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Constructing CoRes—a Strategy for Building PCK in Pre-service Science Teacher Education

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Abstract This paper presents findings from an exploratory study into a science teacher education initiative that seeks to build the foundations on which novice teachers can begin developing their pedagogical content knowledge (PCK). The initiative involved the use of Content Representations (CoRes), which were originally developed as part of a strategy for exploring and gaining insights into the PCK of expert science teachers. As the student teachers explored existing CoRes the course lecturer saw potential for more effectively developing their PCK through engaging them in constructing their own CoRes for new topics. When given the opportunity, student teachers found the task challenging and their lack of classroom experience and experimentation proved to be a limiting factor. However, the contribution such a task could make to their future PCK development remained a distinct possibility in the lecturer's view. In the following year she carefully scaffolded the learning prior to CoRe construction such that the student teachers could more readily access relevant knowledge when attempting such a task. Their resultant CoRes and comments indicate that with appropriate and timely scaffolding the process of CoRe construction does have the potential for PCK development for novice teachers.

Keywords Content Representations (CoRes) · CoRe design · Pedagogical content knowledge (PCK) · pre-service science teacher education

Introduction

Many science graduates entering teacher education courses are naïve about the cognitive demands that teaching will make of them (Loughran et al. 2008), and do not appreciate that

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effective teaching is a skilled and purposeful activity involving complex processes of pedagogical reasoning and action in order to facilitate sound student learning (Shulman 1987). In addition such novice teachers are often unaware that pedagogical reasoning and action are underpinned by a complex knowledge base that experienced teachers draw upon and progressively develop from the time they first enter the teaching profession. This observation is supported by research which indicates that many science student teachers actually lack a deep conceptual understanding of science, such that their ideas about particular science topics are fragmented and disorganized (Loughran et al. 2008). This superficial grasp of subject matter by novice teachers tends to result in pedagogy that is intent on delivering facts and algorithms but inefficient when it comes to accessing key ideas that their students need for science understanding in the immediacy of the classroom teaching and learning environment (Gess-Newsome 1999).

Shulman (1987) proposed a number of domains or categories to deal with the complexity of the knowledge base experienced (good) teachers draw upon. These categories include:

- Content knowledge;
- General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter;
- Curriculum knowledge, with particular grasp of the materials and programs that serve as ‘tools of the trade’ for teachers;
- Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their special form of professional understanding;
- Knowledge of learners and their characteristics;
- Knowledge of educational contexts, ranging from workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; and
- Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds.

(p. 8)

This knowledge is sourced from scholarship in the content discipline of science, educational materials and structures, science education research and the wisdom of practice (Shulman 1987).

Taking a constructivist perspective on learning, the process of building this professional knowledge base can be understood through the concepts of ‘mental structures’ i.e., an individual’s concepts, schema or mental models and ‘conceptual change’ (Leach and Scott 2003). In the constructivist view individual learners come to given situations with pre-existing understandings and beliefs and attempt to make sense of experience by making links with their prior knowledge. This process may involve little/no change to existing mental structures while in other instances individuals are motivated to change their existing structures and construct different structures to make sense of new information. In other words, they have constructed their own new knowledge.

Novice teachers come to teaching with wide and varied prior experiences and beliefs about the profession and what teaching involves. 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 1-year pre-service training course. Rather, it evolves and accumulates over time and with practice (Nilsson 2008). What then can teacher educators 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?

Exploring PCK to Learn About Teaching

Recently, a promising development in teacher education by Loughran et al. (2006) has emerged that centres on the academic construct of pedagogical content knowledge (PCK), which was originally introduced by Shulman (1987) to encapsulate a category of teachers' professional knowledge considered unique to each individual teacher. Shulman (1987) originally defined PCK as "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learning, and presented for instruction" (p. 8), and "the particular form of content knowledge that embodies the aspects most germane to its teachability" (p.9). However, this highly specialized form of professional knowledge is embedded in individual teachers' classroom practice (Padilla et al. 2008) and is rarely articulated within the teaching community of practice. To help clarify the nature of a teacher's PCK Shulman (1986b, 1987) proposed that it comprises two components: knowledge of what he calls 'representations' i.e., instructional strategies illustrations, analogies, explanations and demonstrations that teachers use to make certain subject matter comprehensible to their students; and knowledge of students' 'learning difficulties' i.e., students' misconceptions, naïve ideas gained through interpretation of prior learning, experiences or preconceived ideas about a topic, as well as knowledge of any other potential barriers to learning subject matter, such as how concepts inter-relate and strategies to help solve problems. Various researchers since Shulman have explored and expanded upon the PCK concept, particularly the knowledge domains that appear to contribute to a teacher's PCK. For example, Grossman (1990) envisaged PCK as a transformation rather than a blend of knowledge, and originating from three rather than two knowledge domains which she identified as: (1) subject matter knowledge and beliefs, (2) pedagogical knowledge and beliefs, and (3) knowledge and beliefs about context. These knowledge domains are sourced from a teacher's observation of classes as a student and teacher, specific courses she/he has experienced during teacher education and classroom teaching experience. Grossman further conceptualized PCK as comprising four components adding conceptions of purposes for teaching subject matter and curricular knowledge (what concepts and skills need to be learned and when and why) to Shulman's knowledge of students' understandings and of instructional strategies—the rationale being that these two extra components are inherent to a teacher's classroom thinking and action. Magnusson et al. (1999) built on these ideas and in their work went on to propose five components of an experienced teacher's PCK:

- orientations towards science teaching (since teacher's knowledge and beliefs related to their teaching goals and approaches will influence their classroom practice)
- knowledge of curriculum
- knowledge of assessment (since what is to be assessed, how and why, also influences a teacher's practice)
- knowledge of students' understanding of science
- knowledge of instructional strategies

Abell (2008) in an overview of how the concept of PCK has evolved since Shulman first introduced the construct, has emphasized that PCK must be seen as more than the sum of its components. She points to the synergistic nature of PCK where teachers "not only possess PCK, they employ the components of PCK in an integrated fashion as they plan and carry out instruction. Teacher use of PCK involves blending individual components to address the instructional problem at hand" (p. 1407).

Against this background of thought about PCK, the approach by Loughran et al (2006) sought to elucidate the nature of PCK from practitioners' points of view and was a response to growing interest in the notion of a scholarship of practice where attention is focused on investigating and depicting "a teacher's grasp of, and response to, the relationships between knowledge of content, teaching and learning in ways that attest to practice as being complex and interwoven" (Berry et al. 2008, p. 1271). Using frameworks known as Content Representations (CoRes) and Pedagogical and Professional-experience Repertoires (PaP-eRs) Loughran et al. (2006) attempt to make explicit the links that exist between the knowledge of content, teaching and learning for science teachers. CoRes as originally devised, represent conceptualizations of the collective PCK of expert teachers around a specific science topic, including "the key content ideas, known alternative conceptions, insightful ways of testing for understanding, known areas of confusion, and ways of framing ideas to support student learning" (Loughran et al. 2008, p. 1305). In essence CoRes attempt to portray holistic overviews of teachers' PCK related to the teaching of a particular science topic, e.g., chemical reactions, to make the tacit nature of this expert PCK explicit to others. Presented in the format of Resource Folios, the CoRes are accompanied by Pa-PeRs, which illustrate how specific aspects of the topic aligned to the CoRe are brought to life in teaching by expert teachers. PaP-Rs are narrative accounts designed to illustrate specific instances of that PCK in action.

Already the promise of CoRes and PaP-eRs for highlighting and exemplifying some of the deeper and more elusive aspects of what constitutes quality teaching for student teachers has been illustrated in preliminary studies of their use in pre-service education. In the study by Loughran et al. (2008) a pre-service science teacher educator sought to highlight PCK via CoRes and PaP-eRs to help his student teachers investigate and come to understand the complexity of learning to teach science. He also hoped the CoRes and PaP-eRs would assist the student teachers to develop "a highly integrated picture of science knowledge, as well as awareness of key science ideas in order to teach for understanding" (p. 1303) that he believed they required for good science teaching. In what he termed the 'PCK approach', he invited student teachers 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 the study strongly suggest that the focus on PCK using CoRes and PaP-eRs to frame their thinking about the links between science content and pedagogy did help the student teachers to gain a more sophisticated view about learning to teach science and how to teach for understanding.

Background to this Study

In this present study, a pre-service science teacher educator on becoming aware of CoRes and PaP-eRs in the literature on PCK decided to introduce them into her science education course since they were very much aligned with her evolving views on what constitutes effective teacher education. Her pedagogical approaches to teacher education were strongly influenced by constructivist views of learning (Leach and Scott 2003) and the ideas of Shulman (1986, 1987) i.e., good teaching is a purposeful and skilful activity involving 'pedagogical reasoning and action' and that good teachers possess a professional knowledge base built up over time and experience. Shulman (1987) explains that in an ongoing process of comprehension, transformation, and instruction of particular content to students, and subsequent evaluation and reflection on the teaching and learning that occurred, a good teacher draws upon an existing personal professional knowledge whilst also adding new comprehensions. It is through this process that teachers build up their professional expertise and capabilities. Thus in her teaching programmes, the teacher educator sought to help her students build the foundations of their future professional knowledge base for teaching, by providing opportunities for them to engage in pedagogical reasoning and action within the limitations of an academic university course. Typical opportunities might include planning teaching sequences for given scenarios e.g., teaching rates of reactions to a mixed ability class of 14 year old students, and presenting to peers for feedback; devising assessment criteria for fair testing; or reflecting on a lesson planned and taught while on teaching practice. She also strongly promoted reflective thinking as a means of professional growth through episodes of reflective writing in workshops where student teachers were asked to evaluate their own learning in relation to Shulman's knowledge domains (1987, p. 8).

While the teacher educator recognized that opportunities for the development of student teachers' PCK could really only occur while on teaching practice, she wanted to introduce the construct of PCK to her student teachers during her science education classes and to help the student teachers begin to recognize elements of PCK in action. When she discovered CoRes and PaP-eRs in the research literature she quickly identified them as a much needed and potentially valuable means of introducing, modeling, examining, and developing awareness of PCK for her student teachers. In her view the format of the CoRes and their accompanying Pap-eRs allowed the reader access to many facets of the PCK possessed by experienced science teachers in content areas commonly taught in junior science programmes.

As part of an ongoing action research programme, concerned with the impact of various initiatives on the quality of student teacher learning, she decided to introduce CoRes and PaP-eRs through a series of reflective and discussion tasks into her secondary science and chemistry education programmes. She rationalized that through exposure to the CoRes and PaP-eRs of expert teachers and through opportunities for students to design their own CoRes, her students might gain access to the thinking and basis upon which expert science teachers make decisions about their pedagogy for particular science topics/concepts. This paper reports on the second phase of this initiative when insights gained from the first trials with the use of CoRes and PaP-eRs in her teaching programme were reflected upon and used to redesign the approach for phase two.

Key insights for the teacher educator gained from the first phase were:

- The value of working with CoRes and PaP-eRs for enhancing the student teachers' ability to recognize and articulate aspects of the nature of PCK and raising their awareness and understanding of PCK as a specialized form of professional knowledge.
- The need for a more structured pedagogical approach to learning about the nature of PCK and its components by student teachers, such that their learning about PCK is maximized and they can begin to amass the component knowledge bases and the thinking skills required for the building of their own future PCK.
- Designing their own CoRes is a useful pre-planning tool for student teachers when thinking about what their own PCK might look like for particular topics—a kind of working hypothesis that could be tested and evaluated when they plan and teach the topic for the first time.

- Awareness by the teacher educator that her own understanding of the complexity of the PCK construct was in its infancy and somewhat naive. She needed increased understanding of the construct such that she could consciously look for and prompt recognition by student teachers of the components of PCK, as identified by Magnusson et al. (1999).

Thus in the second phase of the initiative the teacher educator's pedagogical purpose became more focused on helping student teachers acquire a set of generic strategies for developing the knowledge bases required for attempting to build the PCK components contained in CoRes. She carefully planned a pedagogical approach that had preparation for PCK development using CoRe construction as a key course objective. This approach included a series of learning activities early in the science education course that familiarized student teachers with many of the sources of information that contribute to PCK development and to the thinking required for the selection and use of relevant information in designing a CoRe. The 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, 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 and texts. Then in the second phase of her pedagogical approach she set the students a number of exercises targeted at the construction of a specific CoRe (see details in the Methodological approach section below). This phase began approximately 10 weeks into the 30-week programme after student teachers had experienced their first teaching practice in schools (6 weeks duration). As part of her ongoing action research programme she was concerned with the impact of this pedagogical approach on her student teachers' understanding of how to teach science and the overarching research question that guided her inquiry was:

- How effective was the scaffolded approach to CoRe construction in providing a possibly useful foundation for the development of PCK for particular chemistry topics?

To guide data coding and analysis, the following sub questions were asked:

- did the scaffolding strategies enhance student teachers' abilities to design a CoRe?
- to what extent did the content of their CoRes reflect the components of PCK as identified by Magnusson et al. (1999)?

Methodological Approach

This inquiry was conducted within an interpretivist paradigm using a case study approach (Bryman 2008, Cohen et al. 2007) and an action research design known as *practical action research* (Creswell 2005). The action research component involves a dynamic, flexible and iterative methodology, allowing the researcher to spiral back and forth between reflections about a problem, data collection and action. The methodology, as outlined by Creswell (2005), comprises a general spiral of generic steps that allows the researcher to pursue solutions to identified problems in collaboration with other researchers or mentors, and to enter the spiral at any point appropriate to the particular action research project. This practical action research design had been used over a number of years with some success by the teacher educator to introduce and evaluate various initiatives in her teacher education programme, including reflective journals and co-constructive teaching and learning approaches (Hume 2010). The CoRe initiative arose as part of this ongoing action research.

To contribute to the trustworthiness of the research process (Guba and Lincoln 1989) particular attention was paid to strategies that would maximize the quality of data gathering and processing within the constraints of the study. For instance, while the representativeness and typicality of the findings might be compromised by the small sample size, strategies such as prolonged engagement and triangulation (Cohen et al. 2007; Guba and Lincoln 1989; Patton 1990), helped to promote the dependability, confirmability and credibility of the study. Participant observation, semi-structured interviews by a fellow researcher and analysis of documents such as course planning notes and reflective journals [student teachers and teacher educator] (Moon 1999) were utilized to reduce the likelihood of researcher bias (Erickson 1998) and produce sufficient evidence to allow convergence (Bell 1999; Keeves 1998).

This study involved the researcher and nine students in a pre-service teacher education course in chemistry. The course caters for students with science degrees (with chemistry as a substantial component) who are seeking entry into the teaching profession and contributes towards a 1-year programme in secondary teacher training. Graduates of this programme serve an internship for a further 2 years in schools before becoming fully certificated secondary teachers. The course also provides for undergraduate students completing a conjoint 4-year degree in chemistry and teaching—four of the nine participating teachers were in this category. All students had undertaken the preliminary exercises introducing them to PCK and the CoRes and PaP-eRs in the science course, which had run earlier in the year, and were keeping reflective journals (Hume 2009) as part of the requirements for both the science and chemistry papers. As stated earlier the process of scaffolding CoRe construction began in earnest after the first teaching practice in schools. The sequence of activities (sourced from the science educator's planning notes and reflective journal) over four 3-hour workshops was as follows:

- First in small groups the student teachers were asked to establish what pre-existing concepts and skills students at a given level of schooling Year 11 (15-16 year olds) might have for a specific topic—in this instance *Atomic structure and bonding*. These pre-existing ideas could also include likely misconceptions. Before they embarked on the task, the class in general discussion established likely sources for such information such as the national science curriculum statement; text commonly used in chools; and reputable Internet sites such as BESTCHOICE at Bestchoice.net.nz, ChemSource at intro.chem.okstate.edu and the Royal Society of Chemistry at www.rsc.org.
- In the second stage the student teachers worked in three small teams to brainstorm and select relevant and appropriate concepts and skills that school students might be expected to learn for *Atomic structure and bonding* for Years 11, 12 and 13 of their senior schooling. They also consulted national qualification materials (standards; exam papers and accompanying marking schedules and examiners' reports) since high status qualifications exert a strong influence on the nature of the student-experienced curriculum (author cited). Each team worked on one of the respective years and then as a class collated their findings and discussed to gain an overall picture of how the sequence of concepts and skills evolved over the 3 years.
- In the 3rd stage a blank CoRe template was provided for the student teachers as attention turned to another topic, this time *Redox Reactions*. The timing of the workshops for the graduates and conjoints differed slightly during this section of the course so the circumstances meant that the graduates worked together as a team on the next exercise, as did the conjoints. In this exercise the student teachers together brainstormed and selected concepts and skills for a Year 12 class studying the topic

Redox Reactions. Once complete, they had the added task of determining 5–8 key ideas (enduring understandings) for Redox Reactions and recording these on the CoRe template.

- Finally, in groups they explored available resources, locating (and sometimes trialing amongst themselves) evaluating and recording potential teaching and learning experiences for the *Redox reactions* topic. 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 collective *Redox Reactions* CoRe and then the groups shared and discussed their respective CoRes in the whole class forum.

In subsequent workshops the student teachers were given the opportunity to tackle another CoRe, on the topic of *Quantitative Chemistry*, again for a Year 12 class. Again they chose to work collaboratively as two groups.

Data Collection

Data collection in the chemistry course focused on: the workshops during which the student teachers were preparing for and constructing their own CoRes for specific chemistry topics, the content of the resultant CoRes; and the student teachers' perspectives on the usefulness of such a process for stimulating the development of aspects of their own PCK. Data were recorded in the form of student reflective journals, audiotaped interviews (done by a colleague using a semi-structured interview schedule prepared by the researcher), student artefacts (their CoRes) and field notes recorded in the researcher's reflective journal. Student teachers were viewed as intentional participants in workshop activities and the interpretive analysis considered both their perspectives of classroom reality and those of the researcher.

Data Coding and Analysis

Student teachers' comments from interviews and reflective journals were coded in relation to references about:

- the effectiveness of the scaffolding strategies in building the knowledge bases required to design a CoRe
- their awareness and/or development of tentative components of future PCK for a particular topic as a result of CoRe construction

Observational data were examined for indications of increasing independence and competency on the part of student teachers when locating appropriate information for designing their CoRes. The completed student CoRes were examined for components of their possible PCK for a particular topic.

Analysis involved determining the level of independence and competency that the student teachers gained in CoRe design through the scaffolding process, and the extent and nature of their PCK development in relation to the Magnusson et al. (1999) model as illustrated in the CoRe content and their comments in interviews.

Findings

It appeared that the scaffolding strategies introduced into the pre-service chemistry teacher education course built the capacity of student teachers to locate and select/determine relevant information for CoRe design that might form the basis of future PCK development, despite their lack of teaching practice. Of particular significance were the capabilities they developed that appeared to be transferable. The teacher educator reflected in her journal that the student teachers tackled CoRe design with more purpose and confidence than students in the previous year; they more readily located relevant information and did this with increased independence of her as their lecturer.

> My observations were that students this year still found the initial Redox CoRe difficult to do, but valuable to do. They needed less direct help from me to complete the task—the students were able to do more of the actual locating and selection and/or determination of content themselves despite the earlier timing in the course. My role seemed to be more one of prompting and suggesting—they made the decisions ... the second CoRe on Quantitative Chemistry was done virtually independently of me and very quickly. The conjoints chose to work together again and their second CoRe was done in their own time outside the workshop sessions.
>
> Reflective journal notes, teacher educator

Students expressed appreciation of the preparatory work done in workshops to enable them to approach the CoRe design with the skills to find appropriate sources of information. The step-by-step collaborative approach to developing a CoRe was also valued.

> 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.
>
> Carol (pseudonym), post-interview

They realised how working together to design their CoRes and continued practice with CoRe creation was contributing towards their preparation for classroom teaching and learning.

> I did the one that (the course lecturer had) 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 ..
>
> Malcolm, (pseudonym), post-interview

The students were able to produce collective CoRes whose content indicated some feasible components of PCK (Magnusson et al. 1999), i.e., components likely to be part of the PCK of experienced chemistry teachers. Table 1 is the CoRe on *Quantitative Chemistry* produced by the conjoint student teachers, which exemplifies many instances of possible components of PCK worth trialing in their first teaching forays.

Table 1 CoRe on *Quantitative Chemistry* produced by the conjoint student teachers

	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 $6.023 \times 10^{\wedge}23$ 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 an 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 visualizations and diagrams to ensure that the students can apply the knowledge. Avagadro's number	The students may form misconceptions 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 visualize 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 visualize 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 visualize these abstract concepts. Can relate to real life concentrations.	Students may need to have quantitative analysis in industry.
Other factors that influence your teaching of this idea	Most of the concepts within quantitative analysis are abstract and require the need for models and visualizations. 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 (concentration of contaminations 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.			

(Note in the following section selected text from the students' Cores is italicised to support the findings). Notable features of the student teacher CoRes 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 standalone 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 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 has a strong influence on what is learned at this level (author cited)

- explanations and elaborations within the CoRes 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. For instance, 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. Or 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.* Similarly 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 the act of CoRe design was heightening awareness of the components of PCK, like knowledge of *curriculum* and *instructional strategies* for example.

> 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

> 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 misconceptions and ... wow! ... get those ironed up first, yeah.
>
> Malcolm, (pseudonym), post-interview

Finally another significant finding is confirmation that engagement in this action research cycle prompted growth in the professional learning of the teacher educator and development of her own PCK for science teacher education

> CoRe design entails the identification of key ideas or enduring understandings with an analysis that includes justification of the key ideas chosen, any difficulties students may encounter learning these ideas, related misconceptions students may hold and appropriate instructional sequences and strategies for the intended learning. To complete this design task requires thorough familiarization with the content to be taught, the sources of that content and the rationale for that content choice. Working with students to help them complete their CoRes enabled me to re-familiarize and/or update my knowledge of current national curriculum statements, qualifications requirements, common chemistry misconceptions, and sources of appropriate instructional strategies such as text, electronic resources and the Internet. The gathering and interpretation of data from sources such as observations, students' reflective journals and artifacts (their finished CoRes) to identify signs of emerging PCK greatly enhanced my understanding of what curricular content I needed to teach in this course. I strongly sense that the same thing will happen for my student teachers if they continue this practice—I see it as a very useful pedagogical tool in my chemistry education course. For me, the act of researching CoRe design has simultaneously deepened my own knowledge of a PCK component (curriculum knowledge) and allowed me to synthesize new PCK. This experience has heightened my awareness that there is a PCK that expert science teacher educators build over time and that action research is a viable means of fostering such PCK growth.
>
> Reflective comment, teacher educator

Implications and Follow Up Research

The findings in this study confirm that working with CoRes in a planned and strategic approach in student teacher chemistry education is very valuable for raising their awareness of the nature of the components that serve as the foundation for PCK (Magnusson et al. 1999); for building their knowledge of those components for given topics and groups of students; and for their appreciation of the thinking and experience required to develop that very special kind of professional teaching knowledge known as PCK. As a tool for developing these foundational components, the design of a CoRe is no easy task for student teachers. However, if carefully scaffolded the CoRe design process enables student teachers to begin accessing and accumulating some of the knowledge of experienced science teachers in ways that can help to bolster feelings of confidence and competence when they come to organize that knowledge into their first model of PCK. Clearly 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 designs could be a good start for such growth. These exercises allowed student teachers to build knowledge of the components that they could then transform into a form of tentative PCK for particular topics and students. It is hoped they can take this tentative PCK into their first classroom planning and teaching experiences confident in the knowledge that they have a strong basis upon which to learn how to teach specific chemistry content effectively. The teacher educator is optimistic that this process of CoRe design can have positive and lasting effects on the PCK development of novice teachers.

To confirm her optimism the teacher educator intends to follow up on her novice teachers to investigate how useful they found their chemistry CoRes (redox and quantitative) in planning and teaching these topics in their first year of teaching and if they find value in carrying on the practice of CoRe construction for other science/chemistry areas. She also wants to determine to what extent and in what way their tentative PCK stood up to the rigours of reality in the classroom and how their emerging PCK might change as a result of their teaching experience.

This study had a very small sample size, which poses significant limitations on the trustworthiness of this research design. However it is the intention of the teacher educator to continue this action research and follow-up into the use of CoRe design for laying the foundations for future PCK development with similar cohorts of students in following years. The hope is that the results from this small study may be replicated and improved upon.

In conclusion, one student interestingly speculated on the value of designing CoRes with her teaching colleagues once she began teaching.

> Yeah, I think that would be really beneficial to do with teachers ... say like, next year in my department or whatever... it would be quite useful if they are open to it and if there's time and stuff to show them what it's about ... to tell them like how to get the big ideas. They probably would know the big ideas anyway, but that's something that we've done quite a lot on ... how to find the big ideas ... but then the filling out of the boxes because they would have taught it a lot more. Then they're going to know and I think it would be quite helpful for me ... especially as a beginning teacher.
>
> Carol (pseudonym), post-interview

Her comments prompted thought about possible extensions to this study that include the involvement of associate and/or fellow teachers of these neophyte teachers, in schools where the student teachers begin their teaching careers, in collaborative CoRe design tasks as a form of professional learning for all concerned. Such involvement would require experienced teachers to be convinced of the value of such exercises which can only begin to happen through exposure to and experience with CoRes as professional learning tools.

References

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education, 30*(10), 1405–1416.

Bell, J. (1999). *Doing your research project*. Berkshire, UK: Open University Press.

Berry, A., Loughran, J., & van Driel, J. H. (2008). Revisiting the roots of pedagogical content knowledge. *International Journal of Science Education, 30*(10), 1271–1279.

Bryman, A. (2008). *Social research methods* (3rd ed.). New York: Oxford University.

Cohen, L., Manion, L., & Morrision, K. (2007). *Research methods in education* (6th ed.). New York: Routledge.

Creswell, J. W. (2005). *Educational research. Planning, conducting, and evaluating quantitative and qualitative research.* New Jersey: Pearson Education Inc.

Erickson, F. (1998). Qualitative research methods for science education. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 1155–1174). Dordrecht: Kluwer.

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 51–94). Dordrecht: Kluwer.

Grossman, P. L. (1990). *Making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Guba, E., & Lincoln, Y. (1989). *Fourth generation evaluation*. Newbury Park: Sage.

Hume, A. (2009). Promoting higher levels of reflective writing in student journals. *Higher Education Research & Development, 28*(3), 247–260.

Hume, A. (2010). A personal journey: Introducing reflective practice into pre-service teacher education to improve outcomes for students. *Teachers and Curriculum, 11*, 21–28.

Keeves, J. P. (1998). Methods and processes in research in science education. In B. Fraser & K. Tobin (Eds.), *International handbook of science education* (pp. 1127–1153). Dordrecht: Kluwer.

Leach, J., & Scott, P. (2003). Individual and sociocultural views of learning in science education. *Science & Education, 12*, 91–113.

Loughran, J., Berry, A., & Mullhall, P. (2006). *Understanding and developing science teachers' pedagogical content knowledge*. Rotterdam: Sense Publishers.

Loughran, J., Mulhall, P., & Berry, A. (2008). Exploring pedagogical content knowledge in science teacher education. *International Journal of Science Education, 30*(10), 1301–1320.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Boston: Kluwer.

Moon, J. A. (1999). *Learning journals. A handbook for academics, students and professional development*. London: Kogan Page.

Nilsson, P. (2008). Teaching for understanding: The complex nature of pedagogical content knowledge in pre-service education. *International Journal of Science Education, 30*(10), 1281–1299.

Padilla, K., Ponce-de-Leo, A. M., Rebado, F. M., & Garritz, A. (2008). Undergraduate professor's pedagogical content knowledge: The case of 'amount of substance'. *International Journal of Science Education, 30*(10), 1389–1404.

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. Newbury Park: Sage.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–22.