

Investigating Content Representations (CoRes) as Pedagogical Tools for Science Teacher Education

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Introduction

In this article I discuss how use of scholarship and action research led me to introduce an intervention into my science education programmes called Content Representations (CoRes). My initial findings strongly indicate CoRes could be very useful tools for helping student teachers develop the professional knowledge base they need for teaching.

Using action research to investigate my teaching practice

In a conscious effort to learn how to take on the role of teacher educator (teaching others how to teach science) I have become engaged in a more formal and focused form of reflective practice, known as action research. This engagement was a direct result of involvement in an induction programme for new teaching staff at my university where I was encouraged to undertake further studies for a Postgraduate Certificate in Tertiary Teaching (PGCert(TertTchg)). The study programme required me to use my emerging scholarship in tertiary teaching, gained from reading the literature in this field, and the methodology of action research to investigate a pedagogical problem I was experiencing in my teaching. Action research in education involves participants in a form of disciplined self-reflective inquiry that is collaborative and designed to enable them to understand, improve and reform their educational practice (Engstrom, Engstrom & Sunito, 2002; Kemmis & McTaggart, 1988). Since our PGCert(TertTchg) 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 action research component in this approach involves a dynamic, flexible and iterative methodology, allowing the researcher to move back and forth between reflections about a problem, data collection and action. 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.

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My action research was set in the teaching context of science education courses that cater for students with science degrees who are seeking entry into the teaching profession. These courses contribute towards a one-year programme in secondary teacher training. Successful graduates serve a further internship for two years in schools before becoming fully certificated secondary teachers.

Novice teachers in my science education courses come to teaching with wide and varied prior experiences and beliefs about the profession and what teaching involves, and often they are naïve about and/or do not appreciate the demands that teaching will make of them (Loughran, Mulhall & Berry, 2008). In my experience some have real difficulty adapting to a professional teaching role. For example, accomplishing such a role in classrooms where their students appear unmotivated and struggle with science can be difficult for novice teachers if they themselves have been successful learners in science. Such experiences may challenge their long held views about learners, and teaching and learning in science, and need to be addressed if they are to become effective teachers of all students in science.

Research also indicates that many student science teachers will 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 their students develop the key ideas that are needed for science understanding and appreciate that ‘less is more’ (Gess-Newsome, 1999). My student teachers commonly over-cram lessons with content and use transmissive modes of teaching, which lends support to the research findings above.

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.

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, Krajcik & Borko (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)

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!

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 maximize 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 (see details below). 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). 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 where 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, 2008). 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 in teams 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, they were then required to decide upon 5-8 key ideas or enduring understandings that Year 12 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 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 groups. For a full account of the research design see Hume & Berry (in press)

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.

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 (of the CoRe) and then brought it back the next time, we had class and went through every part.

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.

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 CoRes (see for example Figure 2) whose content exemplifies many instances of growing awareness of PCK components (Magnusson et al., 1999) and a useful foundation for their future PCK.

	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 6.023×10^{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 visualisations and diagrams to ensure that the students can apply the knowledge. Avagadro's number can cause the students	The students may form a 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 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.				

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

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 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 taken from their CoRes 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* as qualifications that 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. 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 CoRe design was heightening their 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

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. I feel motivated to devise and trial new pedagogical approaches and strategies and my research activity is giving me clear direction and purpose. Any modifications that I make to my teaching approach are likely to have positive outcomes for my students because my decisions are being guided by evidence-based reasoning specific to our teaching and learning situation and targeted at our identified needs. There is a real sense that I am learning how to teach in higher education (Ramsden, 1992).

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