Outcomes-based Science Units that Enhance Primary and Secondary Science Teachers' PCK

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Abstract

Science pedagogical content knowledge is the special amalgam of content and pedagogy that is uniquely the province of teachers and is a key focus in science teacher education. Primary school teachers and junior high school teachers who teach outside of their main area of expertise often have limited science content knowledge which is manifest as limited science PCK. Some primary school teachers use activities that work and while junior secondary science teachers use units that work as a supplement to, or substitute for, science PCK. This study explores the extent to which activities and units that work played a role in primary and secondary teachers' planning and implementation of a new outcomes-based science syllabus. Using two case studies, we show that activities and units that work played a major role in the teachers' thinking and teaching. The primary school teachers relied on activities from a number of sources, whereas the high school teachers tended to rely on units from their textbook. This study has implications for teacher professional development and pre-service teacher preparation.

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INTRODUCTION

Pedagogical content knowledge (PCK) was proposed by ; as a essential component of an effective teacher's professional knowledge. PCK is "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (1987, p.8) that represents the subject in a way that is comprehensible to others (1986, p.9). He points out that while PCK is derived from subject content knowledge and pedagogical knowledge, it is more than a teacher's knowledge of a particular content area and the pedagogy that enables him/her to teach that content. Shulman's distinction between content knowledge, pedagogical knowledge and PCK was a conceptual proposition, which has subsequently been explored by a number of researchers. Science PCK has been subject to intensive investigation over the last few years, with some consequent clarifications with respect to science teaching and learning. However, a number of aspects remain unclear, as will be explained later.

PURPOSE AND SIGNIFICANCE

While varying degrees of student learning can be accounted for by cultural and socio-economic factors, subject content knowledge and pedagogy are widely recognised as the main contributors to effective student learning. We therefore need to ask: How does content knowledge integrate with pedagogy to produce the PCK that satisfies the learning needs of a particular group of students? How do effective teachers know when to ask the crucial question that causes a student to reconsider his or her ideas? "What are the sources of analogies, metaphors, examples, demonstrations and rephasings" (Shulman, 1986, p.8) and the planning of activities and units that work? PCK facilitates flexible and adaptive teaching of the type where a biology teacher can describe and explain cells to Year 8 students one lesson and Year 12 the next in a way that meets the needs of both classes. Indeed, effective teachers use their PCK to accommodate the different needs and abilities within the same class in a way that neither trivializes nor complicates the learning process. While PCK is the knowledge and skill that sustains the teacher 'as an artist' it is, nevertheless, an elusive quality.

In primary and secondary science teaching, therefore, PCK has come under close scrutiny as a key aspect of teacher knowledge that influences student learning outcomes. If PCK is to be a useful construct for understanding and enhancing teachers' work, its nature, how it is developed, and the extent to which it can be shared needs to be understood. A better understanding of PCK can then be used to enhance pre-service teacher education, and in-service teacher professional development. The research reported in this paper sets out to explore those aspects of science PCK which remain unclear, and in particular to compare and contrast similarities and differences between the science PCK held by secondary and primary school teachers.

Theoretical underpinnings

The pedagogical content knowledge (PCK) construct is one of seven suggested knowledge bases required for teaching (Shulman, 1987). Shulman suggested that PCK differed from content knowledge and knowledge of general pedagogy and consisted of representations of subject matter, student conceptions, and understandings of specific learning difficulties . In a sense, it was knowledge of how to teach specific content in specific contexts — a form of knowledge in action . Other studies, such as that by , argued that there were four central components to PCK: knowledge and beliefs about purpose, knowledge of students' conceptions, curricular knowledge, and knowledge of instructional strategies. Sources of PCK, according to Grossman, are classroom observation — as a student and during preservice teacher education; studies in science; teacher education programs; and personal classroom experience. renamed the construct pedagogical content knowing (PCKg) to highlight the ways their findings differed from Shulman's PCK. They claimed that PCKg comprises four components: knowledge of students, knowledge of environmental contexts, knowledge of pedagogy, and knowledge of subject matter. Based on that work, Cochran and Holder ; then developed fine-grained detail for each of these components, and showed how they are interrelated but also tend to overlap. As might be expected, these components and subcomponent details also overlap some of Shulman's other knowledge categories, thus revealing some of the complexities and inter-relatedness of teachers' knowledge structures.

Science PCK and secondary school teachers

The main focus of studies of science PCK has been on secondary school teachers, with some progress being made in understanding the construct. For instance, have constructed a model for the "structure" of science PCK, showing how the different elements work together. An underlying plank of PCK in their model is the teacher's science content knowledge.

Efforts have also been made to understand how science teachers use science PCK, and to document some teachers' PCK about teaching particular science topics . Methodologically, this is somewhat problematic , but it has explored ways of representing science PCK to other teachers in professional development contexts. During Ian Mitchell's presentation of a paper at the Australasian Science Education Association conference , he explained the planning process, which explicated many details of his science PCK. Unfortunately, this work is not yet documented. In Mitchell's explanation, a planning framework begins with science content, moves its focus onto the students and ideas about learning, then generates activities that are consistent with both. This differed from the pattern reported by , where the teachers tended to focus on content then activities. Mitchell, however, acknowledged that many teachers do not use his pattern of considering the students and ideas about learning, which are based on constructivist ideas (see . How, then, do secondary school teachers construct science PCK, and how is this evidenced in their teaching? Some ambiguity about these questions remains and will be explored in this paper.

Science PCK and primary school teachers

In considering how Grossman's PCK components apply to science PCK, primary school teachers tend to be uncertain about purpose , students' conceptions , and instructional strategies that are appropriate to science . Consequently, many primary school teachers have limited science PCK, which is consistent with reports of the difficulties many teachers have when teaching science (e.g., . The nature of science PCK for primary school teachers is not yet well understood. reported how a teacher augmented her science PCK through the use of printed resource materials. took a different perspective by suggesting that for many primary school teachers, 'activities that work' may become a substitute for science PCK. Certainly, activities appear to play a key role in primary school teachers' science planning . In contrast to secondary school teachers' for whom content has a central focus in planning, content is considered by primary school teachers largely in the context of learning outcomes and activities. Therefore, one focus of this paper is how primary school teachers cope with teaching science when many have limited science content knowledge. The other focus is on secondary teachers and the primacy accorded the textbook in their planning.

Focus of the study

In a study of primary school teachers' understanding of the expression, "science activities that work," Appleton and Kindt (1999) suggested that activities that work may be related to primary school teachers' limited science PCK; and for some teachers, may be used as a substitute for science PCK. This postulate arose incidentally from a study of teachers' perceptions of activities that work, and from an earlier study of beginning teachers' science teaching practices (Appleton & Kindt, 1997), rather than from a specific focus on teachers' science PCK. Harrison and Appleton (2000) have also reported work with some middle school/lower secondary school teachers, which suggested that activities that work may also contribute to these teachers' science PCK — particularly those for whom science is not their preferred teaching subject. The study now focuses on two research questions:

1. To further explore the relationship between science activities that work and primary school teachers' science PCK, and
2. To determine the extent to which middle school science units that work are derived from the teachers' PCK and the class textbook.

METHOD

Since the research focus was on teacher-knowledge, case study (Yin, 1994) was considered the most appropriate research method. Two case studies were conducted in a primary and a secondary school. In the primary school, two participating teachers were selected while in the secondary school, the six teachers of Year 8 science were studied. The data sources were interviews with the participating teachers, classroom observations (videotapes) of science lessons, records of planning meetings and documents produced during the study. The data were collected by one author (secondary) and two research assistants (primary). These personnel acted as participant observers in the professional development session and in the classroom implementation. Analysis included transcription of audio sources, multiple viewing of video sources, document analysis and probes of teachers' science PCK. Member checks were employed to ensure that the interpretation of the data was trustworthy and reliable (Guba & Lincoln, 1989).

The participating schools were both Catholic schools in a regional city in Queensland, Australia. The schools were and teachers were a purposeful sample (Patton, 1990) negotiated with the Catholic Education Office and each school. As the schools were focusing on implementing a the new Queensland school Curriculum Council (1999) science syllabus, this document was the starting point for all the teachers.

RESULTS AND DISCUSSION

1. The primary school setting

as the teachers were trying to implement the new outcomes-based science syllabus (QSCC, 1999a), a professional development day was conducted where they were helped plan a unit of work for an appropriate outcome. The professional development day focused on learning outcomes, constructivist-based pedagogy, and how to develop a unit of work based on these principles. Science processes, a key feature of the old curriculum, are incorporated in the new syllabus's theme of *Working Scientifically*. Supplementary materials from the curriculum designers are a *Science Year 1 to 10 sourcebook* (QSCC, 1999b) and *Science initial in-service materials (1999c).* The latter book contains several sample units of work which can be adapted by teachers for their local situation.

Two teachers were involved: Margo was in her fourth year of teaching, and Janice her second. Like the majority of children in their classes, the teachers were middle class Caucasian. They both taught mixed ability and mixed gender Year four classes. A curriculum focus for the school and the teachers was a genre-based language program which was used as an integrating device for theme-based teaching. However, for the purpose of exploring this study, an independent science unit was planned and taught.

The teachers' planning

At the conclusion of the professional development day, the teachers were invited to cooperatively plan a unit of work, with the professional development facilitator being available to help if needed. Margo and Janice were unsure of where to start. They perused resources and the sample units provided with the new curriculum but were dissatisfied with what they found. Although they had been urged during the professional development session to develop their own unit to gain experience with the new curriculum ideas, they preferred to work from the sample units. However, the choice of just six units was not satisfactory for them. Margo and Janice's first choice was a sample unit suitable for Year 4, on animal differences. They perused the suggested activities but none appealed as most involved looking at real animals. They rejected the unit after reading that the children should compare different animal tongues, such as butterflies and frogs. There was nothing in the activity outline which provided for them the necessary science content knowledge about these animals' tongues (e.g., Margo: "What's a butterfly's tongue like?"), let alone what a comparison might yield. It was the end of a long day, so the tired teachers decided to postpone their unit planning to another day. This meant that there would be no assistance from the facilitator when they did work on the plan.

Over the next two weeks, the teachers developed their unit without assistance. They chose a unit on forces, partly because a sample unit on this topic was available, albeit for Year 7, and partly because Margo had taught a similar topic recently. At the professional development they were advised to choose a unit topic that would extend them because assistance was available. The choice was surprising given the usual reticence of primary school teachers to deal with physical science topics. Margo and Janice's choice also seemed related to their desire to help us in our project. They consequently worked in an science area where they admitted that they lacked confidence and background knowledge. This is curious because the biology-based sample unit was rejected because they felt that they had insufficient knowledge to teach it, even though biology is the preferred primary science teaching area. The sample unit was rejected because it required specific knowledge of animal tongues which they did not have. In comparison, the forces unit activities seemed to present few problems, since it resembled activities that Margo had used previously.

In terms of their science PCK, there was a clear difference between the teachers. Margo, with more experience, tended to "set the pace", with Janice deferring to her in most decisions. This behaviour was consistent with the perception that science PCK is partly dependent on experience. Margo was an informal mentor for her less experienced colleague. They rejected out of hand the suggestion that they develop a unit of work "from scratch", as that task was beyond their existing PCK: they lacked the confidence, and perhaps the time, to find the necessary knowledge and activities. They seemed to prefer the pre-packaged unit plans common to the old science curriculum as these provided the essential science content knowledge and PCK for them to teach the recommended activities. Time to search for activities and materials, let alone find and understand science content, often was cited by Margo and Janice as a constraint. They also believed that they were unable to understand the science content should they find it in another source. [A research assistant showed how she sourced needed science knowledge from a Year 10 science textbook but this advice was not seen as helpful.] Margo and Janice wanted the science content knowledge to be obvious in the sample unit and, as they began to implement their plan, it became obvious that they preferred the science content expressed in terms that they could readily convey to the children. Consequently, working in an unfamiliar physics area, meant that they depended entirely upon the suggested activities in the resource materials for their science PCK. In this instance, the sample unit (or more accurately the activities outlined within it) provided the main substance of the teachers' science PCK.

Another source of science PCK, as mentioned earlier, was previous experience. In this case it was Margo's experience with a similar topic (Janice accepted Margo's recommendations without question, as shown by Appleton & Kindt, 1997). Other major influences on their science PCK were their contextual and general pedagogical knowledge, knowledge of the children, and their PCK in other subject areas like language. This was evident in the way they adapted and implemented the activities in the forces unit plan. Remember, the forces plan was designed for Year 7 and, consequently, had to be modified to suit the teachers' Year 4 students. This was problematic as the teachers' sole focus was on the activity descriptions and procedures leaving the contextual and suggested pedagogical information largely unread. That is, they focused almost exclusively on the resources needed and on what the children should do in each activity. They therefore missed crucial information about what learning might occur, how to scaffold the children's learning, critical points of pedagogy, the working scientifically components, and the learning outcomes that the unit was designed to help children demonstrate. The teachers used their previous experience and general pedagogical knowledge to "adapt" the activities to their Year level. Adaptation was at a superficial level and focused mainly on managerial aspects. Outcomes, working scientifically and conceptual learning were not considered and adapted. Consequently, there was a mismatch between the Year 7 activities and the Year 4 outcomes.

Implementing the unit

The teachers were insecure teaching the unit, particularly with participant observers videotaping in the classroom. As a result, they taught the unit cooperatively even though they had never team-taught before. Initially, Margo and Janice were confident about the unit they had planned, but as they implemented it, they increasingly struggled. They began changing the intended pedagogy to fit their previous science teaching practices which often were language-based. They preserved the chosen "hands on" activities, expecting the children to make sense of the science content from their engagement with the materials. Interaction with the children tended to become largely functional by glossing over conceptual questions. They made several attempts to develop the children's understanding, but their lack of concept knowledge made this ineffective.

At one point, Janice realised that a key aspect had been glossed over, and raised this with Margo; however, she again deferred to her more experienced colleague when Margo declared that they had already covered that aspect. Critical facets of the pedagogy embedded in the activity descriptions were thus not followed. For instance, an essential activity that would have enabled the children to understand the culminating activity was amalgamated with the culminating activity. The lesson then had to be curtailed because it was running overtime and the children were left not knowing what they should have learned. The actions taken by the teachers are natural responses by teachers who find that their teaching is not working as expected. Margo and Janice were aware that the unit was not progressing well, but genuinely believed that they were dealing with the activities as intended in the forces unit. They attributed their lack of success to their inadequate science knowledge, and to what they came to believe were impractical philosophies in the new curriculum. To retrieve the situation they resorted to pedagogy which they knew was successful – their previous language-based science practices. The learning emphasis moved to language skills rather than science understanding. For instance, discussion became vocabulary-oriented, and questions intended to provoke student thinking became written test items.

It is noteworthy that at no time did the teachers seek help, despite the presence of two participant observers who were ready and willing to help if invited. Whether this was due to embarrassment or a belief that they were conducting an effective lesson is unclear.

Discussion

Margo and Janice, like many primary school teachers, are not confident about their science knowledge, and feel that they lack the time to explore a wide range of science resource materials and find their needed science knowledge. They prefer units that work; units that contain predictable activities which include sufficient explanations of the science content for them to deal with children's queries, and in a form that is readily presentable to children. The student activities are expected to provide this content so that there are few further demands on the teachers' personal knowledge. The teachers believe that they can adapt the activities and embedded pedagogy to suit their own circumstances, but often do not consider the pedagogical consequences of these adaptations on student learning. Indeed, children's learning in science is not a major consideration because the teachers often do not know what it is that the children should be learning.

The implementation of the unit was typical of teachers who lack the science PCK to teach in a way that enhances children's learning. Their cursory examination of the forces unit's context and pedagogy meant that they were ignorant of critical aspects of the science PCK embedded within the activities and reasons for the activity sequence. Not surprisingly, the activities did not 'work' as planned. The teachers could not pin-point what was going wrong and had little choice but to resort to familiar pedagogy. Their likely preference would have been to abandon the unit, but they persisted (perhaps inappropriately) because of our presence.

In this study, the teachers' science PCK was not extensive: collectively they had limited teaching experience, and their existing science teaching practices tended to be language-based, with the inclusion of some hands on activities. Their limited science content knowledge led them to search for a unit which included detailed activity descriptions and included all the necessary science content and science PCK needed for them to teach the unit. The claim made by Appleton and Kindt (199?) that activities that work become a substitute for science PCK for some teachers appeared true for Margo and Janice. In this instance, they did not notice (or were not attuned to noticing) a number of key aspects of the science PCK outlined in the unit, and the implementation of the unit was not successful. Evidence suggests that their grasp of constructivist-based pedagogy was minimal, and that they retained a mainly positivist view of science (Prinsen, 2001). Perhaps because of their existing knowledge frameworks, they were simply unaware that important science PCK was included in the unit and, in their hurried quest for science content and classroom procedure, overlooked it.

This study raises the question as to whether teaching that uses 'activities that work' as a substitute for science PCK can result in effective cognitive learning in science. In this case study, the factors that limited the teachers' understanding of their chosen activities also prevented them from recognising critical aspects of the intended science PCK. or if some were recognised, how to put what was written into effective practice. Underlying contributions to science PCK must therefore include knowledge about the nature of science and constructivist-based pedagogy. Without this knowledge, science PCK ideas gleaned from colleagues or written sources will not be incorporated into the teachers' own teaching practices as personal science PCK because they would have difficulty using them successfully. We therefore believe it is likely that teachers who lack this knowledge will modify activities to fit with their existing PCK adapted from other subjects such as language, even when the activity descriptions contain many science PCK ideas – just as Margo and Janice did. We raise this conclusion as a tentative assertion: while it cannot reasonably be drawn from just this one case study of two teachers, it is consistent with the findings of others (e.g., Osborne & Simon, 1996).

2. The Secondary School Setting

We now examine the pedagogical content knowledge of Year 8-10 teachers in a catholic secondary college in a regional city of Central Queensland. The teachers' PCK was accessed by researching the way they went about adopting the new outcomes-based curriculum in Year-8 classes. The school is an established catholic college which enrols 800 students across Years 8-12. The study occupied three semesters beginning with a planning phase (Phase 1) in Semester 2, 1999 and an implementation phase (Phase 2) in Semesters 1 and 2, 2000. The six teachers involved in this study were Neil (a chemistry teacher and science coordinator), Jon and Ray (experienced physics and biology teachers respectively and holding science degrees) Lee and Sue (home economics teachers who also teach some science), and Lyn, who began her career as an primary teacher and has minimal science teaching qualifications. This wide range of discipline knowledge is interesting because it allows comparison of teachers with different educational background engaging in a common task.

The new curriculum (QSCC, 1999a) was due for implementation by the school in 2000, therefore, the teachers who were scheduled to teach Year-8 science felt a semester long planning phase was needed and this began in 1999. Throughout Phases 1 and 2, the teachers used their knowledge of science concepts, examples and applications, teaching and motivational strategies, alternative conceptions, assessment and student needs to plan a stimulating Year-8 science program. The teachers were committed to fully implementing the outcomes-based curriculum and were aware of the need to revitalise the existing science program. To use Lyn’s words, "the new course needs to be exciting, the kids spend too much time copying … far too much writing and don’t get to play with the equipment enough". Neil supported this aim and insisted that the new course "must be challenging and fun and we need to let the students show what they can do … I think this new syllabus is way overdue … the old course is boring because it’s got too much content".

The study findings are presented as a purposeful case study and the Year-8 case highlights the influence of the teachers’ PCK because most aspects of their teaching knowledge were accessed as they planned, taught and assessed the new curriculum. During 1999 the six teachers met fortnightly to scrutinise the curriculum documents and to choose an appropriate textbook. Two full-day meetings also were held with 4-6 teachers in attendance to plan the Year-8 scope and sequence and to design innovative assessment tasks that allowed students to demonstrate their mastery of the relevant outcomes. The teachers continued to meet fortnightly throughout Phase 2; that is, in Semesters 1 and 2, 2000. Three full-day workshops were held in 2000 with five Year–8 teachers attending each workshop. The workshops were used to plan and refine assessment tasks and to reflect on taught units.

The teachers’ early planning

The first task was to select a new textbook and *Jacaranda Science 1* (Ash, Buchanan, Lofts & Evergreen, 1999) was chosen because its content had been mapped to the new curriculum and the book was attractive and easy to read. The teachers quickly found, however, that the authors’ mapping of the outcomes to the textbooks was superficial and that the multifaceted nature of the outcomes made the task of assessing students’ demonstration of outcomes much more sophisticated than was initially thought. As the teachers grappled with each outcome, their PCK came to the fore because they had to justify their content and pedagogical decisions to their colleagues.

Take for example Core Learning Outcome (CLO) 4.1 for *Natural and Processed Materials* (NPM). It reads: "Students collect information and propose ideas to explain the properties of materials in terms of each material’s underlying structure". The teachers’ early reaction was to say, "Oh, that’s easy, all we have to do is get them to classify a range of substances … solids and some liquids and then gases and say what their properties are …" (Ray). This was accepted and as the teachers started to plan the activity, Lee and Sue realised and asked "how are we going to, to … deal with something like wood and plastic’s underlying structure? That means we’ll have to teach them about atoms and molecules …".

Because of the multiple processes and concepts embedded in each outcome, Neil tried dividing each outcome into a series of "outcomettes". However, it became evident that each outcome was more than the sum of its parts. The inter-dependence of processes and concepts in each outcome was recognised by Jon and the idea of "outcomettes" was rejected. This decision is evidence that the teachers were beginning to understand the holistic and conceptual nature of outcomes. Their ability to recognise the conceptual barriers and challenges in each outcome required more than knowledge of content and pedagogy; it called on "that special amalgam of content and pedagogy that is uniquely the province of teachers" or PCK (Shulman, 1987, p.8).

Planning activities for the new curriculum

Phase 1 began in earnest with a full-day planning workshop in mid-October, 1999. Previous fortnightly meetings had sensitised the teachers to the strong process emphasis in the *Working Scientifically* and *Science and Society* strands of the new curriculum. These two strands are the major changes in the new curriculum; consequently, the teachers surveyed their past teaching and assessment strategies to find examples of process oriented teaching and assessment that were applicable to the new curriculum. This is often called the "audit model" because past planning and teaching is scrutinised to select known strategies that can be adapted for the new program. Such surveys of teacher ideas are a useful indicator of PCK because as the teachers examined their past teaching, they volunteered aspects of their professional knowledge. The way they use this knowledge to help build units or criticise ideas under discussion demonstrates the detail and depth of their PCK. Issues that the teachers perceived to be important and were discussed comprised concepts, factual content and skills, activities that worked and motivated students, and assessment tools like knowledge and practical tests, investigations, research projects, and model-making. The data that were collected in this and subsequent meetings provide a window into aspects of each participant’s knowledge and expertise—or PCK.

Surveys of past planning, teaching and assessment can result in little more than changing the names on activities and restructuring the course’s scope and sequence. This was not the case here. Ray and Bev (Bev left the school at the end of 1999) suggested teaching activities based on their Year-10 "Design a planet" project. This idea was enthusiastically received and Neil suggested a series of individual, pair and group student projects using this format. The "Design a planet" was decided to be too demanding for Year-8, but the group project format was agreed to, However, Ray added this caveat "this can make students think that they don’t have to learn some facts … I want to keep tests in so we can be sure of what they know … sure that they’ve learned some information". Throughout Phase 1 and 2, Ray reiterated his preference for tests despite the new curriculum’s emphasis on thinking and working scientifically. This signaled the beginning of a low-level disagreement between Neil and Ray. Lyn also became involved in this disagreement during 2000 and, while she initially supported Ray, she later changed to Neil’s view.

The curriculum aim was for students to demonstrate each outcome by showing what they know and can do to meet the relevant CLO. To guide teaching and learning, the Year-8 team agreed to write explicit criteria for each CLO and agreed to provide the students with a criterion sheet for each assessment. This sheet states which criteria needed to be met for the CLO and how the criteria might be demonstrated (e.g., "Have you included an accurate and labelled diagram of your separation machine?"). Elaborating the relevant concepts, content and processes as criteria also helped us understand the knowledge base that the teachers used to plan, teach and assess each unit. As each set of criteria was written by two teachers and then presented to their colleagues, we were able to study the ways the teachers’ defended and modified the criteria during workshops and fortnightly meetings.

Table 1 is our summary of the teachers’ knowledge of concepts, content, assessment and teaching strategies. The summaries are derived from three semesters of participant observation of the teachers as they planned units; presented ideas and arguments to their colleagues; and wrote unit plans and assessments. Informal discussions and interviews with some of the teachers rounded out the data set.

Tests or Open-ended Assessment?

Neil was committed to replacing tests and examinations with a suite of tasks that focused on authentic problem solving and concept learning. He insisted that "I've never run an examination that's told me anything about a student I didn't know already". His planned change is important because it influenced the program that developed and was implemented in Phase 2 in 2000. Despite Neil's desire to eliminate across-the-board tests in all Year-8 classes, the teachers finally persuaded him to include one "comparability exam" at the end of Term 3 in 2000. When the Year-8 review was conducted late in 2000, all teachers—Neil included—agreed that one "examination" was "useful", "needed" or "essential" (opinions varied) and that it did not compromise their commitment to working scientifically; to the contrary, the test triangulated their non-test assessments.

As noted earlier, the survey of teacher-generated teaching and assessment strategies was a useful way to access their PCK. Neil argued that assessment should be integrated with the planning of each unit's teaching content and strategies. This recommendation agrees with Sanchez and Valcárcel (1999) who found this approach the most effective planning model.

The teacher-generated ideas ranged from many to few with the more experienced teachers not always the most creative, nor did they foresee some of the problems associated with their ideas. For example, Neil proposed two teaching and assessment activities aimed at developing *Natural and Processed Materials* CLO 4.1 and 5.3. The first two activities were called "The Separation Machine" and "Cooking Fluids". The separation machine was a practical test where the student brief was to devise ways to separate a simple salad dressing into its component parts (the parts were olive oil, vinegar and parsley flakes). The students had to choose and sequence effective separation methods from those taught prior to the practical test. The taught methods were not directly applicable to the problem and students needed to design and refine the process so that it separated the salad dressing and quantified by mass the percentages of oil, vinegar and parsley. The unit was observed in two teachers' classes and was enjoyed by students and teachers alike and helped many students achieve CLO 4.1 or 5.1.

Table 1

Features and dimensions of the teachers' pedagogical content knowledge.

Teacher	**Specialist teaching area**	**Conceptual knowledge**	**Teaching strategies**	**Assessment strategies**
Sue	Home economics, some science	Competent in Year 8-10 school curriculum content	Traditional—agrees with innovation but feels challenged	Had few ideas of her own, went with the flow, prefers tests
Neil	Chemistry, some physics	Expert in school curriculum physical science concepts and	Investigations, projects, some direct teaching, likes analogies	Few or no tests, prefers a range of assessment profiling. Class

		processes	and models	open-ended
Lyn	Primary come secondary teacher, no specialty	Competent in Year 8-10 school curriculum content	Innovative, and solved problem with "Cooking Fluids"	Very innovative and solved several big problems on how to monitor outcomes
Sam	Physics	Competent in school curriculum physical science concepts and processes	Prepared to try innovations suggested by others, suggested few himself	Likes some tests but like to have students doing interesting things
Jon	Physics and chemistry	Expert in school curriculum physical science concepts and processes	Likes tinkering, strict control, and insists on students hands-on science every lesson	Likes tests claims to favour open-ended activities, but class is very traditional
Lee	Home economics, some science, some biology	Competent in Year 8-10 school curriculum content. Interest in biology	Always seeking new and interesting strategies, very pragmatic	Innovative, keen to try new assessment and motivates other teachers
Ray	Earth science, some biology	Competent in school curriculum earth and biological science concepts and processes	Traditional, teacher centred learning but did plan and run some interesting field trips	Seems to want to stay as he was, missed many meetings, critical

The Cooking Fluids Unit

The second activity designed by Neil, called "Cooking Fluids", was almost a disaster. Neil's problem was that he did not anticipate the dangers involved—students were to cook a standard potato chip in boiling water, dry heat and hot oil. The aim of the activity was for students to develop and conduct a fair test in which they were to identify the variables, design and conduct the experiment, and collect and interpret the data. Depending on the sophistication of the students' experiments, they could meet *Science and Society's* "fair testing" CLOs 3.1, 4.1 or 5.1. Lee and Lyn were home economics teachers first and science teachers second and they immediately recognised the dangers in this activity. When she read the final form of the activity, Lee interjected "you can't do that! Someone's really going to get hurt … we can't supervise them every minute and that's what I'll need to do".

At first, Lee and Lyn were not taken seriously because of inaction from Neil who had invested much time and effort in the activity. It took Lee and Lyn two fortnightly meetings to convince Neil of the flaw in the activity and the activity was only changed after Lee redesigned the activity so that it became safe yet still achieved the intended outcomes. Lee and Lyn's knowledge in teaching cooking alerted them to the dangers and helped them provide a solution. We believe this incident highlighted a weakness in the science teachers PCK (with respect to safety) that was rectified by teachers with a different experience base. The benefit was that the activity was adapted, was successfully implemented, and all teachers learned from the experience. This was an empowering experience for Lee and Lyn. Until this point they were regarded as 'part-time' science teachers and were—at least implicitly—expected to 'follow' the knowledge and skills of the experienced science teachers.

Neil and the author worked on "Cooking Fluids". Apart from the safety issues involved in "Cooking Fluids", Neil was expansive and creative in the way he designed the concept and process learning for this unit. The students were provided with this problem: "You are to compare and contrast the cooking properties of water, vegetable oil and animal fat. Devise a fair test to find the best fluid for cooking a potato chip". The activity was comprehensively framed so that it contained phases that dealt with 1) devise and design; 2) variables analysis; 3) collect, present and interpret data; and 4) decision making about the cooking fluids' properties and uses.

The data derived from notes and audio-taped discussions show that Neil was expert in the conceptual content and the scientific thinking underpinning "Cooking fluids" and "The separation machine'. He was well versed in the relevant alternative conceptions that could arise and used a range of teaching and assessment strategies to encourage open-ended thinking in the students. Neil's commitment to a suite of assessments was purposeful — he wanted to give students the maximum opportunity to demonstrate each outcome. He mostly teaches Year 10-12 and this revealed his one weakness — he expected Year-8 students to have laboratory skills that they did not possess — and this explains his expectation that they could safely work with hot water and hot oil. Neil made it clear that he was less knowledgeable in the biological and earth sciences and deferred to the teachers whose teaching strengths were in these areas. In return, Neil provided teaching and assessment strategy help to Bev and Ray in help them refine the unit "How Ideas about the Solar System have Changed".

Other Units that Work

Two more units were suggested, planned and refined in the workshops held in late 1999. *Earth and Beyond* is an important content area and the "Earth" segment was addressed in a unit called "Volcanoes and Earthquakes" (Bev and Ray) and the "Beyond" segment in the unit "How Ideas about the Solar System have Changed" (Jon and Lee). In 2000, two more units were designed. The *Energy and Change* strand was catered for by a unit and assessment activity called "The drumming machine". Here students used Lego sets to build and test a drumming machine. Jon led this work and when the unit was run, several student groups modified the prescribed design so that it worked just as well but used fewer parts. Jon and Neil recognised this innovation and quickly modified the criteria to enable the award of CLO 5.2 rather than 4.2. One author worked with Lee to develop a task entitled "Living cells". Here the student prepared a wet mount of onion and cheek cells and provided a focused microscopic view for the teacher. Students then compared and contrasted the plant and animal cells in at least three ways to achieve *Life and Living* CLO 5.1. Less detail demonstrated CLO 4.2

Concluding points

As the 2000 school year unfolded, teachers became increasingly frustrated by the difficulty of deciding on student demonstration of outcomes. The outcomes are expansive conceptual statements and assessing student demonstration of them is altogether different to testing the achievement of atomistic content under the previous syllabus. It is important to note that the teachers were teaching Years 9-10 on the old syllabus alongside the new Year-8 syllabus. The potential for conflict was real. The Year-8 team were intent on producing an assessment scheme that would permit them to track the demonstration of outcomes across a number of topics and projects. The answer was slow in coming but with clever analysis of the unit activities, Lyn devised an elegant set of profiles that the other team members refined. We believe that this was another manifestation of PCK because it was more than pedagogy – it was pedagogy that resolved the problem of teaching and assessing conceptual knowledge. The final product was easy to use but was only possible because the teachers debated the issue for more than a term and applied all their knowledge and skills to the problem.

Thus far the project sounds daunting and one wonders why the teachers willingly applied so much effort. Indeed, each fortnight's 45 minute meeting always went well over time. Their commitment was sustained by the evidence that the products were unique and effective in their classes. The final two meetings at the end of Phase 2 in November 2000 reveal some of the teachers' opinions of the new course. As the teachers were 'wish-listing' their classes for 2001, all who taught the new curriculum in 2000 laid claim to Year-8 or Year-9 classes and several made comments like:

> I'll teach any class in eight or nine … even the learning support group … but I really don't want to teach Year-10. That course's too tired and I want to have fun with the kids. I think the eights learned more than in the past and I enjoyed teaching them … student problems were down and their interest was right up, (Lee)

Discussion

The activities that worked in Year-8 were a product of the teachers' perceptions of what and how students should learn. As they worked on units like "The Separation Machine" and "Volcanoes and Earthquakes", there was an evident sense of sharing and camaraderie. There was a distinct move away from content and "chalk-and-talk" teaching to concept and process oriented investigations. This could only happen when the teachers declared their knowledge and interest and sought better ways — from each other and available resources — to make the necessary changes. *Working Scientifically* gradually infiltrated their thinking and teaching. This was possible because most of the teachers took the risk and exposed their knowledge and pedagogy to group scrutiny. The meetings were exciting — on no occasion did the teachers finish on time and they often worked on for another half-hour. We believe that this happened because they felt that their contributions were valued and that they were making a real difference.

The disagreement between Neil and Ray and the way it influenced their subsequent actions suggests a difference in their PCK. Neil's thinking was expansive whereas Ray was set in his ways. Lyn shared Ray's preference for a test approach to assessment but later changed to Neil's view. Indeed, Ray did not attend all the fortnightly meetings in 2000 and made few contributions to the discussion but Lyn became a regular participant and she made many contributions. There is, of course, another dimension here—the dynamics of the science teaching team and the impact of Neil's leadership.

It seems likely that a teacher's choice of teaching and assessment strategies is related to their image of science and what counts as knowledge (Abd-El-Khalick & Lederman, 2000). This leads us to propose that how a teacher assesses his/her students is part of his/her PCK because it determines how and what they will teach. PCK influences the proportions of content and process in a teacher's plans and what is valued as knowledge for that teacher and his/her students. Lyn's thinking and teaching in 2000 supports our assertion that PCKg is a better label for her teaching. She was thoughtful and flexible; indeed, she changed her approach to assessment from a test to an activity orientation as a result of the professional interactions in which she participated. We propose that this was a productive change to her PCK and that it resulted from the integration of her excellent pedagogical skills with the content contributions of her colleagues. The new curriculum and the faculty's commitment to process and conceptual learning became a catalyst for teacher professional growth.

REFLECTIONS

While the primary school teachers and the secondary school teachers in our study used activities and units that work in different ways and from different sources, we found some common uses of science PCK and how PCK relates to activities and units that work. Table 2 summarises the similarities and highlights some of the differences.

Table 2

Primary and secondary school teachers PCK and science units and activities that work.

Secondary	**Primary**
Textbook Teachers insist on using a textbook Strictly observe curriculum requirements • expert practioner • content knowledge • colleagues Unit plan	Curriculum and School Plan Teachers scan available resources Selecting a resource Adapting the resource Unit plan
The collegiality created an environment where teachers "less able" in science were empowered to contribute using expert teaching knowledge (Bell & Gilbert, 1996). The secondary school teachers believed that they already had a comprehensive science PCK, but there were gaps which they were reluctant to acknowledge, and were reluctant to change their plans.	Even though help was available, the primary school teachers did not use it. They knew they lacked science PCK, and expected to find it in the resources so they could "get by" by relying on general pedagogy.

For the secondary school teachers, the textbook provided the initial framework for their science unit. The committed science head of department then acted as a catalyst to mobilise the considerable science PCK at the group's disposal. After examining the textbook's basic set of activities and comparing them with the curriculum requirements, the teachers used their combined science PCK to generate six effective unit plans. The textbook remained important to the unit plans but its centrality diminished as their PCK matured. The non-science teachers were able to contribute by drawing on, in Lyn's and Lee's case, strong pedagogical knowledge which when amalgamated with the science teachers' concept knowledge, produced PCK that enhanced both student learning and the teachers' motivation to teach. The conducive collegial atmosphere was essential to the demonstration of this outcome.

The primary school teachers used the required curriculum and the School Plan as the basic framework for their unit plan. They scanned the resources available to them and settled on a plan which they thought provided sufficient science PCK for them to teach. They drew upon their limited science PCK and their general pedagogy to adapt the resources to create a unit plan. Although the two teachers worked collaboratively, they did not access the help that was available to them. The teachers' choice of resources turned into a poor choice since it did not provide science PCK in the form that they were expecting, nor in a form that they were able to use effectively.

Both groups of teachers made poor choices, but the larger group of secondary teachers produced a more effective science unit because they were able to draw upon a greater range of science PCK than was available to the primary school teachers. Table 2 shows that, despite such differences, there are similarities in the teachers' use of activities and units that work. The pool of science PCK available to the secondary school teachers led to a effective unit plan. The limited science PCK available to the primary school teachers, with inappropriate science PCK in the chosen resources, resulted in an ineffective unit plan.

CONCLUSIONS AND IMPLICATIONS FOR SCIENCE TEACHING

Despite the differences observed in our study of secondary and primary school teachers, the implications for professional development are essentially the same for both school sectors, but with slightly different emphases (see Table 3):

Table 3

Comparison of the professional development needs of teachers.

Secondary	**Primary**
There needs to be a strong focus on the required curriculum, especially its philosophy and rationale. These foci must be compatible with the chosen textbook. The teachers need creative leadership to reconcile differences and in their planning and implementation.	There needs to be a strong focus on the required curriculum, especially its philosophy and rationale. Resources must be scanned to find compatible ones – help from a facilitator may be needed. The teachers need help from a facilitator in their planning and implementation.

Table 3 shows how similar are the needs of primary and secondary teachers. The main differences lie in the role and nature of the help provided. The nature of the facilitator remains the same. The secondary school teachers needed a leader to set a collegial atmosphere, and to encourage them to use their textbook critically by benchmarking it against the required curriculum and their collective PCK. They also needed help with elements of science content and science PCK in generating their unit plan This help mostly came from each other as a result of the supportive but critical environment in which they worked.

The primary school teachers needed an encouraging atmosphere, and help in understanding the focus of the required curriculum. They needed further help in transforming activity resources into a cohesive unit plan consistent with the required curriculum. They also needed help in interpreting key aspects of science content and science PCK. Superficially it appears that the primary school teachers needed more support than the secondary school teachers, but their needs are very similar when it remembered that there were six secondary teachers but only two primary teachers in each team.

This leads to an important conclusion: Primary science teachers are professionally isolated and their need of supportive professional partnerships should be an immediate priority for educational jurisdictions. If we value a scientifically literate society where individuals make informed decisions about heir own lives and about their environment, we cannot neglect the professional needs of primary and secondary science teachers. As this study has shown, PCK is an elusive quality, but when adequate PCK is present, either in individuals or collectively, the quality of student learning is greatly enhanced. It seems imperative that researchers and education administrators assign high priority to the enhancement of teachers PCK in all subject domains.

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