CoRes asTools for Promoting Pedagogical Content Knowledge of Novice Science Teachers

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Introduction

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. The academic construct of PCK is a recognition that teaching is not simply the transmission of concepts and skills from teacher to students but, rather, a complex and problematic activity that requires many and varied 'on the spot' decisions and responses to students' ongoing learning needs. Much has been written about the nature of PCK since Shulman first introduced the concept in 1987, and its elusive characteristics have led to much debate. However, the work of Magnusson *et al.* (1999) is helpful in clarifying this special form of a teacher's professional knowledge by proposing that PCK is made up of five components:

– orientations towards science teaching (knowledge of and about science and beliefs about science and how to teach it)

– knowledge of curriculum (what and when to teach)

– knowledge of assessment (why, what and how to assess)

– knowledge of students' understanding of science

– knowledge of instructional strategies

Thus to acquire the specific PCKs required to teach and assess a variety of science topics to a range of students over their teaching careers, novice teachers have a lot to learn. For this knowledge-building to occur classroom teaching experience is essential.

Many science graduates entering teacher education courses are unaware of the personal learning challenges that lie ahead. They are often naïve about the demands that teaching will make of them (Loughran, Mulhall & Berry, 2008), and do not appreciate that effective teaching is a skilled and purposeful activity involving complex processes of pedagogical reasoning and action (Shulman, 1987). Research also indicates that many of these science student teachers actually lack a deep conceptual understanding of science, with disjointed and muddled ideas about particular science topics (Loughran *et al*., 2008). Their shallow understanding of subject content tends to result in a style of teaching that over-delivers on facts and rules but fails to focus on ensuring that students develop the key ideas that are needed for science understanding, i.e., they lack an appreciation that 'less is more' (Gess-Newsome, 1999).

PCK attempts to capture and articulate what is an elusive and largely unspoken of form of professional knowledge that sets expert science teachers apart from scientists and novice teachers. However, its tacit nature has meant that concrete examples that are useable and applicable in science teaching are difficult to find.

Exploring PCK to learn about teaching

To address the paucity of PCK exemplars, Loughran *et al.* (2006) thought it worthwhile to explore the collective PCK of good science teachers for particular topics in junior secondary science to see if they could tease out some common threads in their pedagogy that might be helpful to beginning science teachers. Once the expert teachers reached consensus on their pedagogical approach for specific topics, Loughran *et al.*(2006) devised strategies known as Content Representations (CoRes) and Pedagogical and Professional-experience Repertoires (PaP-eRs) to make the links between the experts' knowledge of content, teaching and learning about a particular topic more explicit to others. The CoRes, in chart form (Fig. 1), attempt to portray holistic overviews of expert teachers' PCK related to the teaching of a particular science topic. They are accompanied by 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 or vignettes to illustrate specific instances of teachers' PCK (as depicted in the CoRe) in action. Each CoRe and its set of related PaP-eRs were collectively presented in a portfolio format.

Already CoRes and PaP-eRs have been used successfully in pre-service science teacher education to introduce and help novice teachers understand what PCK might involve. In the study by Loughran *et al.* (2008) a pre-service educator invited student teach-

	Important science ideas/concepts		
	Big Idea 1	Big Idea 2	Other
1. What you intend the students to learn about this idea?			
2. Why is it important for students to know this?	**PaP-eR** 1		
3. What else do you know about this idea (that you don't intend students to know yet)?	**PaP-eR** 1	**PaP-eR** 3	
4. Difficulties/limitations connected with teaching this idea		**PaP-eR** 2	
5. Knowledge about students' thinking which influences your teaching of this idea			**PaP-eR** 4
6. Other factors that influence your teaching of this idea		**PaP-eR** 3	
7. Teaching procedures (and particular reasons for using these to engage with this idea		**PaP-eR** 2	
8. Specific way of ascertaining students' understanding of confusion around this idea (include likely range of responses			**PaP-eR** 4

*Fig. 1: **CoRe** (**Co**ntent **Re**presentation) and associated **PaP-eRs** (**P**edagogical **a**nd **P**rofessional **e**xperience **R**epertoires).*

ers to construct their own examples of CoRes and PaP-eRs after they had examined and reflected on those created by expert teachers. The findings from this study strongly suggested that the focus on PCK using the CoRes and PaP-eRs to frame their thinking about the links between science content and pedagogy did help the student teachers gain a more sophisticated view about learning to teach science and how to teach for understanding.

When I first came across CoRes and PaP-eRs last year, I also thought of using them in my science education course at the University of Waikato, since it occurred to me that they could be a very useful means of introducing, modelling, examining, and developing PCK for particular topics in junior science with my student teachers. I introduced the CoRes and PaP-eRs developed by Loughran *et al*. (2006) to the student teachers through a series of reflective and discussion tasks in the workshops, and found they proved very effective in enhancing the student teachers' ability to recognize and articulate aspects of the nature of PCK. These exercises also raised the student teachers' awareness and understanding of PCK as a specialized form of professional knowledge, and they appreciated the insights working with CoRes and PaP-eRs gave them 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
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> *Jackie (pseudonym), journal notes*

The student teachers completed the science education course at mid-year, but I continued to teach a small number of this same group in a chemistry education course for the remainder of the year. In a spontaneous workshop discussion these students reiterated how useful they had found CoRes in thinking about and planning junior science lessons while on their teaching practice. All commented how disappointing it was that none existed in the senior chemistry area. Together we speculated whether using the CoRe structure as a form of 'planning template' could help to frame their thinking as they attempted to construct their own PCK for a particular chemistry topic. So the class (comprising 8 students in total - four chemistry graduates and four doing a conjoint education-chemistry degree) worked initially in pairs on the topic '*Redox Reactions*' using a blank CoRe template for guidance. The PCK they constructed would be essentially hypothetical since they had had little/no classroom teaching experience of the topic, although one had had the opportunity to teach it on an earlier teaching practice.

The student teachers found the CoRe design task challenging and very quickly sought my help and assistance from peers. It was obvious their lack of classroom experience and experimentation was a limiting factor and 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 as my comments below suggest!

> It was a sort of interesting experience for me really, because I didn't know how this would go. I hadn't taught this topic for eight or nine years. So for me it was bringing back all that knowledge that was at the back of my mind … bringing it forward. But what was occurring for me, as you were doing that, was … if I was you, how would I approach filling in those bits? And so I thought, 'Where would I find out that information?' So that's, I think, really what happened when we first started … I just brought in a whole lot of stuff, didn't I? Screeds and screeds of paper, basically.
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> *(Post-class audiotaped discussion with students, Oct 2008)*

The masses of information that I thought relevant and subsequently provided as support for the student teachers during these sessions (e.g., text, achievement standards, exam prescriptions, and examiners' reports) served to both help and confuse them! In interviews after the course they expressed mixed feelings about the construction of their own Chemistry CoRes. All acknowledged the value of the exercise for planning lessons, but most commented on the difficulty of the task or with its format.

> Yes, I think it would be good to use it as planning a unit and then base the lessons on it.
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> *Emma (pseudonym), interview*

> I think it would be quite useful in planning a lesson, especially for me … as opposed to doing it on paper I think I'd rather just take up the whole whiteboard … can draw arrows and rub it out … even link it.
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> *Jack (pseudonym), interview*

> Because I was unsure of the content myself … it was such a new way to look at it I struggled. I jumped all over the place. When I rewrote it, it still looks a mess, but actually made more sense because we'd had a go at it in class. But I still don't know if I'd get this table out and fill it – it sort of disjoints it all … and then you just get a bit confused. [In the future] I would probably do it differently … it just didn't flow for me.
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> *Tammy (pseudonym), interview*

> But maybe that will come with practice if we keep slogging at it?
>
> *Gina (pseudonym), interview*

Despite the mixed response I felt the benefits of this exercise for building a basis for their PCK development outweighed the negatives. Even though the students lacked the experience of practice, they did gain some foundational knowledge upon which they could begin to build their future PCK for particular content areas through CoRe design. On reflection, I could see ways in which the whole process could be better facilitated to maximize their learning possibilities. 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. My pedagogical purpose became more focused on helping student teachers develop a set of generic strategies for accumulating relevant knowledge and skills prior to constructing CoRes and I carefully planned an approach that had CoRe construction and PCK development as key course objectives.

Thus, this year I initiated a series of learning activities early in the science education course that familiarised student teachers with many of the sources of information or elements that contribute to PCK and to the thinking required for the selection and use of relevant information for the content of a CoRe. 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 (see details below). This phase began approximately 10 weeks into the 30-week programme, after the student teachers had experienced their first 6-week teaching practice in schools. The sequence of activities over 4 three-hour workshops was as follows:

- First in small groups the student teachers were asked to determine what pre-existing concepts and skills Year 11 students (15-16 year olds) might have for the topic *Atomic structure and bonding*. These ideas were also to include some common misconceptions. As a class we discussed and identified some likely sources for such information 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.

- Once the possible pre-existing ideas for Y11 were established I placed the student teachers in three small teams. Each team was to brainstorm and select relevant and appropriate concepts and skills that school students might be expected to learn for *Atomic structure and bonding* for a particular year level - Year 11, 12 or 13. For this part of the task they also referred to national qualification materials (standards, exam papers and accompanying marking schedules and examiners' reports) since these high-status qualifications are known to exert a strong influence on what students learn in classrooms (Hume & Coll, 2006). The class then shared and collated their findings to gain an overall picture of how the sequence of concepts and skills evolved over the three years.
- Now attention was turned to another topic, this time *Redox Reactions*. I provided the student teachers with blank CoRe templates and they brainstormed and selected concepts and skills that a Year 12 class studying the topic would be likely to learn. Once they had determined what concepts and skills would be typically included in the topic, the student teachers were then required to decide upon 5-8 key ideas or enduring understandings that students should acquire during the *Redox Reactions* topic – these key ideas were then recorded on a CoRe template.
- Finally, in groups they explored available resources and located and recorded potential teaching and learning experiences for the *Redox Reactions* topic. Sometimes they trialled the activities amongst themselves and evaluated their worth. Their search also included the identification of common misconceptions (both pre-existing and potential) and areas of learning difficulty related to the key *Redox Reactions* ideas they had determined and any specific pedagogical strategies for addressing these misconceptions. This information was then added to the group *Redox Reactions* CoRe and then the two groups shared and discussed their respective CoRes in the whole class forum.

Later on the student teachers were given the opportunity to try designing another CoRe for Year 12 chemistry, this time the topic was *Quantitative Chemistry.* Again they chose to work collaboratively as two groups.

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 hypothetical PCK with more obvious purpose than students in the previous year, and seemed to have more understanding of the task requirements. My support was sought less frequently than 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.

> So she's been really helpful in giving us lots of different things to go to, to look for information, just almost building up a conscious list of where you can source what you need to know …. And we did a separate part each and then brought it back the next time, we had class and went through every part. And it was really helpful that it wasn't just us, that Anne was here 'cos she has taught it lots before .. Cos it was quite, we found it quite difficult because we didn't have actual experience teaching it.
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> *Carol (pseudonym), post-interview*

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.

> I did the one that Anne's just given me and wow! It made you think, it really did, … 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 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
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> *Malcolm, (pseudonym), post-interview*

The students were able to produce CoRes the content of which showed signs of the PCK components (Magnusson *et al*., 1999) that expert chemistry teachers possess. Figure 2 is the CoRe on *Quantitative Chemistry* produced by the conjoint student teachers, which shows many instances of growing awareness of PCK components and provides 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 involve 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 illustrate knowledge of the *curriculum* component, i.e., what concepts and skills are important for students to learning at this stage of their learning; and of *assessment* which has 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). Examples are (i) 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; (ii) 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*; (iii) 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 such as 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, for example, knowledge of *curriculum* and *instructional strategies*.

> 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.
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> *Iris, (pseudonym), post-interview*

> And I know before I did this I just popped into the class and you went ahead, but with this now, it gives you the sort of foundation of what you should be looking at, as I said before, to make sure … 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 mis-

***Fig. 2:** Quantitative Chemistry CoRe designed by the conjoint student teachers' group*

	Big Idea A	**Big Idea B**	**Big Idea C**	**Big Idea D**	**Big Idea E**
What I intend the students to learn about the idea	Moles indicate the amount of a substance and can be calculated from mass and molar mass. Avagadro's No. shows that one mole contains 6.023x10^{23} particles	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.	Stoichiometry is the determination of ratios of the mole relationship in a chemical reaction through the balancing of equations	Concentration of a solution is the amount of substance per unit volume and can be calculated from the volume and moles of a substance.	Quantitative analysis is the determination of a amount of substance. Can be through techniques such as gravimetric (percentage weight) and volumetric (through volume).
Why is it important for the students to know this	Students need to know understand the information behind practical quantitative analysis.	So that they can further understand the make up of the compounds. They can better understand the characteristics of a substance	Students will be able to balance equations and calculate the mass of substances in a reaction to perform accurate reactions	Concentration indicates the strength of the solution and allows the students to understand the characteristics of a substance.	The students need to understand the process involved with qualitative analysis so that they may be able to design their own investigation in year 13.
What else do you know about this idea (that you do not intend the students to know yet)	Moles are related to the partial pressures of the substances.	The applications of quantitative analysis in relation to every day life. This is covered in year 13 in their practical investigations.			
Difficulties/ limitations connected with teaching this idea	The concept of moles is an abstract concept. The teacher needs to use visual-isations and diagrams to ensure that the students can apply the knowledge.	The students may form misconception about the substances as the formulae do not indicate structure.	Need for an understanding of mathematical concepts. The students need to know the conventions of a chemical equation so that they may be able to apply chemical ratios.	Being able to visualise the difference between moles of a substance in solution and the concentration of a solution.	Developing proficiency in technique to ensure that the students are accurate to a satisfactory level.
knowledge about students thinking which influence your teaching of this idea	Ensure that the learning is scaffolded. The terms mass, moles and molar mass are explained individually. The students need to be able to understand and visualise that a mole is unit of substance		Hard to understand the concept of ratios in a reaction. This needs to be explained thoroughly	Need to visualise these abstract concepts. Can relate to real life concentrations.	Students may need to have examples of quantitative analysis in industry.
Other factors that influence your teaching of this idea	Most of the concepts within in quantitative analysis are abstract and require the need for models and visualisations. Analogies will be effective in the teaching of quantitative analysis. However, these must not form misconceptions about chemistry				
Teaching Procedures (and particular reasons for using these to engage with this idea)	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 (Chemsource moles). Demonstrations (molar display-measure a mole of different substances to show different volumes)		Repetition of calculating moles of substances. Teaching step by step.	Analogy of the concentration of boys in the class (girls are the solvent). Anecdotes and relating concepts to real life situations. For example alcohol percentages. Comparing the reaction of combustion of cork in air, and combustion in liquid oxygen where concentration is much higher.	One titration performed as a class so the students can perform the process step by step. Real-life investigations (concentrations of contaminants in water).
Specific ways of ascertaining students understanding or confusion around this idea (include likely range of responses)	Quizzes, Crosswords of definitions, dominoes, fill in the gaps in equations, true/false questions, mix and match, practice questions, concept maps (give the terms as a beginning), students create their own structured overview.				

conceptions and … wow! … get those ironed up first, yeah.

Malcolm, (pseudonym), post-interview

Implications and follow up research

The findings from my exploratory study confirm that working with CoRes in a planned and strategic approach in student teacher chemistry education is very potentially valuable for raising their awareness of the nature of the components 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. As a tool for exploring and beginning to develop these components, the construction of a CoRe is certainly no easy task for student teachers. However, I believe that by careful scaffolding of learning experiences, as illustrated in this paper, student teachers can begin to access some of the knowledge and thinking of expert science teachers without feeling overwhelmed by the requirements to organize that knowledge and thinking into a CoRe. Their lack of classroom experience and experimentation at this stage of their professional careers is a limiting factor in their PCK development, but the findings from this study show CoRe constructions can be a good start. These exercises allowed student teachers to construct a hypothetical form of PCK for particular topics that they can take into their first classroom teaching experiences and try. This hypothetical PCK should give them a strong basis upon which to learn how to teach specific chemistry content effectively and show how CoRe construction could have positive and lasting effects on their PCK development.

The intention now is to follow up with 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.

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