practice, building new PCK for themselves. They also developed in confidence with teaching science, providing an important stepping stone to the construction of science PCK (Appleton 2006).

When I looked at Sonya's and Chelsea's science teaching practices at the end of my time with them and compared this to their previous practices, the most noticeable change was their increased usage of what I consider to be more appropriate science PCK. This had been enabled by improved self-confidence in science and a greater willingness to find out science and science teaching ideas for themselves. They had not become experts in the sense that they acquired large amounts of science content knowledge, but they had found that they could now access the science content that they needed and could use this and their other forms of teacher knowledge to generate and adapt science PCK for the lessons they wanted to teach. Their interactions with the children, in particular, had changed toward a more inquiry-based constructivist orientation. This happened not only because they now had a new repertoire of science PCK for science lesson interactions, but had also modified their views of science teaching and learning.

Characteristics of a Mentor

In relation to research Question 2, I infer from the above that a mentor should have the following characteristics:

- be knowledgeable in at least curriculum, science content, science PCK, general pedagogy, and assessment;
- have high levels of interpersonal skills;
- be recognized by the teacher as an expert who can provide help;
- be classroom current; and
- have considerable time flexibility.

[3] In my experience, teachers do not distinguish between science content knowledge and science PCK, as these are theoretical constructs more useful to researchers and the like.

Conversely, it is essential that a participating teacher go into the professional development willingly, be prepared to have their teaching challenged, try new ideas, and be ready to take some risks (Peers et al. 2003).

Comparison with Other Literature on Mentoring

It was during the conduct of this research that I began to use the term "mentor" to describe the relationship I had with the teachers. After arriving at the above conclusions, I consulted the mentoring literature to clarify whether my notion of mentoring derived from this analysis was consistent with mentoring described more generally. In the following discussion, I link the mentoring literature to the findings of this study. I drew on a seminal analysis of a number of studies of mentoring by Kochan (2002b), who outlined three dimensions of successful mentoring: mentoring is relational, reflective, and reciprocal. She suggested that there are three elements of the relational dimension.

1. *Commitment*. Both mentor and mentee must be committed to the relationship and to making it work. They must be prepared to find time to meet and share.
2. *Caring*. There is an emotional side of mentoring where a sense of caring for each other develops. Important components of this are mutual trust and respect (also, see below), and a willingness to share "both the good and the bad" (p. 279).
3. *Collegiality*. In successful mentoring, both participants need to be comfortable working together and to be able to communicate effectively.

In the instances of mentoring reported in this study, there were high levels of commitment from both teachers and the mentor. Elements of caring, especially mutual respect and trust, developed as the mentoring progressed. Fortunately these were established within a few weeks, enabling coteaching to commence. At the same time as trust and respect developed, we began to feel comfortable with each other, as the level of collegiality increased.

In terms of the reflection dimension, Kochan (2002b) suggested that three important elements were as follows:

1. *Purposes*. Both mentor and mentee need to have a mutual understanding and agreement about the nature of the mentoring and why it is happening.
2. *Partnership Functioning*. The nature of the mentoring relationship should be subject to scrutiny and reflection and evolve as necessary as personal and professional growth occurs.
3. *Progress*. It is also necessary for both participants to reflect on the extent to which the purposes of the mentoring are being met.

The purpose of the mentoring was not clear initially for the teachers in this study. Although I had explained this a number of times, a mutual understanding of the mentoring process developed at the same time as mutual trust and respect. This may well have been because of a perceived power or status differential between university professor and teacher. While the nature of the mentoring evolved as time went on, this was not consciously built in as a component of the mentoring in these programs. However, there were regular discussions as to whether the teachers' needs were being met and with what they needed help. Feedback was also provided as to how the mentor was benefiting from the classroom work with the teachers.

Kochan (2002b) also outlined three elements of the final dimension of mentoring, reciprocity:

1. *Common Values*. Kochan suggested that both mentor and mentee need to have similar values for mentoring to be successful.
2. *Mutual Respect*. This is related to the above element, caring. It is important that the mentor recognize that "many mentees were individuals who had already made contributions" (p. 282) and needed to be acknowledged as having equally valuable knowledge and expertise as the mentor.
3. *Joint Benefits*. The relationship needs to hold benefits for both participants.

On reflection, I believe that both of the teachers and I shared such values as a strong desire for them to reach the best teaching in science that they could and a desire for the students to achieve enhanced learning in science. A level of mutual respect already existed at commencement, but this developed further, quickly. In both of these studies, there were clear benefits to both the teachers and the researcher—the teachers developed professionally, and the mentor was also able to act as researcher of the professional development program. Based on this comparison to the literature, I concluded that the professional development program described here was consistent with the general view of mentoring in other fields and could be used to guide further developments of the program.

Implications for Science Teacher Professional Development

This study has provided a greater understanding about elementary science teacher professional development from the perspective of mentoring. In particular, it shows that mentoring of experienced teachers[4] (as opposed to beginning teacher mentoring) can be a critical contributor to helping teachers make lasting changes to their science teaching practice (Peers et al. 2003).

Formal professional development programs, where teachers are withdrawn from the classroom for intensive work with experts, have been the traditional professional development model in Queensland for many years (Anderson 2000). Some programs have provided ongoing support for teachers as they work with the ideas that were developed in the formal sessions; but this is the exception, rather than the rule. One reason for the continued use of these traditional models is that they are cost efficient: They allow large numbers of teachers to be inserviced by experts for a relatively small cost. Despite this apparent efficiency, they are largely ineffective (e.g., Anderson 2000). A mentoring model, such as that outlined here, is limited in that the number of teachers who can be inserviced is relatively small; and it cannot

[4] Several early career teachers were involved in the various projects. The focus of the professional development was not highly effective for them, as they were still coping with "survival" issues. That is, they needed a different sort of professional development program. My conclusion was to work with teachers with at least 3–5 years' experience.

happen in a day or two, but must be sustained over many weeks. That is, it is cost inefficient.

My experiences with formal professional development sessions over the many years that I have been running them have never before resulted in the extensive teacher-change that I have witnessed in the teachers I have mentored. Some of these teachers, such as those reported in this study, have made extensive changes to their practice, others more conservative changes, while a small minority declined to be involved. The dilemma for education systems is whether to provide cost-efficient professional development that achieves little, if any, change in the classroom; or to provide professional development that is cost inefficient, but highly effective in generating change in classroom practice and enhanced student learning.

On the basis of my mentoring experiences, I suggest that, if science professional development is to be successful in generating teacher change, a major component needs to focus on classroom support that enhances the teachers' science PCK. While there will always be a place for some formal sessions when teachers need to be withdrawn from classes so they have time to think and discuss, unless there is an associated period of classroom support, most teachers are likely to make only minor changes to their practice. Forms of classroom support other than direct classroom intervention have been trialed successfully by others (e.g., Hardy and Kirkwood 1991), so I am not suggesting that mentoring is a panacea for solving the difficulties associated with elementary science teaching. On the other hand, mentoring has been a notable feature of this and other recent professional development projects in both science and technology education (Moreland et al. 2001; Peers et al. 2003). At the very least, mentoring should be further investigated as a means of facilitating effective change in both elementary science teachers' knowledge base and, in turn, their science teaching practices.

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Appendix

During my 30 years as an elementary science teacher educator, I have had extensive involvement in teacher professional development in elementary science. The introduction of a new statewide elementary science curriculum prompted a local private school system to ask me to develop a professional development program to support the new curriculum implementation. This led to a series of research and development projects spanning 6 years in both private and state schools. The projects concluded with the presentation of a proposed elementary science professional development model to the local education office of the private school system.

Since the new curriculum was outcomes based and heavily influenced by constructivism, it was not clear whether traditional professional development models reported in the literature would be effective. The analysis of successful, constructivist-framed science professional development reported by Bell and Gilbert (1996) provided some guidelines, but the main approach adopted was to have teachers determine, as much as possible, the content and nature of the professional development. A series of action research projects ensued, where evaluation of each professional development project guided the shape of the subsequent project.

The first project involved participant observation of a small group of teachers cooperatively planning work from the new curriculum, with professional development provided in situ as the need became evident (Appleton and Harrison 2001). The project concluded with the teachers' reflections and suggestions for professional development that would be effective for colleagues. The next project, which incorporated these suggestions, showed that the model was not effective (Prinsen 2001), resulting in substantial modification of the professional development program based on the research. At this point, comments from the teachers about "activities that work"—and the way they went about planning using such activities—prompted me to revisit earlier research on this (e.g., Appleton 2002) and its relation to science pedagogical content knowledge.

The next project showed that, despite success in having teachers conclude the workshops with a cooperatively planned (with the researcher) ready-to-teach science unit, they did not teach it. On reflection, they later suggested that I should visit them in their classrooms to help them get started. All subsequent projects incorporated this component, which proved to be a key aspect that helped the teachers make actual changes in their science teaching practices. At this time, the professional development was more deliberately framed around development of science PCK (see Appleton 2006, for a summary of those deliberations).

Once the professional development model had been developed to the point where it was beginning to show success in helping teachers, a search began to identify literature that may provide an understanding of what was happening to provide further guidance for improvement. This led to an exploration of the mentoring literature, resulting in a post hoc analysis of the role of mentoring in the professional development, as discussed in this paper. There was one final project after those reported here (see Koch and Appleton 2007).

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