An Analysis of PCK to elaborate the difference between Scientific and Technological Knowledge

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Abstract

This research addressed the key area of early career teacher education and aimed to explore the use of a 'Content Representation' (CoRe) as a planning tool to develop early career secondary teacher Pedagogical Content Knowledge (PCK). This study was situated in the subject areas of science and technology, in which sound teacher knowledge is important to student engagement. The study was designed to examine whether such a tool (CoRe), co-designed by an early career teacher with expert content and pedagogy specialists, can enhance the PCK of early career science and technology secondary teachers. The research design incorporated a unique partnership between expert classroom teachers, content experts, early career teachers, and researchers experienced in science and technology education.

This paper will present an analysis of CoRe development and the effect that had on the early career teacher's PCK. In addition, as the same tools and methodology were applied to both a science and a technology teaching context, differences between the two areas became clear. This paper will elaborate and discuss the differences which arose as a result of the development of the CoRe's and an analysis of PCK differences in science and technology.

Introduction

Research has shown that one of the factors that enables effective teachers is their rich pedagogical content knowledge (PCK), a special blend of content knowledge and pedagogical knowledge that is built up over time and experience. This form of professional knowledge, first theorized by Shulman (1987), is topic-specific, unique to each teacher, and can only be gained through teaching practice. The academic construct of PCK is 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. While 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, there are still gaps in our knowledge about teacher development of PCK. However, the work of Magnusson, Krajcik and Borko (1999) is helpful in clarifying this special form of a teacher's professional knowledge by proposing that PCK is made up of five components. In their view, an experienced teacher's PCK encompasses his/her:

- orientations towards teaching (knowledge of and about their subject and beliefs about it, 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 the subject; and
- knowledge of instructional strategies.

Research in technology education reveals a less well-developed understanding of the role of PCK than exists in science, though an international discourse does exist with studies being reported in both general design and technology education (De Miranda, 2008; Jones & Moreland, 2004; Rohaan et al., 2010; Rohaan, Taconis, & Jochems, 2009; Rollnick & Mavhunga, 2012), as well as in different areas of technology such as Information and Communication Technology (Koehler & Mishra, 2005). While researchers like McCormack (1997, 2004) and Banks (2009) have discussed the nature of knowledge in technology education, international diversity remains a characteristic of the discourse in technology, which is an impediment to the development of PCK in the area of technology education. Consequently, one purpose of this paper is to extend this understanding through the lens of PCK.

To address the paucity of PCK exemplars in science teaching, Loughran et al. (2006) explored the PCK of highly regarded science teachers for particular topics in junior secondary science, to see if they could tease out some common threads in their pedagogy that could be considered as comprising the knowledge base of science teachers, that might be helpful to share within the profession. Loughran et al. developed a set of conceptual tools known as Content Representations (CoRes) and Pedagogical and Professional-experience Repertoires (PaP-eRs) that make explicit the different dimensions of, and links between, knowledge of content, teaching and learning about a particular topic. The CoRes, represented in table form (see Table 1), attempt to portray holistic overviews of expert teachers' PCK related to the teaching of a particular topic. They contain a set of enduring ideas about a particular topic at the head of the columns, and a set of pedagogical questions for each row.

Table 1. Sample CoRe matrix

TOPIC	Enduring idea 1	Enduring idea 2	Enduring idea 3	Enduring idea 4
Why is it important for the students to know this?				
Difficulties connected with teaching this idea				
Knowledge about student thinking which influences teaching about this idea				
Teaching procedures				
Ways of ascertaining student understanding or confusion about the idea				

CoRes have been used successfully in pre-service science teacher education to help novice teachers understand what PCK might involve and to develop their own representations of teaching in particular topic areas. In the study by Loughran et al. (2008), a pre-service educator invited student teachers to construct their own examples of CoRes after they had examined and reflected on those created by expert teachers. The findings from Loughran et al.'s (2008) study strongly suggest that the focus on PCK using CoRes 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. Another study along similar lines also sought to promote science student teachers' PCK through CoRe design (Hume & Berry, 2010). The student teachers found the task challenging and their lack of classroom experience and experimentation proved to be a limiting factor in being able to develop CoRes successfully. However, the contribution such a task could make to their future PCK development remained a distinct possibility.

This developing body of literature related to teacher PCK suggests that research into the use of expert-informed CoRes in the untested arena of PCK development by early career secondary teachers is important. Further, neither the role of experts of content in the formulation of CoRes, nor the analysis of resulting student outcomes when early career teachers use CoRes in their classrooms, have been extensively examined. This innovative research consolidates and builds knowledge about the use of CoRes to help address the gaps described above. Addressing these gaps in the research could help contribute to effective development of PCK for secondary teachers of science and technology, which will support success for all types of learners.

Research design and methodology

This research addressed the key area of early career teacher education and aimed to research the use of a CoRe as a planning tool to develop early career secondary teacher PCK. The study was designed to examine whether such a tool, co-designed by an early career teacher with expert content and pedagogy specialists, can enhance the PCK of early career science and technology secondary teachers. A research design was developed that incorporated a unique partnership between expert classroom teachers, an expert scientist and an expert technologist, early career teachers of science and technology, and researchers experienced in science and technology education.

This study built on nascent work by Hume and Berry (2010) into the use of CoRes in secondary teacher education. It combines the previously-mentioned frameworks of Shulman (1987) and Magnusson et al. (1999) on PCK with the work of Loughran *et al.* (2006) on CoRes to address the development of secondary teachers of science and technology. Teachers typically enter secondary teaching in New Zealand with a degree in a specialist subject area plus one year of teacher education. These teachers then have specific content knowledge upon entering secondary teaching, such as biology, chemistry or physics in science, and may come with a much broader range of backgrounds in technology, such as electronics or engineering. Evidence suggests that, even with this degree background, these early career teachers find it difficult to conceptualise the key concepts behind science and technology (Gess-Newsome, 1999; Loughran et al., 2008). Whilst their one year of teacher education provides some support for development of general pedagogy, development of PCK in their specialist subject areas is limited in the timeframe available. This issue becomes more acute for early career teachers who find themselves addressing science or technology topics in their classrooms that they may not have covered well in their undergraduate degrees.

This study aimed to address this problem by researching how the development of PCK in early career secondary teachers is influenced through construction and trial of the use of CoRes in specific topics as planning tools for teaching science and technology.

Research questions

The following research questions were addressed:

- How can experts in content and pedagogy work together with early career teachers to develop one science topic CoRe and one technology topic CoRe to support the development of PCK for early career secondary teachers?
- What differences are revealed between science and technology through the development of the CoRe?
- How has engagement in the development and use of an expert-informed CoRe developed an early career teacher's PCK?

Data collection

This study employed an interpretive methodology using an action research approach (Creswell, 2005) involving a cohort of 2 early career secondary teachers of science and 2 of technology, as practitioner-researchers as they undertake their second or third year of teaching. The study was organized in three phases.

Phase 1 of the study was the design of one CoRe in a science topic and one CoRe in a technology topic. Each CoRe was designed with the help of an expert scientist or an expert technologist who provided advice on the key ideas of the content knowledge for the topic of the CoRes, and an expert teacher of science and another of technology at secondary level who provided advice on the pedagogical questions appropriate to address those key ideas. The experts and the early career teachers co-constructed the CoRe(s) in a workshop situation facilitated by two of the researchers who are experienced in working with teachers, and who are familiar with research-informed challenges in teaching and learning in science and technology. Two different researchers observed and made field notes of the process of construction of the CoRe to determine the nature of the contributions made by the expert scientist/technologist, expert teachers, and the early career teachers. This was followed by focus group interviews.

Phase 2 began an action research process for the teacher in partnership with a researcher. Each early career teacher who was engaged in developing the CoRe then undertook a period of planning for delivery of a scheduled unit using the CoRe as a planning tool. In this process the researcher's role was asking why and how questions of the early career teacher as they planned their unit with or without taking account of the CoRe. The early career teachers were asked to keep a reflective journal that records their thoughts about the CoRe collaborative design development process and how they used the CoRe in planning.

In **Phase 3** of the study each early career teacher delivered a science or technology unit using the CoRe as a guide and they co-researched, with a researcher partner, the outcomes of its use with one class of students. This involved observation of classroom activity by the researcher while the teacher was delivering the unit, to promote reflective conversations in an action research process between the teacher and researcher around the teacher's delivery of appropriate and relevant content, and its appropriate pedagogy, as specified in the CoRe. Three class periods during which one or more of the enduring ideas from the CoRe is a focus for teaching and learning was observed. Data as field notes from the three classroom observations focussed on how the teacher works with their students and how the students respond. Reflective conversations were held between the researcher and the early career teacher at the conclusion of each of these observations and any changes the teacher planned to make in future lessons in response to their experiences in the unit was noted. A focus group interview of students was conducted by the researcher at the end of the unit to examine how the students' learning experiences may have been influenced by the pedagogical structure in the CoRe. The focus group encouraged the teenage students to share their views and experiences in a supportive manner.

Data analysis was structured around the three research questions as shown in Table 2 below using an Activity Theory framework. This framework was further informed by communities of practice and PCK frameworks and the CoRe itself as appropriate in each phase.

Table 2. Research Summary

Research Question	Data source	Data analysis
How can experts in content and pedagogy work together with early career teachers to develop one science topic CoRe and one technology topic CoRe to support the development of PCK for early career secondary teachers?	Field notes from observation of the contributions and interactions within the workshop groups, and interviews at the end of the Phase 1 workshop.	Data content analysed against a community of practice framework of contributions and interactions regarding content and pedagogy for the topic.
What differences are revealed between science and technology through the development of the CoRe?	Teachers' reflective journals, classroom observations, teacher's reflective conversations,	Observations and focus group interview content analysed against a framework of content knowledge and pedagogy and each CoRe compared.
How has engagement in the development and use of an expert-informed CoRe developed an early career teacher's PCK?	Teachers' reflective journals and interview with the teacher.	Data content analysed against the five components of PCK in relation to the CoRe.

Findings

The content and pedagogy experts generally worked constructively with the early career teachers (ECTs) in designing their CoRes. The ECTs noted that they highly valued the input of the experts and felt that the design process had enabled them to identify and access the knowledge about the key concepts of the topic, as well as learn new pedagogical techniques for delivering particular content material. All the ECTs reported that they felt that being involved in discussions with the experts in the construction of the CoRe helped them to understand the big picture of the topic. Although the teachers kept in mind the needs of the curriculum and assessment through these discussions, they felt that the CoRe discussions were somewhat liberating in allowing exploration of what the topic itself was all about. Figure 1 illustrates how the research team saw the connections between the CoRe and other influences on teaching and learning at secondary school level.

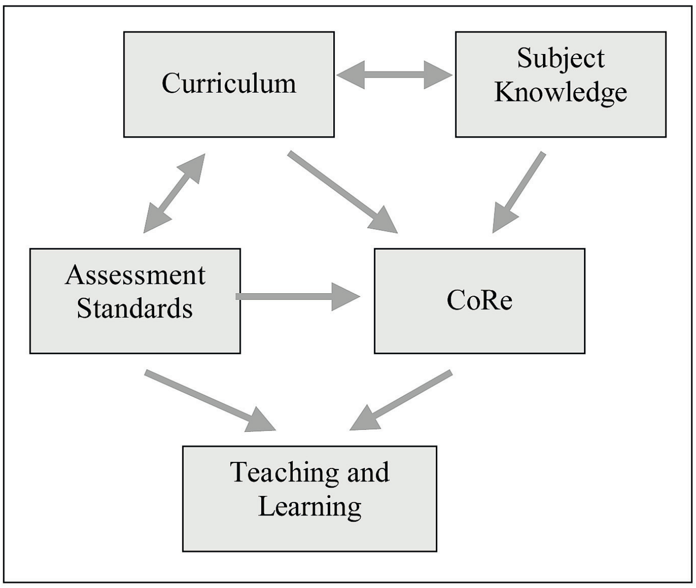

Figure 1 Model of how a CoRe might fit in senior secondary schooling

There was a variety of teacher response to using the CoRe in their planning. For the technology teachers, the CoRe encouraged them to weave more conceptual thinking into their lessons, something which the students found a little difficult, as they were more used to focussing on practical skill development. However, the teachers felt that the additional conceptual thinking would help the students understand more of the fundamental ideas behind materials technology, which they would be able to transfer to future projects.

There was a marked difference between the way the Science ECTs and the Technology ECTs approached the task of developing the conceptual "Enduring Ideas" for the CoRe topics of Organic Chemistry and Materials Technology respectively. The science teachers much more quickly developed a consensus about the Enduring Ideas, because they already had in mind a common idea of what was important for this topic, developed from text book and curriculum agreement, and so the discussion involved simply deducing from this agreed list which ones they wanted to include in the CoRe. In the technology group, there was a sense of developing the list of potential enduring ideas from first principals, consequently there was far more negotiation and justification in the workshop leading to the development of agreed enduring ideas. There was no schema that was familiar to all the workshop participants which could provide a common starting point. Consequently a lot more of the workshop time was spent by the technology group coming to agreement on the enduring ideas.

In the case of Science, the process of choosing the topic was relatively unproblematic. An initial choice was made to move from Science to the subset of Chemistry, and then within that, the area of Organic Chemistry was selected as the topic for the CoRe. In the less structured epistemology of Technology, Materials Technology was selected as the topic, a second tier level of knowledge organization. It may be the case, that had a third tier area been selected as the topic (for example Composite Materials), as was done in Science, the more narrow subset may have resulted in less discussion and debate and a faster resolution in agreeing to the 'enduring ideas' of, say, Composite Materials Technology.

The immediate usefulness of the CoRe seemed to lie in different areas for Technology and Science. The science ECTs seemed to get the most benefit from seeing the need for and developing with confidence, examples of organic chemistry in authentic contexts to support the theoretical understandings they were focussing on developing with their students. In Technology the ECTs saw the immediate benefit in quite the opposite way. For them the opportunity to see the big picture of Materials Technology, to articulate its theoretical underpinnings and consequently development of a philosophy that was conducive to a rational epistemology was perceived to be the main benefit. What followed from this was a more thoughtful approach to developing lesson content by the ECT's as evidenced by the introduction of a range of different pedagogies and teaching resources. Whereas in the absence of the CoRe, the technology teachers would just teach those aspects of materials technology that the students needed to complete their current project.

The application of the CoRe to a teaching unit was different in Science and Technology. In Science, the chemistry CoRe was truly a content representation, dealing with a discrete and contained unit of work which was treated as such by textbooks and was aligned with the curriculum for this year level. In Technology, the Materials CoRe had to be contextualized within a project which permitted the application of the content. So it was not a self contained content representation, but rather a topic that could be applied within a project context.

The practical/theoretical dichotomy was an aspect of both the science and technology teacher's implementation of the CoRe, but in opposing ways. The science teachers noted that after an examination of, and through discussion of, in particular, the pedagogical questions related to the content ideas, they had a deeper understanding of the importance of engaging in practical activities in order to assist students understanding of the relevance of the topic. The reverse outcome was the case for the technology teachers. After the realization of the need for a conceptual framework prior to determining the enduring ideas for the topic during the first workshop, the teachers felt that students also needed a broader framework of understanding than their immediate and felt needs related to the completion of their current project. Consequently, during the implementation of the CoRe, the teachers planned for more classroom activity than they normally would in order to provide this framework for the students, and to spend time generalizing from the specifics of their current project to broader principles that could be applied elsewhere. A number of students indicated that they did not appreciate this provision, reflecting their belief that the main reason for their being in class was to get on with building something.

In the context of a CoRe, the differences between that nature of technological and scientific knowledge have not been considered by research. Relevant technological knowledge is defined by its usefulness to the task at hand. If it does not help to achieve a specific goal then it is neither useful nor relevant and so can be discarded. Consequently it is difficult to predetermine what technological knowledge is relevant because problems that may arise in the pursuit of a technological goal cannot be anticipated. So the notion of designing a CoRe in the current format and using that as the basis for the design and implementation of a unit of work in technology is fraught.

An additional and related issue in the implementation of a CoRe in technology education as a means of enhancing a teacher's PCK is the importance of both conceptual and procedural knowledge. Vincenti (1984) describes conceptual knowledge as explicit, the theory of technology. Procedural knowledge is the often tacit driver of decision making and relates to appropriate decisions made through designing, problem solving, modelling, testing and planning. Parayil (1991) interestingly characterizes this tacit knowledge as papyrophobic in nature, admittedly less so as time goes on, but maybe still recognizable in many technology classrooms. The early career technology teachers in this research highly valued procedural knowledge, but this was not really elaborated in the CoRe, which is why they felt they had to re-contextualize what had been developed in the first workshop.

The assumption has been, in the application of CoRes to the area of Science, that the 'enduring ideas' relate mainly to conceptual knowledge. In an application to Technology, the ideas need to be reflective of both procedural and conceptual knowledge. The integration of this knowledge in a Technology CoRe could also assist in overcoming the common dichotomy between theory and practice in Technology, by having questions which consider both in an integrated way.

Implications of this study

Teacher professional development and learning. This study has indicated that CoRes developed in this way have potential for helping ECTs access content experts' and expert teachers' knowledge and experience. Our findings revealed a willingness for the experts to be involved in the CoRe process, and that they felt that they gained a better understanding of the challenges that beginning teachers face in teaching their subject. Both the experts and the ECTs enjoyed the opportunity to discuss the key concepts and the ways to teach them. There was evidence that the mutually-informing outcomes of these discussions represented a worthwhile investment of time for all parties concerned. However, it was also clear that to create space for such a design process outside of a funded research project, would require time commitment and innovative ways to collaborate between ECTs and experts.

This leads to consideration of how all ECTs can benefit from being involved in CoRe design with experts across a variety of learning areas and topics. Whilst participants in this project clearly appreciated the opportunity to work face to face with experts, it would seem unlikely that this opportunity could be provided for all ECTs in all learning areas. A potential solution to this dilemma may be the use of electronic media. Applications such as Wikis or e-portfolios via computer are already being used as collaborative work spaces in many areas of education. Bringing together a group of ECT's and some experts in a virtual space may allow for collaborative but asynchronous (and therefore time-flexible) development of CoRes. This has potential for involvement of greater numbers of ECTs in a cluster, and also facilitates consideration of the ongoing evolution of a CoRe as ECT PCK develops. This latter idea is important, as development of PCK should not be seen as reaching an endpoint. Indeed, in this study, it would be of interest to return to our ECTs in years to come to examine how their PCK had further developed, and what a revised CoRe of the same concept might then look like.

The nature of CoRe design and PCK in different learning areas. A further implication of this study arose from the unsurprising finding that the nature of each learning areas is different, for example, in this study between science and technology. These differences were manifest in the historical conceptual thinking underlying the learning area, the way that the subject is taught, and the traditional backgrounds of the teachers in those subjects. These differences raise implications for the design of CoRes in different learning areas. The original CoRe structure was designed in science, and whilst the technology teachers were able to work with the CoRe structure, there was some debate at the end of the project as to whether the set of eight pedagogical questions might be the most appropriate ones for all learning areas. Further research into the use of CoRes in other learning areas would help to respond to this question.

The concept of the content area or topic that a CoRe refers to is relatively unproblematic in Science. Science has a well-established epistemology leading to an established organisation of knowledge into accepted topics of inquiry. Technology on the other hand has a shorter history of study as a philosophical enterprise and no commonly agreed upon epistemology. Robust debate still exists about the nature of knowledge in technology and the way knowledge empowers technological practice. The results of this research indicate that as the concept of CoRe design is widened to incorporate teaching and learning in areas other than Science, what is considered to be a “content area” or topic within that learnig area may need to be considered carefully.

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