Using CoRes to Develop the Pedagogical Content Knowledge (PCK) of Early Career Science and Technology Teachers

Research has shown that one of the factors that enable effective teachers is their rich *Pedagogical Content Knowledge* (PCK) (Loughran, Berry, & Mulhall, 2006), 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, 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.

In recent studies of PCK (Kind, 2009; Rohaan, Taconis, & Jochems, 2010), the point is made that expert teachers are not born with PCK, and it is a lengthy process for novice teachers to acquire the bank of skills and new knowledge needed to become professional teachers who are experts in their fields. In secondary science and technology teaching, it has been argued that many graduates entering teacher education courses are unaware of the learning challenges that lie ahead for them personally, and are often naïve about and/or do not appreciate the demands that teaching will make of them (Cowie, Moreland, Jones, & Otrel-Cass, 2008; Loughran, Mulhall, & Berry, 2008). These early career teachers may not understand that effective teaching is a

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skilled and purposeful activity involving complex processes of pedagogical reasoning and action (Shulman, 1987).

Research in science education also indicates that many of these student teachers actually lack a deep conceptual understanding of their subject matter, having disjointed and muddled ideas about particular topics (Loughran et al., 2008). Interestingly, the limited research that has been done into science teachers' content knowledge around the nature of science suggests that a significant proportion of teachers have struggled with these aspects in the science curriculum (Baker, 1999) and have consequently not usually incorporated aspects of the nature of science into their teaching (Loveless & Barker, 2000). The increased emphasis on the nature of science in the science and the nature of technology in the technology learning areas within *The New Zealand Curriculum* (Ministry of Education, 2007) makes this even more of a concern. These struggles with content knowledge and the nature of science are particularly significant for secondary teachers, who were the focus of this study. As science knowledge and technological development grows apace, creating strategies to enable teachers to develop PCK around novel topics and pedagogical challenges will support success for learners in the 21st century.

Research in technology education reveals a less well-developed understanding of the role of PCK, 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), as well as in different disciplines 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, specifically the development and implementation of a CoRe in technology.

Kind (2009) identifies three common factors that appear to contribute to the growth of PCK in early career teachers. The first factor is the possession of good subject matter knowledge; the second is classroom experience, with studies pointing to significant changes occurring in the early months and years of working as a teacher; and the third is the possession of emotional attributes like personal self-confidence and the provision of supportive working atmospheres in which collaboration is encouraged.

Recently, a number of researchers in science teacher education have begun investigating and devising pedagogical approaches that help early career teachers to conceptualise their professional learning and begin laying a foundation for their own PCK development (e.g., Abell, 2008; Loughran, Berry, & Mulhall, 2006; Loughran, Mulhall, & Berry. 2004; Nilsson 2008). While there is still debate over the very nature of PCK (Kind, 2009), this new field of research offers much potential for improved teacher education, but it is problematic. For example, a key issue emerging for developers of such approaches in science and technology education has been the virtual absence of concrete examples of expert teachers' PCK, since this highly specialized form of professional knowledge is embedded in individual teachers' classroom practice (Padilla et al., 2008) and rarely articulated within the teaching community of practice. Some recent classroom-based studies in science and technology education, such as Cowie et al. (2008), have begun to elaborate on this; however, it still represents a gap in our knowledge that this research will contribute to filling.

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, which 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 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. In the following year, Hume 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 promoting PCK development in novice teachers.

This developing body of literature related to teacher PCK, both internationally and in New Zealand, 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 content experts 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 and addresses 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 investigate 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, 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 the 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). It was based around a cohort of two early career secondary teachers of science and two of technology, practitioner-researchers in their second or third year of teaching. This cohort of teachers was chosen because they are just beginning to establish themselves in their profession and have some teaching experience to draw upon in planning and delivery.

Phase 1 of the study was the design of one CoRe in a science topic and one CoRe in a technology topic. These topics were brought to the research by the early career teachers as topics within which they would like to enhance their own PCK. 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 secondary teacher of science and another of technology who provided advice on the pedagogical questions appropriate to address those key ideas. The experts and the early career teachers co-constructed the CoRes in a workshop situation facilitated by two of the researchers who are experienced in working with teachers and familiar with research-informed challenges in teaching and learning in science and technology.

A community of learners approach was adopted that encouraged each group member to contribute their ideas drawn from their experiences in distinct socio-historical communities of practice. This connection between different communities of practice was supported by development of an object, the CoRe, that lies at the boundary of each community (Wenger, 1998). Such boundary objects have previously been shown to bring teachers and researchers together (Otrel-Cass, Cowie, Moreland, & Jones, 2009). The workshop included instruction on the purpose and use of CoRes by the researchers. Two different researchers observed 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. Data were gathered using field notes during these observations of the workshop interactions, with a view to understanding how the members of the different communities work together. At the conclusion of the workshop, these observing researchers conducted short interviews with each representative group (content experts, expert teachers, early career teachers) regarding their experiences in the group and their feelings about the development of the CoRe. This addressed the first research question, which examines how the groups work together to share and co-create knowledge of how to teach a science or technology topic and, ultimately, the early career teachers' PCK. This question addressed a gap regarding expert input into CoRe development.

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. This planning process was reflected upon through an action research partnership with one of the researchers experienced in secondary science or technology teacher education. In this process the researcher's role was asking *why* and *how* questions of the early career teacher as they planned their unit, taking account of the CoRe. The researcher respected the planning norms of the teacher and their school and did not try to unduly influence the planning process in ways that are not consistent with the CoRe, and the unit plan constructed remained the property of the teacher. The early career teachers were asked to keep a reflective journal that recorded their thoughts about the CoRe collaborative design development process and how they used the CoRe in planning. The early career teachers discussed these reflections about their experiences in using the CoRe for planning with their researcher partner and how this contrasts with their classroom experiences from their first years of teaching in general and within the science or technology topic (Kind, 2009). Data from the reflective journals and discussions helped address the second research question. These methods of data collection stimulated recollection for the teacher and allowed for dialogic investigation of the meaning of the experiences that the teacher had through the process of planning.

Phase 3 of the study was the phase in which each early career teacher delivered a science or technology unit using the CoRe as a guide and 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 in order 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, were observed. Data from field notes on 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 were 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 from the classroom observations and focus group interview, the teacher interview, and a final reflective conversation with the teacher addressed the second and third research questions.

Data Analysis

Data analysis was structured around the three research questions, as shown in Table 2 (next page), using an Activity Theory framework. This framework was further informed by communities of practice, PCK frameworks, and the CoRe itself, as appropriate in each phase. This occurred as follows:

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.

Phase 1. Data collected in this phase examined the nature of the contributions brought by each group member and the interactions between group members within the CoRe development process. Data from field notes and short interview transcripts were content analysed against a Community of Practice framework that acknowledged contributions and interactions in one dimension and content and pedagogy in a second dimension, as befitting the key components of the activity system. The outcome of this phase—the CoRe—was analysed as an outcome of the workshop activity system.

Phase 2. Data collected in this phase examined how the early career teacher and a researcher worked together in using the CoRe developed in Phase 1 to co-plan a unit of work addressing the chosen topic of the CoRe. Data from field notes, teacher reflective journals, and transcripts of reflective conversations between the teacher and researcher underwent content analysis against a framework constructed from the five components of PCK as described by Magnusson, Krajcik, and Borko (1999): (a) orientation towards teaching for that topic, (b) knowledge of curriculum, (c) knowledge of assessment, (d) knowledge of students' understanding of the topic, and (e) knowledge of instructional strategies. The outcome of this phase—the unit plan—was analysed as an outcome of the process of translating the CoRe into the unit plan.

Phase 3. Data collected in this phase examined how the early career teacher and their students experienced a unit delivered on the topic of the CoRe. Data from field notes from the three classroom observations and the student focus group interview were content analysed against a framework of content knowledge and pedagogy derived from the CoRe. The student pre- and post-unit questionnaires were analysed for evidence of understanding of the enduring ideas of the topics as determined in the CoRe by the use of descriptive statistics. The final teacher interview was content analysed using the framework of the five components of PCK, as described by Magnusson, Krajcik and Borko (1999), in relation to the CoRe to triangulate the student data by examining the extent of development of the early career teacher's PCK for their classroom practice. The outcome of this phase was then analysed as an outcome of the process of delivering the unit using a CoRe-designed unit plan. Analysis of the workshop data in Phase 1, the interview and journal data in Phase 2, and the observation and interview data in Phase 3 was carried out by the researchers. Findings were collated and presented to the whole research team for interpretation and discussion in a second one day workshop. The relationship between the research questions, the data source, and the data analysis is represented in Table 2.

The CoRes

Appendices 1 and 2 show the CoRe that was developed by the technology teachers (Appendix 1) and the CoRe that was developed by the science teachers (Appendix 2). This was the outcome of the first workshop and was used as the basis for the early career teachers to plan their unit of work.

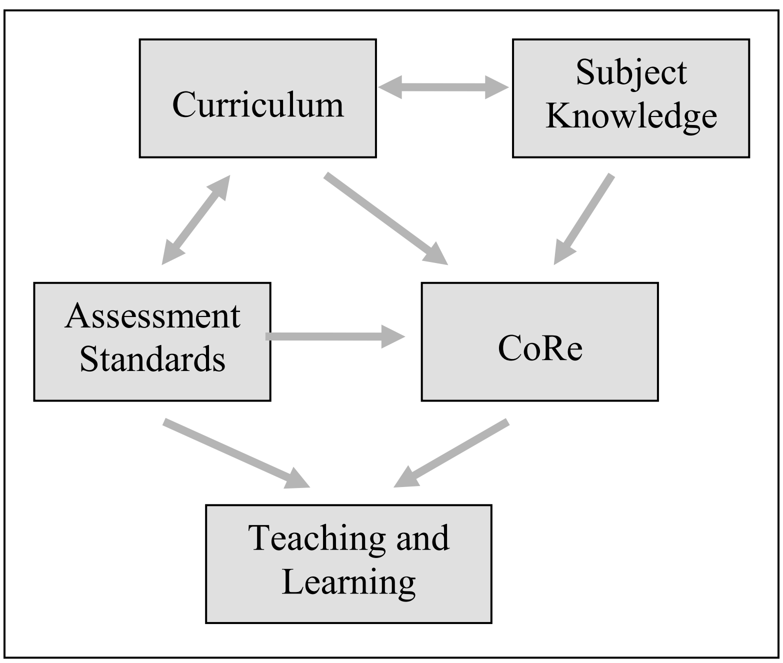
Quality Assurance

Quality assurance in this research was enhanced in a number of ways. First, multiple perspectives from several communities of practice that are related to classroom teaching and learning were provided by engagement of all team members in the process of CoRe design. Second, prolonged engagement between the researchers and the teachers through the unit planning and delivery phases, triangulated by reflective conversations and the teachers' reflective journals, provided a sound picture of the teachers' experiences of planning using the CoRe. Third, the influence of the CoRe during the teaching phase was examined through observation, questionnaires, and interviews. Fourth, student questionnaires and focus group questions were piloted for validity; teacher interview questions were peer-evaluated and piloted where feasible; and all individual interview transcripts were participant-validated. Finally, preliminary themes and findings from the data were discussed by the whole research team, ensuring that multiple perspectives from several communities of practice were brought to bear in the interpretation of the data.

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 below 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 marked difference between the way the science group and the technology group approached their workshop task of developing the conceptual enduring ideas for the CoRe topics of Organic Chemistry and Materials Technology respectively. The science group 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 that could provide a common starting point, with the teachers tending to come from a curriculum perspective and the experts deriving their schema from a more disciplinary origin. 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.

There was a variety of teacher response to using the CoRe in their planning. For one chemistry teacher, the CoRe encouraged her to change the teaching sequence within the topic to focus on students learning some fundamental knowledge, which she felt paid off when she considered the students' overall learning outcomes. For the second chemistry teacher, the CoRe design process encouraged her to focus more on relevant examples to illustrate how the topic was important in students' daily lives. The teacher found this stimulating, and the students enjoyed learning about these examples, but the teacher noted a need for resources that provided more real-world applications of the chemistry topic that she could readily access for teaching. For the technology teachers, the CoRe encouraged them to weave more conceptual thinking into their lessons, something that the students found a little difficult, as they were more used to focusing 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.

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 ECTs, 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 that was treated as such by textbooks and was aligned with the curriculum for this year level. In technology, the Materials Technology 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, the pedagogical questions related to the content ideas in particular, 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.

CoRes have been traditionally developed in the context of science education, and most research since has been in the context of science. The questions typically used in a CoRe relate to the nature of scientific knowledge and the pedagogies of science education. The differences between science education and technology education have been elaborated elsewhere, and this research has indicated that the questions generally used in a CoRe may not be appropriate in assisting to enhance technology teachers PCK.

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.

This highlights a question related to the applicability of the standard CoRe questions to the subject area of technology. Are these the best questions, given the nature of technological knowledge, for teachers to consider in developing their PCK? The questions are:

- What do you intend the students to learn about this idea?
- Why is it important for students to know about this?
- What else do you know about this idea (that you do not intend students to know yet)?
- Difficulties/limitations connected with teaching this idea.
- Knowledge about students' thinking that influences your teaching of this idea.
- Other factors that influence your teaching of this idea.
- Teaching procedures (and particular reasons for using these).
- Specific ways of ascertaining students' understanding or confusion around this idea.

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 that consider both in an integrated way.

Implications of 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 workspaces in many areas of education. Bringing together a group of ECTs 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 area 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 learning area may need to be considered carefully.

A concern that arises from this research is its scalability. It would not be logistically nor economically feasible for teachers to be engaged in day-long workshops with experts to develop CoRes for use in their teaching as a way to enhance their PCK. It may be possible to use electronic means to facilitate broader consultation, and this research team is developing a proposal to test this notion.

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Appendix 1: Technology Education CoRe

Materials Technology (Year 11)			
	Enduring ideas		
Pedagogical Questions	**The structure of materials determines its behavior.**	**The structure of materials determines the best processing techniques for making products**	**Design decisions are informed by knowledge of materials properties**
What you intend the students to learn about this idea	Material structure determines its functionality and suitability for a given purpose. (Brick wall analogy) Behavior – mechanical, chemical, etc. Composite materials – designed to produce new properties	By applying techniques, you can alter the structure or shape of the material. Main groups: moulding, joining, extrusion, cutting/machining,	Design requirements are met by a combination of material properties and shape.
Why is it important for students to know about this	To help them make informed decisions for material selection. The select the appropriate materials for a specific purpose.	So students can successfully complete their functional projects.	This allows the consideration of a number of viable options.
What else you know about this idea (that you do not intend students to know yet)	Bonding types, atomic structure, importance of defects.	Advanced processing techniques, TIG welding, steam bending, thermal evaporation, laser cutting, rapid proptotyping.	Failure analysis, factor of safety calculations
Difficulties/limitations connected with teaching this idea	Students see relevance. Nature of school facilities Prior course experiences Assessment structures (e.g., ITO's)	Access to equipment, health and safety requirements, student preconceptions (e.g., wood, saw, and nails. Diversity of projects/contexts (e.g., 20 different projects in the one classroom)	Lack of knowledge and experience of materials by students. Lack of design knowledge, modeling, testing, visualization.
Knowledge about students' thinking which influences your teaching of this idea	Misconceptions related to terminology – stress, strain, stiffness, toughness, sustainability.	Previous curriculum experience. Background experience with tools and equipment. Materials choices based on prior experiences.	Maths ability, science knowledge, academic ability to understand concepts. Range of student ability. Differentiated learning.
Other factors that influence your teaching of this idea	Attitudes of staff and the rest of the school.	Intermediate school experiences and what goes on there.	Access to materials. Cost. Time. Equipment. Computer, internet.
Teaching procedures (and particular reasons for using these to engage with this idea)	Demonstrations, relevant examples. Across the spectrum of materials. Hands on. Models (plasticine, spaghetti, chocolate)	Hands on after instruction. Experimentation. Activity to teach a concept.	Industrial examples of how people do this. Evaluating examples, deconstruction; physical/cognitive. Videos, uTube segments. (e.g., electric fence).
Specific ways of ascertain students' understanding or confusion around this idea (include likely range of responses)	Whether the product they design is fit for purpose Evidenced in context, design decisions that are made and their justifications.	Whether the product they design is fit for purpose Evidenced in context, design decisions that are made and their justifications.	Whether the product they design is fit for purpose. Evidenced in context, design decisions that are made and their justifications.

Appendix 2: Science Education CoRe

Organic Chemistry (Year 12)					
	Enduring ideas				
Pedagogical Questions	**Organic compounds are named and drawn using the IUPAC system**	**Functional groups control the reactivity of an organic compound**	**The physical and chemical properties of a substance are determined by its structure**	**Organic chemistry allows us to meet society's needs, resolve issues, and develop new technologies**	**Experimental investigations help chemists understand properties**
What you intend the students to learn about this idea	Functional groups (names and formula and how to convert between) Names (of compounds with 1-8 carbons) – prefixes and suffixes Number, substituent and parent name Molecular and structural formula incl. condensed	Different patterns of reactivity of those functional groups specified in Year 12 achievement standard	Isomerism – structural and cis/trans Properties of naturally occurring molecules Homologous series – trends as C chain increases Markovnikov's rule	Anesthetics, fumigants, polymers e.g .PVC, petroleum, distillation esters, breathalysers, solvents, vinegar etc	Molymods (3D models). Reflux and distillation. Separation.
Why is it important for students to know about this	Is the basis of organic chemistry a systematic approach that enables logical thought? Terminology is accepted internationally – enhances scientific literacy and communication.	A fundamental concept of organic chemistry. A way of categorizing the reactions of organic compounds – can predict the behavior of a substance.	Leads to an ability to understand other forms of isomerism and to predict reactions with molecules of different chain length and functional groups	Organic chemistry can both help meet society's needs and create issues to be resolved. Relevance and purpose – being able to make informed decisions over use of chemicals.	
What else you know about this idea (that you do not intend students to know yet)	Other functional groups (e.g., amides) Names of molecules with more than 8 carbon atoms	Reactions of other functional groups not included here (e.g., secondary/tertiary alcohols, alkanes with epoxides, etc.)	Optical isomerism and E, Z isomerism	Condensation polymerization. Student dependent and time dependent. Development of illegal substances	
Difficulties/limitations connected with teaching this idea	Some compounds have common names that can confuse students (e.g., acetic acid). Another language to learn (hard for ESOL), and lots of terms that are similar.	Being able to correctly identify the functional group amid so many different reactions. Tendency to compartmentalize learning and not make links to other learning. Learning other reactions that are involved.	3D spatial awareness of isomers. Lack of models	Teacher lack of knowledge of real world – not easy to find information. Research of information takes time.	

Appendix 2: Science Education CoRe (Continued)

Knowledge about students' thinking which influences your teaching of this idea	Understanding the conventions of structural formula. Prior experience/knowledge of some everyday organic compounds (e.g., octane)	Their knowledge of acid-base reactions Links to everyday contexts Their knowledge of redox reactions possibly	Limited experience of 2D and 3D thinking (e.g., rotation of bonds)	Interests of students – boys/girls. Answer to "Why do I need to know this?"	
Other factors that influence your teaching of this idea	Availability of Molymod equipment for visualization Need for kinesthetic activity	Having classroom wall space for reaction maps	Difficulty with spatial thinking – possibly more so in girls	Answer to "Why do I need to know this?" The enjoyable part of teaching and learning.	
Teaching procedures (and particular reasons for using these to engage with this idea)	Starting from parent alkane and scaffolding from there – building up with functional groups Verbalising names for reinforcement Model building, YouTube clips and animations	Illustrative experiments, video clips, reaction maps, class notes, animations, role plays	Animations to show rotation of bonds Molymods – manipulation Carry out reactions with actual substances	Popular music with chemistry messages. Student inquiry. Video clips, news stories	
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)	Naming given organic compounds Questions, assignments, peer assessments, BestChoice – mastery, card games, dominoes, mix n match	Naming given organic compounds Questions, assignments, peer assessments, BestChoice – mastery, card games, dominoes, mix n match. Use of models, role plays	Naming given organic compounds Questions, assignments, peer assessments, BestChoice – mastery, card games, dominoes, mix n match. Use of models, role plays.Identify structural formula for a given molecular formula	Identify fallacious chemical examples of advertising Develop questioning disposition Debates	