Enhancing pedagogical content knowledge in a collaborative school-based professional development program for inquiry-based science teaching

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Abstract

This study reports on the trial of a school-based professional development process aimed at helping science teachers improve their inquiry-based science teaching skills. This process focuses on developing the pedagogical content knowledge of teachers through peer collaboration, under the guidance of a teacher educator. A multi-method interpretive approach is employed to capture the development of such knowledge in the research process. The findings reveal both the potential for collaborative professional development in in-service teacher training, and the challenges faced by both primary school science teachers and teacher educators in promoting inquiry-based science teaching. The implications of the findings are discussed to develop a more in-depth understanding of the nature and processes of pedagogical content knowledge.

Background to the Research

A new General Studies (GS) curriculum integrating science and social studies was implemented in Hong Kong in 2004. The science component is to be taught through inquiry (CDC, 2002). However, research has identified the inadequacy of teachers' content knowledge as one of the major issues facing primary science education in Hong Kong (So, Cheng, & Tsang 1998). Such inadequacy makes it difficult for primary teachers to adopt more interactive approaches to teaching science (Abell & Roth, 1992; Childs & McNicholl, 2007; Newton & Newton, 2001; Sanders, Borko, & Lockard, 1993).

Teaching science through inquiry requires that teachers master not only the substantive, but also the syntactical structure of the discipline (Schwab, 1962). The latter comprises the processes essential for inquiry into scientific phenomena. Thus, teachers need to develop their own understanding of scientific inquiry before they can lead students to understand and apply these processes. Both these two types of knowledge constitute the subject matter knowledge (SMK) which is required by science teachers as described by Shulman (1987). Apart from this, Schulam also identified another form of teachers' knowledge, pedagogical content knowledge (PCK), , which "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). Researchers have argued that such knowledge is contextual and specific to particular topics (Cochran et al., 1993; Shulman, 1987; Van Driel et al., 1998). Magnusson, et al. (1999) described PCK for science teaching as embodying five components: orientation to teaching science, knowledge of students' understanding of science, the science curriculum, assessment, and instructional strategies in the context of scientific inquiry. It involves an understanding of the contribution of inquiry-based instruction to learning science, students' scientific reasoning, and the ways to guide them to construct substantive scientific ideas through formulating appropriate learning objectives and designing relevant inquiry-based activities and assessment tasks. According to Keys and Bryan (2000), inquiry-based instruction demands in-depth pedagogical content knowledge. As far as science teaching is concerned, inquiry-based teaching should aim not only at enhancing substantive knowledge, but also syntactical knowledge. This implies that PCK involves the blending of scientific content knowledge, the concepts of inquiry, and pedagogical skills to develop this knowledge and these concepts in students, while taking into account students' abilities and interests. This attention to these students' attributes is particularly noteworthy in light of the finding that children appear to be capable of much richer scientific thought than previously envisaged (Metz, 1995; Tytler and Peterson, 2004), although students' alternative conceptions of particular topics still abound (Driver, et al., 1985; Osborne and Freyberg, 1985).

School-based Professional Development Efforts

As the above review shows, the development of school-based university-school collaborative efforts to articulate and develop teachers' PCK and SMK for the design and implementation of inquiry-based instruction is a successful strategy. This study seeks to answer the following two further research questions.

1. To what extent can the process of collaborative school-based professional development advocated in this research help within-school communities of primary teachers to develop SMK and PCK for teaching science through inquiry?
2. What challenges do teachers and teacher educators encounter in applying this model within the school context?

Table 1: A tentative model of collaborative school-based professional development for GS teachers

Teacher educator's tasks	**Stage in the teaching cycle**	**Teachers' tasks**
Collaborating with teachers; Coaching and facilitating teachers to develop and integrate knowledge bases; Facilitating peer interaction and collaboration; Providing technical advice	***Planning*** 1. Selecting the theme/problems for scientific inquiry 2.Eliciting students' alternative conceptions 3. Setting learning objectives and designing inquiry tasks 4. Preparing lessons (e.g., resource management)	Researching knowledge of learners Clarifying their own SMK Making connections with different knowledge bases to develop PCK Interacting and collaborating with peers and teacher educators to enrich PCK
Observing and supporting	***Implementation*** 5. Delivering instructions, guiding students to learn through inquiry, providing explanations	Applying PCK Reflecting on their SMK and PCK Supporting peers in teaching
Facilitate teacher evaluation	***Evaluation*** Evaluating teaching and learning	Reflecting on their SMK and PCK in relation to student learning Suggesting future development and changes

In this study, primary school teachers collaborated with a teacher educator, the author of this article, to develop and reflect upon lessons that promote inquiry-based science teaching. To guide the actions of both parties, the following professional development model was proposed.

Both the teachers and the teacher educator were engaged in the same teaching cycle, but their focus was different. The teachers were concerned with how they could make use of the inquiry-based approach to teach science and what knowledge, particularly SMK and PCK, they needed to develop to do so. The teacher educator was focused on how in-service teachers can be helped to develop the necessary knowledge base to teach through inquiry and what role the teacher educator plays in this process. Thus, this research can be considered to be both ethnographic and interpretive. The researcher experienced the process of knowledge construction and reflection with the teachers, while collecting data for his own research.

Two learning communities were established in two different schools. The panel heads of the two schools had previously participated in an in-service training workshop on inquiry-based teaching and had tried out some of the workshop activities in their classrooms. Both expressed interest in developing the capability to implement inquiry-based teaching in their schools. Four teachers were involved in School A, and six in School B, all co-opted by their panel heads. They were thoroughly briefed on the research framework so that they were clear about the roles expected of them. The School A teachers worked with Primary 3 students (aged 8-9) and the School B teachers with Primary 5 (aged 10-11). The topics chosen were, respectively, the expansion and contraction of air and electricity. For each school, a wide range of evidence was collected from the following sources.

1. Lesson planning meetings (LPM)

Lesson planning meetings (LPM) were conducted with the teaching team to plan the lessons. In the first meeting, apart from brainstorming how the lesson could be designed, the teachers were encouraged to elicit the students' conceptions and misconceptions by designing a pre-lesson test. This test was also utilized by the teacher educator to explore the teachers' SMK, so as to help them clarify their own understanding of the topic. The same test was administered to the students after the lessons. In subsequent meetings, the teachers suggested inquiry activities to develop concepts relevant to the topic. These meetings served the dual purpose of eliciting teachers' PCK in the form of teaching ideas, and further developing those ideas and their underlying knowledge bases through collaboration with the teacher educator. All the meetings were videotaped, and transcribed for further analysis.

2. Field notes of observers (VRL/FN)

Field notes were taken by the teacher educator who observed some of the lessons. Records were made of teachers' instructions and explanations, and teacher-student and researcher-student interactions in the inquiry process, with particular focus on identifying teachers' SMK and PCK. All lessons were videotaped to supplement the field notes.

3. Teachers' reflection journals (TJ)

Teachers wrote reflection journals shortly after each lesson. These journals were divided into three parts: (1) teachers' SMK for teaching through inquiry; (2) teachers' conceptions of students' knowledge and their ability to inquire; and (3) teaching strategies and their perceived effectiveness. The teachers were encouraged to substantiate their reflections with specific classroom episodes.

4. Team evaluation meeting (TEM)

Team evaluation meetings were held to analyze the post-test results, facilitate the in-depth sharing of teachers' reflections, and discuss further improvements to the lesson design and instructions.

5. Teachers' questionnaire (TQ)

Anonymous teachers' questionnaires with items ranked on a 5-point Likert scale were administered after the evaluation meetings to elicit teachers' perceptions of the study outcomes in five aspects: their development of SMK, their understanding of students' knowledge and skills, their perceived knowledge of instruction design, their confidence about teaching through inquiry, and collaboration with the teacher educator. The questionnaire items were reviewed by two science educators to ensure face validity. The analysis presented here focuses on the transcribed video-records of the LPMs, TJs, and TEMs, supplemented with the field notes taken by the teacher educator on six observed lessons. These qualitative data, including statements made by teachers/students/the teacher educator or dialogues among these parties, were read thoroughly before coding them as short episodes. These episodes were classified into three categories that reflected (1) teachers' SMK, (2) their understanding of students' conceptions and reasoning, and (3) their understanding of their own instructional strategies. The latter two reflect teachers' PCK.

Results and Analysis

Case One: School A (Grade 3)

Topic: Expansion and contraction of air Teachers involved (all teachers in both schools are given pseudonyms): Nancy (the panel head), Helen, George, and Tim

Planning of the Lessons.

In the planning meeting, the teachers were passive and expected input from the teacher educator. Nancy referred to a reference book with an interesting science experiment to illustrate the expansion and contraction of air: a glass bottle is covered with a deflated balloon and immersed into either hot or cold water. This initiated a discussion on inquiry activities and the scientific concepts they sought to develop.

> Nancy: I used to think that the skin of the balloon expands, but not the air. The results of the experiment do not convince me that I am wrong.
> Helen: I guess students might have the same idea as you.
> George: So, how are we going to convince students that it is the air that expands?

This episode shows that some of the teachers confused the expansion of air with the expansion of solids and assumed their students would have the same misconception. This was followed by another exchange.

> Teacher educator (TE): Do you know about the trick of dropping an egg into a bottle with a narrow neck using hot and cold water?
> Nancy: Yes, but I am not sure how it works exactly.

The TE then explained the principles of this experiment.

> George: Yes, that sounds interesting, but I don't think Grade 3 students have any clue about air pressure, because even we are not familiar with it. Please could you explain to us what exactly air pressure is about.

As can be seen from this exchange, the SMK of these teachers was quite varied. Their own unfamiliarity with air pressure appeared to influence their prediction that the concept was beyond the reach of their students. They were then asked to discuss the students' conceptions of the topic of air, as follows.

Nancy: They should not have done anything about air in lower grades, because we plan according to our textbook. The unit on air and its properties is for Primary Four.

TE: But do you have any clue why the topic of the expansion and contraction of air precedes more basic topics about air?

George: It is probably because this topic is not restricted to air. It also introduces the expansion of solids and liquids, whose properties have already been covered.

Helen: Yes, the curriculum seems to be problematic. The topic of air should precede the topic of expansion and contraction, because if students have no idea about air, they will not be able to make sense of its expansion and contraction.

In this episode, the teachers are reflecting on and integrating different types of knowledge, including their knowledge of the learners' abilities and the topic sequences deemed to be conducive to the progressive development of relevant concepts, and transforming them into their PCK for this air expansion and contraction unit. All teachers agreed that it was instructive to check the children's understanding before designing the lessons. With input from the teachers, the TE helped them to design a pre-test to check students' understanding of the relevant concepts of air, such as air occupies space, air is capable of contraction and expansion, and air exerts pressure. Two selected pre-test items are provided in Appendix 1A.

The results were then discussed in the second LPM, during which the teachers began to analyze students' understandings of the topic. This led to the generation of some reasonable hypotheses about students' understanding of air, which can be seen in the following transcript.

George: Quite a lot of students (42%) said that water would fill up an inverted cup as it was lowered into water. This seems to show that not many of them knew that air occupies space

Nancy: The results show that although many students were able to predict that a balloon will expand when it is placed in hot water and contract in cold water, many of them did not realize that air will leave the bottle when it is immersed in hot water.

TE: What does that tell you about students' understanding of the expansion of air?

Nancy: It may show that students do not really understand that it was the air in the balloon that expanded. They might interpret it as the skin of the balloon expanding, but not the air inside.

Tim: Quite a number of students (39%) have the idea that a balloon bursts when it is pricked with a needle because of the high air pressure inside. Based on this analysis, the teachers discussed the activities to be included in the lessons, thus connecting their knowledge of students with their instructional strategies.

Nancy: I think it is very important to consolidate students' conception about the existence of air and that air occupies space before leading them to inquire into its expansion and contraction.

George: We could ask the students to invert a cup with tissue paper inside it and then force the cup into the water. The tissue paper will not get wet because of the air inside. These episodes show the teachers becoming increasingly aware of the necessity of sequencing the topics in a progressive manner, so that the teaching of fundamental concepts preceded that of the more advanced ones. Recognizing that the teachers were ready to progress further, the teacher educator continues to lead the teachers through the planning process.

TE: How could you develop students' conception of expansion and contraction? The teachers began to blend the content to be learnt by students with the pedagogy of inquiry-based learning by drawing on the activity they just learnt from the teacher educator.

Tim: I would include the egg-in-a-bottle activity to make the inquiry more fascinating. It is very interesting and can be treated as a problem-solving task to test students' application of what has been learnt. Again, the issue of content sequencing was brought up by George.

George: We need one more activity in between to give students some basic idea of the expansion and contraction of air.

Helen: Could we use the balloon-in-the-bottle activity? The teacher educator stepped in again to remind the teachers of what have been discussed earlier, that is, students may confuse the expansion of air with that of solids.

TE: Aren't we a bit wary that students may confuse the expansion of air with the expansion of the balloon?

The TE suggested an alternative activity to replace the balloon-in-the-bottle activity: placing soap film over the mouth of a plastic mineral water bottle. This film then becomes a soap bubble when the bottle is placed in hot water, with the bubble reverting to flat film and continuing to move down the neck of the bottle when it is placed in ice-cold water. The teachers were very excited about this activity and considered it a better alternative. Through this process of deliberation, the teachers generated some feasible teaching strategies.

Teachers' Reflections on Implementation

The teachers were asked specifically to reflect on their SMK in the TJs and TEMs, as well as their perceived knowledge of the learners and their instructional strategies

Subject Matter Knowledge (SMK)

The teachers were particularly positive about the improvement in their SMK, as illustrated by this entry in Nancy's journal:

> The planning sessions helped me a lot in clarifying my conceptions about the topic. I used to think that the reason the egg dropped into the bottle is that the egg contracted when cooled. I now have more confidence in teaching this topic.

However, not all of the teachers were as confident. George was particularly explicit in this regard in his TJ:

> George: I also know more about the concept of air pressure after the planning meetings, but I think air pressure is too difficult for the students probably because I don't have enough confidence to explain it to them. That is why I explained the results of the last two activities solely in terms of the expansion and contraction of air instead of air pressure.

This shows that teachers' SMK is still very much an issue. They tended to avoid concepts that they did not understand well and considered to be too difficult for the students, for example, air pressure, even after some students had shown some understanding in the pre-test.

Pedagogical Content Knowledge (PCK)

Knowledge of learners' conceptions and reasoning. In the second part of their reflection, the teachers shared their insights and understanding of the conceptions and abilities of their students after the lesson. For instance, Nancy was surprised that the students' ability to conduct inquiries was far better than she had expected.

> Nancy (in her TJ): Students could design their own methods to solve the egg-in-the-bottle problem, which was beyond my expectation.

However, there were times when the teachers' perceptions contradicted the evidence, as can be seen in the following excerpt from a TEM.

> Helen: After the experiments to demonstrate the presence of air, students could tell that the air inside the inverted bottle prevented water from entering, but I don't think that they had any clue about the existence of air pressure.

At this point, the TE shared from his field notes the results of a discussion with a group of students from Helen's class immediately after they had completed the inverted bottle experiment.

> TE: Why can't the water move into the bottle?
> Student1 (S1): Because of air.
> S2: Because the air presses on the water; therefore it cannot enter.
> S3: Because the air resists the water.
> S4: Because there is pressure (critical episode 1). [From the TE's FN.]

When the teachers were asked what this episode said about the students' understanding of air, Helen made the following response.

> Helen: I didn't realize that some students had the idea of pressure in their minds. I should have explored their ideas further.

This episode created cognitive dissonance among the teachers, which not only stimulated them to reflect critically on the way they assessed their students' level of understanding, but also forced them to reexamine their approach to guiding students toward reasonable explanations. It vividly demonstrated to the teachers that student ideas are worthy of further exploration and that underestimating them may actually restrict their learning. The exchange between the students and teacher also enables students to learn from each other, and encourage others to raise their own questions for further exploration of the phenomenon concerned.

Teachers' instructional strategies. During the TEM, the teachers discussed the student instructions and explanations that they had found to be particularly effective.

> Nancy: I had tried to use analogy to make the concept of the existence of air appear to be less abstract. I had some sweet-smelling candies in a cup. I also let go of an inflated balloon so that they could feel the air coming out of it.
> George: When students were working on the inverted bottle, I noticed that some had difficulty in observing the water level inside because the bottle was too tall. So, I asked them to take out the bottle, screw on the cap, and push it into the water again. If the water level stayed the same, we knew that water had not entered the bottle.

Another way to understand teachers' PCK is by analyzing their use of questioning and the way they respond to students' answers. Such analysis was also used to stimulate reflection in the TEMs. The TE introduced two teacher-student dialogues from the VRL and FN.

> Nancy: Why did the soap bubble expand when the bottle was put into hot water and contract in cold water?
> S1: The water vapor made the soap bubble larger.
> S2: The hot water caused the soap bubble to expand; the ice cold water made it contract.
> Nancy: You've got it almost correct. The fact is that the air inside the bottle expands when heated and contracts when cooled.

> George: Which thing expands and contracts in the two experiments?
> S1: Air George: What happened to the air inside the bottle with hot water outside?
> S2: It expanded.
> George: Yes, we could easily observe it with the aid of the soap bubble. And what about the ice cold water? What does this tell you about the air inside the bottle?
> S3: It contracted.

The teachers were able to tell the difference between the questions used in the two cases. Nancy seemed to ignore the possible gap in students' understanding, that is, they may not know that it is the expansion of air that causes the soap bubble to expand. George's questions were more specific and led students to explain the results in terms of the air inside the bottle. In contrast to Nancy, George facilitated the students' deduction of the correct answer from the results.

With regard to the development of their own PCK to improve inquiry-based instruction, teachers came up with different suggestions for future applications based on their own reflection.

> Nancy: I think computer simulation may help to explain the concepts of air and its expansion and contraction to students.
> Tim: Students should be led to think more about the results of one experiment before going on to the next. We may need additional experiments in between to consolidate students' understanding.
> Helen: I think students should be led to apply the knowledge learnt from the inquiry to their daily lives. That's what we have not considered in this trial.

Case Two: School B (Grade 5)

Teachers: Greg (grade panel head), Judith, Clara, Mandy, Tom, Jane

Topic: Electricity

Planning of the Lesson

The teachers decided that they would like to teach the topic of electrical conductivity through scientific inquiry. The discussion was initially based on the textbook. As the meeting progressed, the teachers became very enthusiastic about clarifying their own doubts and misconceptions, and the TE was bombarded by an array of questions: Can water conduct electricity? Why are we told not to touch a switch with wet fingers if water is only a very weak conductor of electricity? The meeting then moved on to a discussion of what might be included in the pre-lesson test to elicit students' ideas about electrical conductivity, and the teachers were asked to consider substances other than those suggested by the textbook, such as different liquids and graphite (in a lead pencil). They thought this was a good idea, but had never done anything like it before.

It was clear that the teachers' SMK was not particularly strong and that their knowledge was derived mainly from everyday experience and the textbook. After the teachers tried out a number of activities themselves, pre-lesson items designed to elicit the students' preconceptions about conductors and insulators were formulated (see Appendix 1B). The following transcript from the second LPM illustrates how the teachers tried to make sense of the students' preconceptions as portrayed in the pre-test results.

> Clara: I don't understand why nearly 60% of the students did not know that coins can conduct electricity.
> Greg: They probably do not know that coins are made of metal.
> Tom: Ah! A lot of them know that tap water can conduct electricity. They probably got this from their parents.
> Clara: I cannot imagine why some students (9%) considered that the colour of a substance may determine whether it can conduct electricity.

In the second LPM, the teachers focused on the planning and sequencing of activities, and it was agreed that students should learn about closed circuits before moving on to conductors and insulators. This was so they would be able to test the conductivity of materials. Although there were arguments over how open-ended the activity on closed circuits should be, due to different student abilities, the teachers eventually agreed to allow students to connect circuits by themselves and then determine which would work and which would not. Because some of the necessary materials such as ammeters were not available in the school, and the teachers apparently lacked the confidence to instruct the students in setting up the circuits, they suggested that the experiment be presented in the form of a videotaped demonstration.

Teachers' Reflection on the Teaching Process

The teachers were asked to reflect on their SMK and PCK after the teaching process.

Subject Matter Knowledge

The following examples of teacher reflections about SMK were extracted from the TJs.

> Judith: I have gained confidence, but there are still many everyday terms about electricity that I cannot completely understand, for example, watts and electric potential. Hence, I do not have enough confidence to teach this topic.
>
> Clara: Although I have some knowledge about electrical conductivity, I don't have enough confidence to deal with students' questions.
>
> Mandy: I was able to grasp the concept after reading some references.

These comments provide further evidence that teachers' SMK has a direct impact on their level of confidence in teaching a particular topic. Underlying this lack of confidence appears to be the common perception that the teacher's major role is to impart scientific knowledge.

Pedagogical Content Knowledge

Knowledge of students' conceptions and reasoning ability. In the eyes of the teachers, the students, regardless of their ability, were very interested in the inquiry activities. They were greatly impressed by their students' ability to connect circuits, test their ideas, and then conclude that only a closed circuit would work. In the TEM, Judith vividly related her experiences and feelings in this regard, as follows.

> Judith: Some groups tried to test as many contact points as possible on the light bulb. They were so observant, and they made very good drawings as well. However, I didn't know how to explain to them why only some circuits worked, as I do not know how a light bulb is wired inside. I need to study that bit later.

The teachers were also struck by the students' creativity in formulating and making logical explanations/hypotheses, although some of them were based on misconceptions. This can be seen by Greg's comments in the TEM.

> Greg: When I asked the students to figure out why a lead pencil could conduct electricity, they explained that it contains lead, which is a metal (the students thought that a lead pencil actually contained lead not graphite), but said that the light bulb is probably dimmer in this case because the amount of lead is not that high or because lead cannot conduct electricity as well as iron or copper.

Another example of students formulating hypotheses was cited by Jane. She wrote about an episode in her TJ to show how her students made sense of the results by their own reasoning based on their knowledge about the different types of liquids.

> Jane [to the entire class after showing the videotape demonstration]: Can you explain why the four liquids differ in their ability to conduct electricity?
> S1: Because there is nothing inside the distilled water.
> S2: Mineral water and tap water contain impurities.
> S3: Orange juice also contains impurities.
> S4 [to the teacher]: What are these impurities?
> S5: [to the teacher]: How is distilled water made?

This episode shows that students actually went beyond explaining the results to a more in-depth enquiry about the nature of those "impurities" that enables mineral water, tap water and orange juice to conduct electricity, and how these impurities could be removed.

Teachers' instructional strategies. The teachers were also asked to reflect on how they had made use of questioning to further students reasoning ability and to identify problems for further investigation. An episode from one of Greg's lessons was discussed for illustration. Some of Greg's students discovered that the "copper" wire was able to conduct electricity only when its ends, but not its other parts, were connected to the circuit. In fact, this wire was coated with polyester, which is an insulator. Before the activity, the polyester coating on the two ends of the wire was removed with sand paper. As the students were obviously puzzled by this seemingly anomalous result, the TE intervened in the lesson with Greg's consent, and the results from the VRL were shared with the teachers.

> TE [to the entire class]: Can you figure out why this is the case?
> S1: Electricity can flow through only when the ends of the wire are connected.
> TE: Can you think of a reason for this? S2: I guess electricity can only flow from one end of the copper wire to the other end. It cannot flow out from the middle.
> TE: Can you put your idea to the test? [Silence.]
> TE: Can you test your idea using another type of metal wire, say, iron wire?
> S3: Yes, we can test whether the iron wire lets electricity out at the middle. [The bulb lights up no matter which part of the iron wire is connected to the

battery.]
S4: There must be something special about this copper wire.
TE: That sounds reasonable. Any further idea as to what makes this wire so special?
S4: Ah! There might be something on the outside of that part of the copper wire that blocks the flow of electricity.
TE: How can you prove that your idea is correct? [The students could have been allowed to come up with more ideas for further inquiry, but as the lesson had already overrun, they were given the answer.]

The teachers were encouraged to share similar instances that could prompt further student investigations as an important part of PCK for inquiry. One idea was that students could be encouraged to further explore why some metallic objects conduct electricity better than others, thus leading to inquiry into the factors that influence electrical conductivity.

Questionnaire Findings

The questionnaire findings are presented in Appendix 2. Despite the small sample size, the average ratings provide some indication of teachers' overall perceptions of the outcomes of this collaborative project. With regard to SMK, they generally agreed that they had become more familiar with the concepts relevant to the topic, although they did not rate their perceived competence in handling students' questions as highly. They agreed that their knowledge of learners and their ability to design and implement inquiry-based instruction had also been enhanced. However, not all were confident enough to adopt such instruction independently. This is no doubt because of the limited opportunity they have had to practice this type of teaching. Particularly noteworthy is the near consensual view that collaboration with the TE had enhanced their professional skills in conducting inquiry-based instruction.

Discussion and Conclusion

As this study involved only two schools and ten teachers, it is not possible to generalize its findings to other school contexts. Nevertheless, it has generated a number of interesting findings about the impact and challenges of professional development that emphasizes university-school collaboration and the development of teachers' PCK for inquiry-based teaching.

The findings of the two cases indicate that these teachers were still concerned about their SMK, although their responses on the post-study questionnaire were more positive. It would be reasonable to conclude that they developed a better understanding of the SMK through coaching and reflecting upon their own misconceptions. However, several issues arise from the teachers' persistent sense of inadequacy in handling students' questions. First, this lack of confidence meant they dared not venture too far from the planned activities. Second, they tended to interpret the students' level of understanding through the lens of their own SMK. The concepts that the teachers themselves found difficult were perceived as being too demanding for the students. Third, the teachers made use of different teaching strategies to overcome their lack of confidence to a certain extent. For instance, some teachers videotaped experiments to substitute for hands-on activities. This is consistent with research findings (Smith, 1999; van Driel et al., 1998) that teachers tend to use general pedagogical knowledge to compensate for inadequacy in SMK.

The findings also have implications for the type of SMK that primary teachers need to be able to teach science through inquiry: SMK should be understood not only in terms of scientific concepts, but also in terms of the nature of scientific inquiry. This aspect of SMK will allow teachers to guide students through the inquiry process, including formulating hypotheses, designing experiments to obtain evidence, and making explanations based on that evidence. Little evidence of this type of SMK was found among the teachers in this study.

The analysis of the pre-lesson test results and lesson episodes challenged the teachers' perceptions of students' understanding of the topics and reasoning ability. Such cognitive dissonance on the part of the teachers could stimulate a reassessment of their existing knowledge of learners.

The findings also shed light on the rather elusive nature of PCK. First, teachers' PCK is continually expanding and developing, based on their reflections on their teaching experiences. In the two case studies presented here, the teachers' PCK developed throughout the lesson, as they received feedback from the students on their existing understanding of the topic and on the effectiveness of the teaching strategies so far employed. Second, PCK for scientific inquiry is both contextual and generic. It is context-dependent, because the nature of the topic and the learning context inevitably influence the inquiry strategies the teacher employs. It also contains elements that could be generalized to different inquiry situations, including the design of student-centered activities for the observation of natural phenomena, and the identification of questions to investigate. Third, PCK is idiosyncratic; that is, it contains many elements that are characteristic of the individual teacher. PCK varies with teachers' SMK, their perception of their students' level of understanding and reasoning ability, their teaching style, and the teaching approach considered to be suitable for particular students. For instance, in the inquiry into the existence of air, George employed carefully structured experimental activities to lead the students to discover this existence, whereas Nancy utilized students' everyday experiences with air.

Challenges for Teachers

The model employed in this study presented considerable challenges to the teachers with respect to the development of SMK and PCK. The first challenge for primary school teachers is to equip themselves with the knowledge about the nature and processes of scientific inquiry, and to re-orientate their view of their role from that of knowledge provider to that of facilitator of inquiry. There may be no need for them to impart substantial subject matter to their students, as is required of their secondary school counterparts. Instead, primary school teachers can lead students to use scientific inquiry to understand the basic concepts underlying everyday phenomena and to develop their reasoning and inquiry skills in so doing. This reinforces the view of Magnusson et al. (1999) that teachers' orientation toward teaching is an integral component of PCK for science teaching.

The second challenge for teachers is to learn to treat the TE as a partner who can facilitate their development of SMK and PCK, rather than simply as a coach who will provide them with survival skills. Unfortunately, the latter seems to be the dominant view adopted in many in-service training workshops that address curriculum reforms. As this new mode of professional development depends on teachers' in-depth reflections, the development of the metacognitive skills and attitude necessary to become a "reflective practitioner" is the third challenge that needs to be met for teachers to benefit fully from their own action research and from their interactions with peers and the TE.

Challenges for Teacher Educators

In this study, the role of the TE was a multi-faceted one that varied with the different stages of the teaching process. In the planning stage, the TE acted as leader to set the direction and framework for teacher development and to orientate the teachers to connect the different forms of knowledge bases into PCK. The TE was also a mentor to clarify teachers' misconceptions of the teaching topic, a co-researcher exploring with them students' understanding and misconceptions of the topic, a facilitator who could facilitate collaboration among teachers, and a resource person to suggest alternative activities and help teachers to locate useful references or apparatus and materials for student investigation. During implementation, the TE supported the teachers, actively observed and listened to the students during activities, modeled the instructional strategies for eliciting student conceptions, and guided students in their inquiry. In the evaluation stage, the role involved leading teachers to share their reflections and learn from their experiences, and co-evaluating with them the outcomes of their professional development. Overall, the TE is a researcher who treats the entire process as an opportunity for continuous research on the improvement of the effectiveness of in-service professional development. There is a striking similarity between these roles and those assumed by the inquiry-based science teachers discussed by Crawford (2000). Thus, teacher development can be viewed as a constructive process that embraces the important elements of inquiry to build up essential knowledge bases for teaching.

There are obvious limitations in this study that need to be addressed in forthcoming research. For instance, the teachers' ability to reflect on their classroom interactions or critical episodes was hindered by their limited experience of professional development of this kind, and by their rudimentary understanding of the nature and processes of scientific inquiry. Additional rounds of collaborative research and teaching are obviously needed to enhance their ability to reflect on the quality of teacher-student interactions, guide students to inquire, and, hence, enhance their own PCK for teaching through inquiry.

Implications

The lessons learned from this study have important implications for in-service professional development. They demonstrate that collaborative school-based professional development that involves the development of learning communities within schools, in partnership with TEs, could be an effective means to develop a greater degree of PCK ownership among teachers, and such communities could supplement, if not replace, traditional workshop-based in-service teacher training activities.

As this study proves, a framework of professional development goals that focuses on SMK and PCK development is useful in helping teachers to embrace inquiry-based science teaching. This framework should lead teachers to seek answers to three important questions: (1) what do teachers need to know about the topics concerned and the scientific inquiry process? (2) what do students know about the topics, and how do they reason through inquiry activities? (3) what instructional strategies are effective in leading students through scientific inquiry? Whereas the planning stage is useful in eliciting and developing teachers' SMK and knowledge of students, the implementation phase is more effective in facilitating their understanding of students' reasoning ability and the development of teaching strategies to further this ability. Engaging teachers in collaborative development that focuses on the construction of PCK also allows the TE to develop a better understanding of teachers' needs and how they can be met.

If one of the goals of professional development for science teachers is to enhance their knowledge base, particularly their PCK, for teaching through inquiry, then there is a need to further conceptualize how that base is developed. The working model shown in Figure 1 is based on the insights developed in this study combined with previous research.

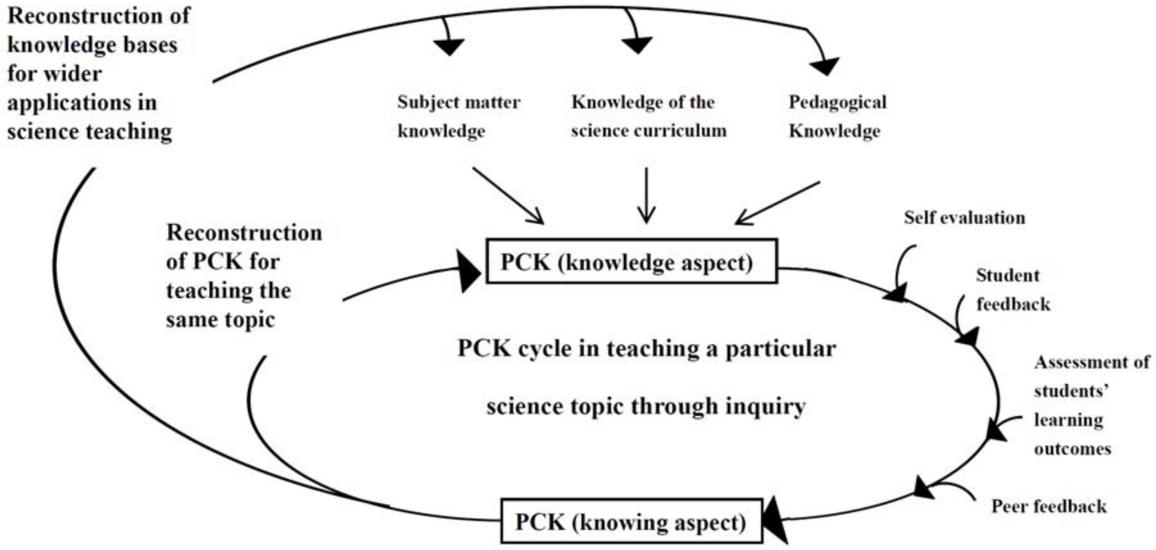

Figure 1: *Model for the development of PCK for teaching a particular science topic through inquiry*

This model uses a micro-perspective to depict the interrelationship between PCK and other knowledge bases, and the development of PCK as a cyclic event in the teaching cycle. When planning a lesson, the teacher needs to integrate different types of knowledge, and then transform them into PCK for inquiry-based instruction for that particular topic. This PCK can be further differentiated into knowledge and knowing. Initially, the knowledge aspect is generated as the outcome of the transformation process in the planning stage and comprises the baseline knowledge on which the teacher plans his or her lesson. As the lesson proceeds, it becomes highly fluid and dynamic as the teacher interacts with students and reflects continuously on these interactions. He or she may experience cognitive dissonance in the process, thus rendering his or her existing knowledge aspect of PCK problematic or insufficient. This reflection process, which constitutes the knowing aspect of PCK, is not restricted to the aftermath of the lesson, but also takes place throughout it and influences it in two ways. First, it informs the knowledge aspect of PCK, and, second, it results in the ad hoc adjustment, as far as the situation allows, of the teacher's instructional strategies.

This knowing aspect of PCK further extends the notion of pedagogical content knowing (PCKg) in Cochran et al. (1993), which emphasizes PCK as active processes of knowledge construction rather than as a static body of knowledge, and Appleton's (2006) idea of transforming existing PCK into experiential PCK. It is also in line with Van Driel & Beijaard's idea about the development of PCK as a result of external input, collegial interactions and experimentation in practice (2003). Differentiating between the knowledge and knowing aspects of PCK facilitates teachers' awareness of its developmental nature. The relationship between the two aspects is analogous to that between content and processes in science. Any new understanding generated from different sources of input may be applied to the teaching of the same topic or to the wider context of science teaching. For instance, teachers may develop new content knowledge as a byproduct of student queries, and this may be applied to the teaching of other topics. Teachers' reflections on the nature of scientific inquiry may also stimulate them to rethink the purpose of the primary science curriculum, thus leading to a more in-depth understanding of science education. Furthermore, certain inquiry-based strategies, such as videotaped demonstrations, that have proved to be effective in a current application could be applied to other science topics or even other subjects, eventually becoming integrated into teachers' general pedagogical knowledge. The knowing aspect of PCK can be regarded as an integral part of Shulman's (1987) generic notion of pedagogical reasoning. Teachers should be encouraged to recognize the usefulness of the PCK cycle construct and then develop the disposition to reflect on their own PCK cycles, thus making them increasingly effective. This cyclic PCK model can be adopted as a transition model for inquiry-based instruction to pave the way for the development of a more mature and comprehensive model as more research evidence becomes available.

As this study was necessarily restricted to one academic year because of funding constraints, future research could cover a longer time span to trace teacher development in subsequent teaching cycles. Finally, a number of questions have been raised by this study that need to be addressed in future research: what kinds of input from the TE can better facilitate teachers' learning through the teaching cycle? what specific strategies can facilitate the reconstruction of knowledge bases through reflection? how far can this mode of teacher training go toward supplementing existing in-service or even pre-service teacher training approaches?

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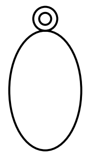
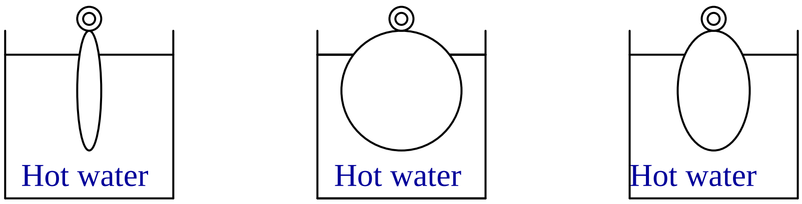
Appendix 1A

1. What happens when an air-filled balloon is put into hot water?

Original balloon





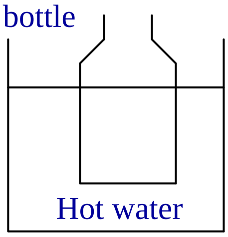
A. Balloon becomes smaller

B. Balloon becomes larger

C. No change in size

2. What happens when an unfilled glass bottle is put into hot water?

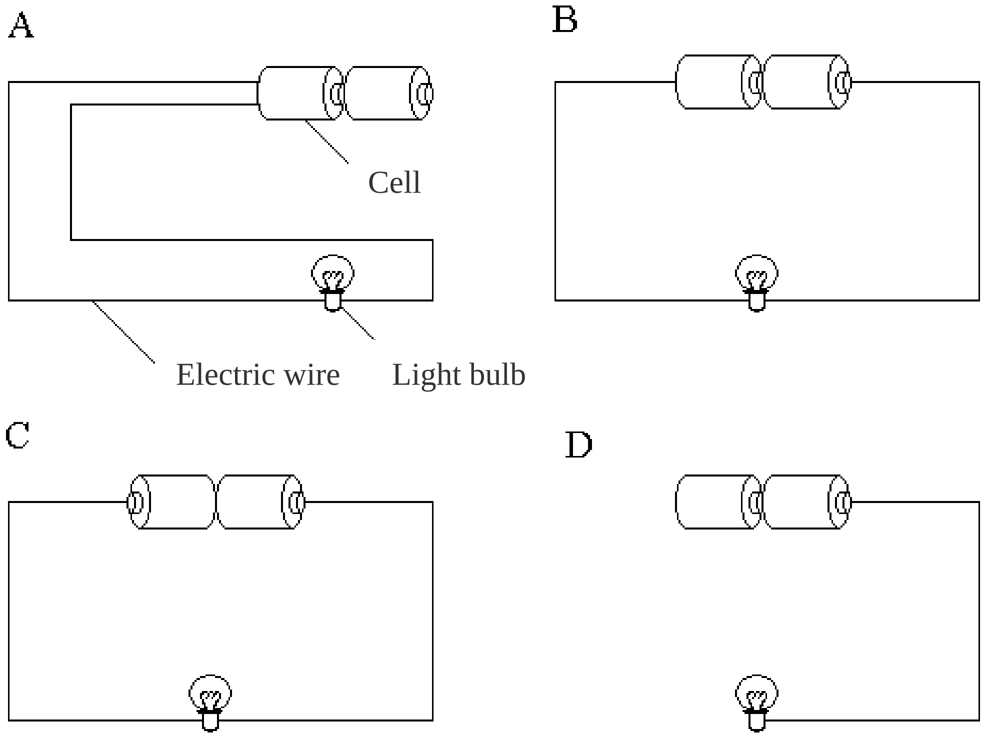
Unfilled glass bottle



A. Some air will flow out of the bottle.
B. Air from outside will flow into the bottle.
C. There will be no change.

Appendix 1B

1. In which of the following setups will the light bulb(s) light up? (You may circle more than one choice)



2. Which of the following items can conduct electricity? (Please tick as appropriate.)

Material	High	Medium	Low/Non-conductor
Iron nail			
Copper wire			
Coin			
Ice lolly stick/ wooded stick			
Pencil lead			
Distilled water			
Mineral water			
Tap water			
Orange juice			

Appendix 2

Statistical Analysis of the Teacher Questionnaire, Showing the Mean and SD

Item	5	4	3	2	1	Mean	SD
1. I feel more confident about teaching inquiry-based science.	4	6	0	0	0	4.4	0.52
2. I have become more familiar with the scientific concepts of this topic.	7	3	0	0	0	4.7	0.48
3. I find it more difficult to teach inquiry-based science.	0	1	0	2	7	1.5	0.97
4. I can determine students' incorrect concepts of the topic more easily.	1	6	3	0	0	3.8	0.63
5. I have become more aware of students' incorrect concepts of scientific knowledge.	1	6	3	0	0	3.8	0.63
6. Through the workshop, I came to realize the importance of understanding students' prior concepts when teaching science subjects.	1	9	0	0	0	4.1	0.32
7. I am better able to design inquiry-based activities to trigger students' motivation to explore natural phenomena.	0	10	0	0	0	4.0	0
8. By guiding students in scientific inquiry activities, I can clarify their misconceptions more easily.	0	9	1	0	0	3.9	0.35
9. I can teach the same topic better in future by adopting the same teaching approach.	3	7	0	0	0	4.3	0.48
10. Thanks to the workshop, I am more confident in my ability to apply inquiry-based teaching to other topics.	0	10	0	0	0	4.0	0
11. I have a better understanding of inquiry-based learning and teaching on reflection.	2	7	1	0	0	4.1	0.57
12. I can answer students' questions about this topic more easily.	1	9	0	0	0	4.1	0.32
13. I have learned how to design, organize, and use inquiry-based teaching materials and equipment.	0	9	1	0	0	3.9	0.35
14. I need more instructions to independently design and apply inquiry-based teaching.	0	5	4	1	0	3.4	0.70
15. Collaborating with tutors from the HKIED has extended my professional pedagogical knowledge of scientific inquiry-based learning and teaching.	4	6	0	0	0	4.4	0.52
16. I know more about students' scientific thinking and their limitations.	0	10	0	0	0	4.0	0

5: strongly agree

1: strongly disagree