Introduction

The promotion of reflective practice amongst participants in teacher education programmes (e.g. Bain et al, 1999; Moon, 1999; Loughran & Corrigan, 1995; Shireen et al, 2003; Wallace & Louden, 2003) and the wider teaching community is widely championed for enhancing professional learning and growth. As a classroom science teacher for over 25 years and now a science teacher educator, I have come to realise how important a role reflection plays in shaping improving my pedagogy, i.e. my ability to make learning more accessible to my students. Some 20 years ago I was a participant teacher in the Learning in Science (Teacher Change) Project (Bell & Gilbert, 1996) and I remember how we were encouraged to think and learn from our experiences of trying out new pedagogical approaches in our classrooms. The insights I gained from this involvement in purposeful reflection revitalised my teaching and stimulated my interest in seeking out and trying new pedagogical strategies that might provide better learning opportunities for my students. Since our PGCertTT course had also specified the design, trialling and evaluation of an intervention(s) to address our pedagogical problem, a form of action research design known as practical action research (Cresswell, 2005) seemed ideal. The methodology comprises a general spiral of generic steps that lets the action researcher pursue solutions to his/her identified problems in collaboration with other researchers or mentors, and to enter the spiral at any point appropriate to the particular action research project.
In contrast, experienced expert science teachers possess a special blend of science content knowledge and pedagogical knowledge for teaching particular science topics to particular groups of students, that is built up over time and experience. This form of professional knowledge, termed *pedagogical content knowledge* (PCK) by Shulman (1987), is topic-specific, unique to each science teacher, and can only be gained through teaching practice – it is the knowledge that sets an expert science teacher apart from a scientist expert in that field. However, it is a very difficult form of knowledge to tie down and exemplify, because teaching is a complex and challenging activity that requires ongoing and informed decision-making in response to an individual student’s learning needs. It tends to be a fluid entity, constantly changing and evolving as classroom circumstances dictate. Experienced teachers very rarely discuss and share their PCK with fellow teachers, often because there are few opportunities in busy professional lives to do this. Consequently, this very valuable form of professional knowledge tends to be hidden and largely unknown.

A pedagogical problem
The in-depth professional knowledge and capabilities possessed by an experienced science teacher obviously cannot be built by an individual overnight, and certainly not in a one-year pre-service training course. Rather, it evolves and accumulates over time and with practice (Nilsson, 2008). Until recently, there have been few concrete examples that are useable and applicable for science teaching. What then can teacher educators like myself do to help novice teachers begin to build the foundations they need to start a successful teaching career.
and equip them with the capabilities and capacity for ongoing professional learning throughout their careers? This is a pedagogical problem that I have become aware of recently as I have witnessed my students’ reflective thoughts in earlier action research and delved more into the literature around PCK. My intention now is to recount how I have attempted to solve the problem by finding ways to access expert teachers’ PCK to facilitate my student teachers’ understanding of its nature, how it is constructed and how they could start to build their own.

In the PCK literature, I found a number of writers who had explored the nature of PCK in greater depth and some concepts and strategies that held real promise for my science education courses. For example, Magnusson et al (1999) had identified five generic components of a science teacher’s PCK that are generally agreed upon in the science education field, which can give student teachers some broad insights into the nature of PCK. These components include his/her:

- orientations towards science teaching (the teacher’s knowledge of science and the nature of science, and beliefs about science and how to teach it)
- knowledge of curriculum (what concepts and skills to teach and when to teach)
- knowledge of assessment (what to assess, why and how)
- knowledge of students’ understanding of science (including their prior knowledge and misconceptions and potential misconceptions)
- knowledge of instructional strategies (proven appropriate and effective)

**Figure 1 CoRe (Content Representation) and associated PaP-eRs (Pedagogical and Professional experience Repertoire) (Loughran et al, 2004, p. 376)**

<table>
<thead>
<tr>
<th>Important Science Ideas/Concepts</th>
<th>Big Idea 1</th>
<th>Big Idea 2</th>
<th>Etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What you intend the students to learn about this idea.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Why it is important for students to know this.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. What else you know about this idea (that you do not intend students to know yet).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Difficulties/limitations connected with teaching this idea.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Knowledge about students’ thinking which influences your teaching of this idea.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Other factors that influence your teaching of this idea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Teaching procedures (and particular reasons for using these to engage with this idea).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Specific ways of ascertaining students’ understanding or confusion around this idea (include likely range of responses).</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Lines from the PaP-eRs represent the links to particular aspects of the CoRe.
More recently, Loughran et al (2006) decided to explore the collective PCK of experienced science teachers for particular topics in junior secondary science, in the hope of teasing out some common threads in their pedagogy.

To help the expert teachers come to a consensus on their pedagogical approach for specific topics, and to make the links that exist between the experts’ knowledge of content, teaching and learning about a particular topic more explicit to others, Loughran et al devised strategies known as Content Representations (CoRes) and Pedagogical and Professional-experience Repertoires (PaP-eRs) (2006).

The CoRes are tools that attempt to portray holistic overviews of expert teachers’ PCK related to the teaching of a particular science topic in a chart form (see Figure 1). Each CoRe is accompanied by a suite of PaP-eRs, which are descriptions of how specific aspects of the topic aligned to the CoRe have been taught by the expert teachers. PaP-eRs are written as personal narratives to illustrate specific instances of individual teachers’ PCK (as depicted in the CoRe) in action.

A possible solution

I introduced these CoRes and PaP-eRs to my science student teachers through a series of reflective and discussion tasks in the workshops, late in the secondary science course. They proved very effective in raising student teachers’ awareness and understanding of PCK as a specialised form of professional knowledge and providing insights about teaching science.

‘I found this task interesting because it brought up some ideas that I did not know about and problems that we could face as teachers… when we are teaching we need to be more aware that it is not necessarily the content that is of most importance but it is how we are teaching and why…I really like how CoRes break down a topic into what is intended to be taught, why it is important, what the teacher should know, difficulties that could arise, assessing the level of the students, how to teach each concept…it helps me identify what I need to work on and be aware of how I can work around complications that arise as I teach each concept.’

Jackie (pseudonym), journal notes

Later, in a chemistry education course involving some of the same science students, I experimented with the CoRe structure as a form of blank ‘planning template’ to help to frame the student teachers’ thinking for their future PCK around a particular chemistry topic. All found the CoRe design task challenging and it was obvious their lack of classroom experience and experimentation limited their ability to carry it out. As I tried to facilitate the process, I found myself taking on the role of team leader, supplying or directing students to appropriate sources of information and guiding the required thinking. In this role I could see the depth and extent of thinking required to complete a CoRe – it was no easy task!

Refining the solution

Despite students’ lack of classroom teaching practice and the difficulties they experienced with CoRe design, I sensed real benefit in the exercise as a process for
building some foundations upon which their future PCK development could be based. On reflection, I could see ways in which the whole process could be better facilitated to maximise their learning possibilities. So, when planning the science and chemistry courses this year,

I set about ‘deconstructing’ the process of CoRe formation and purposefully designed a sequence of learning experiences in the lead-up to the CoRe design task that should scaffold the required thinking and learning process more effectively.

Thus in 2009, as an intervention, I initiated a series of learning activities early in the science education course, designed to help the student teachers develop a set of generic strategies for accumulating relevant knowledge and skills prior to constructing CoRes. These activities introduced and engaged students in critical analysis and reflection on the purposes of science education, the nature of science, the national science curriculum statement (MoE, 2007), learning theories and misconceptions in science, pedagogy and teacher beliefs about teaching and learning, assessment including national qualifications, and the worth of various science education websites. They also participated in preliminary exercises introducing them to PCK and CoRes and PaP-eRs. Then, in the second phase (the chemistry education course), I set the student teachers some exercises targeted at the construction of a specific CoRe. This phase began approximately 10 weeks into the 30-week programme, after the student teachers had experienced their first teaching practice in schools (6 weeks’ duration). Briefly, the sequence of activities involved:

- determination of pre-existing concepts, misconceptions and skills Year 11 students (15-16 year-olds) might have for the topic Atomic structure and bonding from sources such as the NZ science curriculum statements (1993, 2007); text commonly used in schools; and reputable Internet sites, such as BESTCHOICE, CHEMSOURCE and the Royal Society of Chemistry;
- subsequent determination of concepts and skills that school students might be expected to learn for Atomic structure and bonding at Years 11, 12 and 13 in turn, from similar sources plus national qualification materials; and
- group design of a CoRe for Year 12 students for the topic Redox Reactions using blank CoRe templates. To complete this task required the student teachers to first decide upon 5-8 key ideas or enduring understandings that Year 12 students should acquire during the Redox Reactions topic, followed by research into potential Redox teaching and learning experiences.

(See Hume & Berry (2010) for full details of this teaching and learning sequence and the research design.)

Later on, the student teachers were given the opportunity to try collaborative design of another CoRe for Year 12 chemistry; this time the topic was Quantitative Chemistry.

Findings
The strategies I employed this year to prepare students for CoRe design seemed to improve the student teachers’ confidence and ability to locate and select/determine
relevant information for CoRe completion, despite their lack of teaching practice. They went about constructing their tentative PCK with greater confidence than students in the previous year, and seemed to have more understanding of the task requirements. My support was sought less often compared to the previous year and the student teachers worked independently of me for the second CoRe on Quantitative Chemistry. They were very appreciative of the preparatory work done in workshops and valued the step-by-step, collaborative approach to gathering relevant materials and developing a CoRe.

One student expressed how much the collaboration and continued practice with CoRe creation was contributing towards his thinking and preparation for classroom teaching and learning:

‘What we did find is that doing it on your own you get a pretty good idea what's going on. But then when you get all the other…the team members coming in and getting their bits in...“Ooh, for crying out loud, I forgot that!” and “Ooh, that's quite a good idea. I might try this. I might try that.” But once you've done a few of them...I think you've got a real good...

**Figure 2** Quantitative Chemistry CoRe designed by a secondary chemistry student teachers’ group.

<table>
<thead>
<tr>
<th>Big Idea A</th>
<th>Big Idea B</th>
<th>Big Idea C</th>
<th>Big Idea D</th>
<th>Big Idea E</th>
</tr>
</thead>
<tbody>
<tr>
<td>What I intend the students to learn about:</td>
<td>Specific ways of understanding or confusion around this idea (include likely range of responses)</td>
<td>Molecules indicate the amount of a substance and can be calculated from mass and molar masses. Avagadro’s No. shows that one mole contains $6.023 \times 10^{23}$ particles</td>
<td>The empirical and molecular formulae show the composition of a molecule and can be used to calculate the percentage composition of individual atoms in a substance</td>
<td>Concentration of a solution is the amount of substance per unit volume and can be calculated from the volume and moles of a substance.</td>
</tr>
<tr>
<td>Why is it important for the students to know this?</td>
<td>Students need to understand the information behind practical quantitative applications of quantative analysis</td>
<td>Students will be able to understand the make up of the compounds. They substances in a reaction can be calculated to perform accurate applications of quantative analysis</td>
<td>Students may form a chemical equation so that they may be able to calculate the mass of a substance.</td>
<td></td>
</tr>
<tr>
<td>What else do you know about this idea (that you do not intend the students to know yet)?</td>
<td>Molecules are related to the relative mass of a substance.</td>
<td>The students may form a chemical equation so that they may be able to calculate the mass of a substance.</td>
<td>Concentration indicates the strength of the solution and allows the students to perform accurate calculations.</td>
<td></td>
</tr>
<tr>
<td>Difficulties/ limitations connected with teaching this idea</td>
<td>Ensure that the learning diagrams fold out clearly</td>
<td>The concept of moles is an abstract concept. The substances as the formulae do not indicate the structure.</td>
<td>The students may form a chemical equation so that they may be able to calculate the mass of a substance.</td>
<td></td>
</tr>
<tr>
<td>Knowledge about students thinking which most of the concepts within quantitative analysis are abstract and require the need for models and visualisations. Analogy of the concentration of a solution and the chemical equation as a concentration of a chemical reaction. This needs to be abstract concepts. Can be explained thoroughly relating to real life concentrations.</td>
<td>Avagadro’s number can make students think about relacións</td>
<td>The students may think about the relationship of ratios and concentrations in a reaction. This needs to be abstract concepts. Can be explained thoroughly relating to real life concentrations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other factors that influence your teaching:</td>
<td>Sequence of learning objectives follow from left to right. Diagrams of moles in solution. Activity calculating the relative mass of beans, relate to the elements (Chemsourse moles). Demonstrations</td>
<td>Repetition of calculating moles of substances. Analog of the teaching step by step. Concentration of boys in the class (girls are the minority).</td>
<td>Quizzes, Crosswords of definitions, dominoes, fill in the gaps in equations, true/false questions, concept maps (give the terms as a beginning), students create their own structured overview relating concepts to real life situations. For example alcohol percentages. Comparing the reaction of...</td>
<td></td>
</tr>
</tbody>
</table>
idea of what should be going on...I think it's trying to get you to think, to pre-reflect, as such, to make sure you think about those things before it happens.’

Malcolm, (pseudonym), post-interview

The students were able to produce CoRes (see, for example, Figure 2) whose content exemplify many instances of growing awareness of PCK components (Magnusson et al., 1999) and a useful foundation for their future PCK.

Notable features of the student teacher CoRes on Redox Reactions and Quantitative Chemistry that could be interpreted as illustrations of their collective development of possible PCK components include:

- the selection and expression of the key ideas as full stand-alone statements, which give a sense of enduring understandings that students need to develop, rather than simply noting down headings, phrases or questions, e.g.:
  - ‘Redox reactions involves a transfer of electrons’
  - ‘Oxidation numbers are a tool for keeping track of electrons’
  - ‘Electrolysis is a non-spontaneous redox reaction’
  - ‘Quantitative analysis is the determination of an amount of substance’

The above statements taken from their CoRes illustrate knowledge of the curriculum component, i.e. what concepts and skills are important for students to learn at this stage of their learning; and of assessment as qualifications that have a strong influence on what is learned at this level (Hume & Coll, 2009)

- explanations and elaborations within the CoRes that were more detailed than those completed by student teachers in the previous year and frequently showed keener awareness of issues around students’ understandings, another component of an experienced teacher’s PCK according to Magnusson et al. (1999). Such improvements included:
  - an awareness that chemists view the world of materials on three levels and that students need to be able to move between levels in their thinking in order to understand chemical ideas, e.g. inclusion of the terms micro, macro and symbolic in the key ideas of the Redox Reactions CoRe; and ...(can) link micro to macro ... when explaining why the idea of transfer of electrons is important to know for students in the Redox topic.
  - the limitations that a lack of mathematical understanding can have on student learning in balancing redox equations and quantitative chemistry and how this might be countered, e.g. ‘hard to understand the concept of ratios in a reaction. This needs to be explained thoroughly’.
  - how the abstract nature of concepts within quantitative analysis need particular pedagogical strategies if effective learning is to occur, e.g. ‘the concept of moles is an abstract concept. The teacher needs to use visualisation and diagrams to ensure that the students can apply the
knowledge and do a molar display – measure a mole of different substances to show different volumes.'

- a greater repertoire of potentially useful instructional strategies, another PCK component, for promoting learning and monitoring the nature of science understanding, e.g. use of the analogy of the concentration of boys in the class – girls are the solvent to help learners make links between concrete examples and abstract ideas like concentration in quantitative chemistry; relate concepts to real life like alcohol percentages to bring relevancy to the learning; and true/false questions and concept maps (give terms as a beginning) to determine if there is confusion about aspects of the big idea in quantitative chemistry.

In the interviews, the student teachers also indicated awareness of how CoRe design was heightening their awareness of the components of PCK, like knowledge of curriculum and instructional strategies, e.g.

'I don’t know where I’ll end up but the CoRe, content representation model, I would like to think that I’d have those for the units, ‘cos then it forces you to be quite clear about those big concepts. And I think that clarity around that is what I’m really aiming for, when you’re actually delivering, you’re making sure that material’s orientated to delivering those key concepts.'

Iris, (pseudonym), post-interview

‘You’ve got to know what the kids have done before…according to the curriculum what they should be doing and how you’re going to do it…’

Malcolm, (pseudonym), post-interview

and of students’ understandings:

‘...And once you start looking into the websites and that, there’s a lot of information out there and a lot of misconceptions as well…trying to make sure that you cover misconceptions because, even in our classes, there are quite a few misconceptions and...wow!...get those ironed up first, yeah.’

Malcolm, (pseudonym), post-interview

Implications and follow-up research
The findings from this exploratory study suggest that using CoRes as part of a planned and strategic pedagogical approach in student teacher chemistry education is potentially valuable for raising their awareness of PCK (Magnusson et al, 1999) and of the thinking, background knowledge and experience required to develop that very special kind of professional teaching knowledge. The careful scaffolding of learning experiences prior to CoRe design enables student teachers to begin accessing and organising some of the knowledge and thinking possessed by expert science teachers without feeling overwhelmed. Their lack of classroom experience and experimentation at this stage of their professional careers is a limiting factor in their PCK development, but CoRe constructions can be a good start. The process allows student teachers to construct a tentative form of PCK for particular topics that they can now take into their first classroom teaching experiences and trial – a kind of pre-planning tool. Hopefully this tentative PCK will give them a strong basis upon which to learn how to teach specific chemistry content effectively. I see it as a very useful new pedagogical tool in my chemistry and science education courses.
My intention now is to continue the action research cycle and follow up on these novice teachers to investigate how useful they find their chemistry CoRes (redox and quantitative) in planning and teaching these topics in their first year of teaching, and if they have carried on the practice of CoRe construction for other science/chemistry areas. It would also be interesting to determine to what extent and in what way the PCK content of their CoRes may change after classroom experience of teaching the topics.

Action research is a valuable and viable means of fostering my continued professional growth as an educator, because it involves me in metacognitive processes that change how I conceptualise processes of teaching and learning. For example, introducing CoRes into my pedagogy for the science and chemistry courses and working with students to help them complete their CoRes enhanced my understanding of what curricular content I needed to teach in this course. The act of researching CoRe design has simultaneously deepened my own knowledge of a PCK component (curriculum knowledge) and allowed me to synthesise new PCK. There is a real sense that I am learning how to teach in higher education (Ramsden, 1992).

References


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