Science Teachers' Views on CoRes and PaP-eRs as a Framework for Articulating and Developing Pedagogical Content Knowledge

Adam Bertram · John Loughran

Abstract This paper reports on a study which was designed to examine how CoRes (Content Representations) and PaP-eRs (Pedagogical and Professional-experience Repertoires) might impact the practice of science teachers by considering how they might value (or not) pedagogical content knowledge (PCK) as part of their professional knowledge. The paper is based on a 2 year longitudinal study that used CoRes and PaP-eRs as a form of intervention with a group of teachers ($n=6$) to determine how they interpreted, used and developed their understanding of PCK over time. The study concluded that the participating teachers developed rich understandings of their professional knowledge of science teaching and were of the view that CoRes and PaP-eRs were significant in shaping that development. As a consequence, the study also validates the use of CoRes and PaP-eRs as a meaningful methodology for examining science teachers' PCK.

Keywords Content Representations (CoRes) · Pedagogical and Professional-experience Repertoires (PaP-eRs) · Pedagogical content knowledge · Science teacher education · Science teachers' Knowledge

Introduction

When Shulman first introduced the notion of pedagogical content knowledge (PCK), he described it as 'the missing paradigm' (Shulman, 1986, p. 7). Although at the time, it appeared to be an attractive construct to researchers, it is difficult to find accounts of its value and use for teachers themselves. In some ways, PCK research became a self-sustaining industry unto itself as it was used as a conduit to the complexities of teachers' professional knowledge and practice but remained closeted in the world of academia. It was an industry for researchers seduced by the attractive but very abstract nature of the

A. Bertram (✉)
Monash University, Northways Rd, Churchill, Victoria 3842, Australia
e-mail: adam.bertram@monash.edu

J. Loughran
Monash University, Clayton, Victoria 3800, Australia

construct, not by teachers concerned with improving their science teaching. As any search of the literature demonstrates (cf. Abell, 2007; Grossman, 1990; Magnusson et al. 1999; Marks, 1990a, b; Tamir, 1988) PCK has long represented the particular and specialised knowledge of teaching particular content that teachers possess and develop over time. But what it looks like, how it might be captured, portrayed or even used by science teachers in any concrete form has long been recognised as a major gap in the literature. One reason might be because PCK is complex and usually so deeply a part of a teacher's intrinsic practice that it is tacit and, more often than not, largely inaccessible (Baxter & Lederman, 1999; Gess-Newsome, 1999; Korthagen & Kessels, 1999; van Driel et al. 1998).

Recently, a framework for capturing, articulating and portraying science teachers' PCK through two complementary instruments: Content Representations (CoRes); and, Pedagogical and Professional-experience Repertoires (PaP-eRs) has emerged as one way of concretizing PCK (Loughran et al. 2006a; the format and layout of both of these instruments are explained in detail later in this paper). Essentially, CoRes offer a sophisticated way of exploring science teachers' knowledge about teaching specific content to particular students. PaP-eRs, on the other hand, offer windows into science teachers' thinking in relation to that knowledge in practice. Loughran et al. contend that both CoRes and PaP-eRs, when combined and explored together (which the researchers termed a 'Resource Folio'), capture and portray science teachers' PCK:

> Resource Folios (as encapsulated by both CoRe and PaP-eRs) offer teachers … a powerful, accessible and useful representation of PCK that in theory is responsive to practice and in practice is important to theory. (Loughran et al., 2006a, p. 26)

When the concept of CoRes and PaP-eRs was first offered, Hashweh (2005) claimed that, at last, these instruments offered:

> … a conceptualisation of PCK that captures both its topic-specificity and its development as a result of interactions between other knowledge and beliefs categories. (p. 276)

Loughran et al. (2006a) provided five Resource Folios as concrete examples of being able to successfully portray science teachers' PCK and were of the view that the implications of their work was 'related to possibilities for science teachers' professional development' (Loughran et al., 2004, p. 382).

This paper reports on a study which investigated one such possibility. In so doing the purpose of this paper is to present the findings of a study (cf. Bertram 2010) which explored how CoRes and PaP-eRs might impact the professional knowledge of practising science teachers by examining how they might *value* PCK as part of that knowledge. To date, no such study has specifically explored and reported on the specific and individual views of practising science teachers on the use of CoRes and PaP-eRs; and how they believe it might have influenced their practice.

The Instruments: CoRes and PaP-eRs

A CoRe is offered to science teachers as a blank template in table format (see Table 1). Across the top row, are the 'Big Ideas' which are meant to represent the major ideas and concepts which are within the particular science content area. Down the left hand column are the CoRe's questions/prompts, which are to be answered for each 'Big Idea'. The prompts include:

- what do you intend the students to learn about this idea?;
- why is it important for students to know this?;

Table 1 A CoRe Template

Year level for which this CoRe is designed:_____	Important Science ideas/concepts					
Content Area:_____	Big Idea A	Big Idea B	Big Idea C	Big Idea D	Big Idea E	Big Idea F
What do you intend the students to learn about this idea?						
Why is it important for students to know this?						
What else do you know about this idea (that you do not intend students to know yet)?						
What are the difficulties/limitations connected with teaching this idea?						
What is your knowledge about students' thinking that influences your teaching of these ideas?						
Are there any other factors that influence your teaching of these ideas?						
What are your teaching procedures (and particular reasons for using these to engage with this idea)?						
Specific ways of ascertaining students' understanding or confusion around this idea (include a likely range of responses).						

- what else do you know about this idea (that you do not intend students to know yet)?;
- what are the difficulties/limitations connected with teaching this idea?;
- what is your knowledge about students' thinking that influences your teaching of these ideas?;
- are there any other factors that influence your teaching of these ideas?;
- what are your teaching procedures (and particular reasons for using these to engage with this idea)?; and,
- specific ways of ascertaining students' understanding or confusion around this idea (include a likely range of responses).

A PaP-eR (Pedagogical and Professional-experience Repertoire) is designed to purposefully unpack a teacher's thinking about science practice in a particular lesson (which had been planned for in the related CoRe). A PaP-eR represents the teacher's reasoning involved in teaching specific aspects of science content and is designed to reveal specific instances of PCK. PaP-eRs can take on any form of the teacher's choosing. It could be a journal, a flow chart of ideas, a reflective piece of writing, etc. In this way, the account of the teacher's thinking and reasoning underpinning the pedagogy of the specific content is articulated for the reader. Together, CoRes and PaP-eRs provide a means for articulating teachers' tacit knowledge by linking it to practice, hence capturing insights into PCK.

Current Research on CoRes and PaP-eRs

To date, there has been little research into ways of capturing and portraying concrete examples of PCK in science teachers' practice. However, CoRes and PaP-eRs offer a methodology for so doing. As any search of the literature demonstrates, studies using CoRes and PaP-eRs are currently underway in many countries including: Australia, South

Africa; South America; USA; Canada; Sweden; UK; and, New Zealand. For example, Rollnick et al. (2008) examined the influence of science subject-matter knowledge on the PCK of two South African teachers. CoRes and PaP-eRs were used as methodological tools to obtain and represent the data. They suggested that CoRes:

> … proved to be a useful methodological tool for constructing a picture of these teachers' PCK. It is possible that CoRes could assist other teachers also, in articulating their PCK … [The use of CoRes and PaP-eRs] allowed salient aspects of these teachers' PCK … to become visible. (p. 1383)

In a study in the United Kingdom, Ratcliffe (2008) used CoRes and PaP-eRs to explore teachers' PCK on the nature of science. CoRes and PaP-eRs were also used to collect and represent data on Latin-American teachers' PCK of the particulate nature of matter (Garritz, et al., 2005). All of these researchers confirmed that CoRes and PaP-eRs offered helpful ways of representing the individuality and particular nature of each teacher's science PCK. Loughran et al. (2006b) also suggested that CoRes and PaP-eRs had potential for use in pre-service science teacher education because they found that they:

> … gave [teachers] a stronger feel for their own professional development … and [enabled them] to explore in more detail the underpinnings of their teaching. (p. 70)

The PCK of primary school pre-service science teachers has been examined in terms of how formative assessment could capture their PCK, and how it develops in ways that contributes to teachers' professional learning (Nilsson, 2010). Also, Loughran et al. (2008) reported on investigating the usefulness of CoRes and PaP-eRs in a pre-service science secondary teacher education program. In both cases, the researchers explored the merits of introducing these two instruments explicitly for student-teachers. In so doing, they examined the notion of PCK and how it affected or shaped student teachers' thinking about their practice and/or development as science teachers. Their research focussed on how the construct of PCK itself influenced participants' views of practice offering insights into how CoRes and PaP-eRs could be used as a heuristic device. They concluded that CoRes and PaP-eRs offered a meaningful way for participants to come to understand PCK, not as academic theory, but more so as a means of viewing, understanding and developing their professional knowledge of practice. They also reported that CoRes had immediate benefits in that they acted as a useful structure for lesson preparation. On this research, Abell (2008) commented that:

> There is evidence that suggests using the PCK framework to set goals, employing research tools like the CoRes or lesson preparation as instructional strategies, aligning assessment with PCK components in an explicit manner, and informing both students and mentor teachers about the PCK construct will lead to stronger science teacher preparation programmes. (p. 1414)

Preliminary tests of validating CoRes and PaP-eRs with practising science teachers have already been undertaken. Loughran et al. (2007) conducted a precursor study where they tested CoRes and PaP-eRs with two groups of science teachers ($n=18$; $n=32$). They were interested to see how CoRes and PaP-eRs were interpreted and how, if at all, they influenced these teachers' thinking on their own practice. The teachers were presented with a completed CoRe and PaP-eR on particle theory. Teachers' responses illustrated that two major themes emerged:

- planning for teaching. The teachers felt that the CoRe offered a useful way of planning, organising and thinking about subject-matter content, and helped in understanding it from a conceptual viewpoint; and,

- re-conceptualisation of practice through professional learning. PaP-eRs were considered to offer new ways of viewing science teaching and learning, which contributed to developing their own professional knowledge further. They also felt that the 'Big Ideas' and questions posed on the CoRe helped them to conceptualise the way they thought about their practice.

Their study concluded that, 'conceptualising PCK through a CoRe and PaP-eRs approach helps to make PCK more accessible for teachers' (Loughran, et al., 2007, p. 101). In this way, the researchers claimed that the methodology of CoRes and PaP-eRs enhanced teachers' valuing of PCK in terms of their professional knowledge of practice and that concrete examples of PCK had been successfully captured and portrayed.

As research into PCK as a useable construct demonstrates (cf. de Jong et al. 2005), the complex nature of PCK makes it difficult to capture and portray. However, CoRes and PaP-eRs appear to offer a first step towards a new phase of research in science teaching and learning. It creates a new way of viewing the theory-practice gap (Korthagen & Kessels, 1999; Pekarek et al. 1996) by creating one way of 'testing for applicability' in the classroom so that theory can inform practice and vice versa (Kind, 2009). Through this type of research, the academic construct of PCK may well become a more meaningful aspect of teachers' professional knowledge and become a more valuable aspect of a shared professional language.

Research Design

The project was a longitudinal study conducted over 2 years. In framing an appropriate research design a major concern was in terms of data collection in relation to the teachers' tacit knowledge of their practice. As the literature has illustrated for a considerable period of time, teachers often struggle to articulate or communicate this aspect of their knowledge (Gess-Newsome, 1999; Korthagen & Kessels, 1999; Polanyi, 1966). Therefore, exploring teachers' views on teaching and learning prior to any introduction to PCK, CoRes and PaP-eRs, and then revisiting their views post-intervention to determine any change, clearly hinged on the need to assist them to explicate their knowledge and understanding of practice. The idea being that any change, subtle or otherwise, that might be due to an awareness of PCK (as a result of this study) needed to be able to be explicitly linked to views of practice. This, therefore, reinforced that an interview based approach to data collection was necessary.

An ethnographic, qualitative approach based largely on interviews was the major form of data collection. In an interview situation, teachers often offer narrative accounts as their way of answering research questions (cf. Clandinin & Connelly, 1996, 2000; Conle, 2003; Connelly & Clandinin, 1990). This enriches the data and provides valuable depth and insight—which may not have been so likely through the use of any other form of data collection instrument.

The first interview (Int. 1) asked participants to describe their pre-intervention views on teaching and learning. Following this, in a separate interview (Int. 2), an introduction to PCK was provided, and the instruments, CoRes and PaP-eRs, were explained. This was achieved by providing participants with a 'Participant Information Sheet'. This sheet provided the following explanation of PCK as adopted in this study:

Pedagogical content knowledge is defined as the unique knowledge a teacher has which marries together content knowledge with pedagogical knowledge in ways that lead to enhanced student understanding. More simply, PCK is a teacher's knowledge

of how to teach specific content in certain ways to particular students that helps the students learn. Pedagogical content knowledge is the understanding, the reasoning, the underpinning and the linking of content and the procedure all blurred together. If these things are not linked like that on purpose, if the teacher is not thinking in that way, then the teacher just happens to have a good activity or an activity which serves another purpose other than student understanding. That is not evidence of PCK. The teacher who has good PCK sees a good activity and says, "I know why that works". If the teacher cannot reason why they do something in a particular way for a particular reason (related to student understanding) then they are not utilising PCK.

This statement was discussed thoroughly with each participant in their individual interviews, so that a solid understanding of PCK (as used in this study) was developed. Similarly, an explanation of CoRes and PaP-eRs were also introduced on the 'Participant Information Sheet' and discussed in the same manner. Participants were provided with a photocopy of Chapter 4 from *Understanding Science Teachers' Pedagogical Content Knowledge* (Loughran, et al., 2006a, pp. 31–58). This chapter offers a completed example of a Resource Folio, presenting one CoRe and eight PaP-eRs on Particle Theory, a topic that would commonly be taught to junior middle school science students.

After being introduced to CoRes and PaP-eRs, participants were asked to make initial comment on their thoughts about the value and usefulness of these constructs to their professional practice. Example questions included:

- Did the concept of PCK appear useful to teacher practice?;
- Could they recognise examples where they might have already used something like this in their own practice?;
- Did they think about PCK as a construct for thinking about the teaching of science?; and,
- Would CoRes and PaP-eRs seem like tools that might draw out instances of teachers' PCK?

Following this, participants were asked to create their own (or contribute to a group) CoRe based on a science unit or topic that they would soon be teaching. This process generally took a few weeks for each participant to complete. Participants were then asked to comment on the process of making the CoRe and to offer their views on how that process influenced their thinking about teaching and learning, and how it influenced their understanding of PCK (Int. 3). The following open-ended questions were used as a general guide in the semi-structured interview schedule:

- How useful (or not) was the process of developing a CoRe (in terms of planning the content to be taught and the way it made you really consider the content in a meaningful way for student understanding)?
- Did the process influence your thinking about your teaching in ways beyond normal?
- What benefits/insights/advantages did the CoRe give to you?
- Do you now think differently about your pedagogy, content knowledge and how you understand your students?
- What were the disadvantages?
- What relationship do you see (if any) between CoRes and PCK?

In a following interview (Int. 4), participants were asked to describe a recent teaching episode (based on some of the content from their CoRe), and to provide as much information as they could, so that a PaP-eR could be developed. Once a PaP-eR had been

developed, in a similar way to the interview about the CoRe, participants were asked to comment on the process of making the PaP-eR and any influence that that process had on their thinking about teaching and learning, and their understanding of PCK (Int. 5). Approximately 2 years after being introduced to the study, participants were reinterviewed about their views on whether CoRes and PaP-eRs (individually and as a combined instrument) had any impact on their long-term practice (Int. 6).

As a conclusion for the whole study, teachers were presented with their initial pre-intervention views on teaching and learning. Given in the form of a 'Homework Task', teachers were asked to respond to these views and contrast them to their current (post-intervention) views on teaching and learning, discussing any changes and adding anything new. A follow up interview (Int. 7) was then undertaken to draw out any further detail which might not have been captured in their 'Homework Task'. Finally, a concluding interview (Int. 8) explored the participants' final views on the entire study (including CoRes, PaP-eRs and PCK and how they believed this impacted or influenced their professional practice).

These interviews elicited many views from the participants. Each participant's responses were analysed separately in individual cases and general themes were listed. Then across all cases, participants' responses were examined to determine what (if any) similar views existed. In so doing, specific category headings that applied across all individual cases were formed and these became the major analytic dimensions for the study as a whole. Under each heading, indicative comments were collated which allowed for a general summary of the participants' views to be captured and presented in order to offer a concise and succinct overall picture of the findings. (These results are summarised in the results section of this paper.)

In terms of the validity and reliability of the study, there are perhaps two areas of weakness. While an ethnographic study is well-established as a research methodology in educational research (Wiersma, 2000), one weakness might be the dominant use of interviews as the major form of data collection—that is, much of the data relies on self-report. A danger with interviews is that the interviewee may provide the interviewer with information that they perceive the researcher wants to hear. Also, the researcher has no way of knowing how the teachers' views align with what they actually do in the classroom if classroom observations are not undertaken. The other weakness of the study might be in the researcher's interpretation and analysis of the data. In turn, the emerging theories and conclusions drawn by the researcher may not accurately represent that which was real. In order to limit these weaknesses and to provide credibility to the methodological design of this study, triangulation was considered. Participants created and developed their own CoRe and contributed to the development of their PaP-eR. These two instruments, in their own right, became part of the data, thus providing some degree of triangulation and further reliability to the data and its analysis. In all cases, analysis of data collected through these processes was represented to participants as an internal validity check not only of the data but also of the analytic outcomes. Participants were given copies of all data sets in order to facilitate data checking, analysis and final portrayal and to allow them to confirm/adjust/reject interpretations in order to gain the most robust outcomes in relation to their views of their perspectives. In regard to the interviewing process, the danger of participants structuring their responses to please the researcher, is mitigated by the extensive and longitudinal nature of the interviewing process and the consistency of the ideas presented across the interviews over an extended period of time. However, this is a legitimate threat to credibility and is acknowledged. This shortcoming does not apply to probes of the teachers' understanding of constructs such as PCK but may apply when they talk about their own individual classroom practice.

Participants

Since PCK is the knowledge of teaching particular content to particular students, PCK is therefore individually unique and personal to each different teacher. With this in mind, six teachers were recruited in order to develop the extensive data sets which would be created through the various interview stages. As this research involved tracking how each teacher's views of teaching and learning changed over time, data was used to create individual cases. In so doing, a picture of each participant's individual development in understanding PCK and their practice was able to be mapped as it emerged.

All six participants were assigned pseudonyms. Four (Julie, Rani, Samantha and Jerry) were members of the same science faculty from an independent, co-educational, Pre-prep to Year Twelve college in Victoria, Australia. These were teacher-colleagues who had indicated an interest in this study and had considered it to be a good opportunity for their own professional development. There was no concern that the validity of the data would be affected by the fact that they all worked with each other at the same school. This study was based on teachers' own personal beliefs and views rather than any form of group collective thinking. Given their enthusiasm to be involved and the advantages of extensive data collection at one site, it was considered that their close association with each other or the researcher, would have very little impact on the data provided by the teachers. It was deemed that the credibility of the study was not threatened and that data collection and timing was actually enhanced.

At the time of the first interview, three teachers of the four (Julie, Rani and Samantha) were teaching mostly middle school science (Years Seven through to Ten) as part of their teaching load. The fourth teacher (Jerry) was a senior specialist teaching Years Eleven and Twelve physics. All of these teachers were experienced having between 8 and 25 years of teaching experience. The remaining two volunteers (Delta and Gordon) of the six were both generalist primary school teachers in government, co-educational primary schools in Victoria but were not from the same school. One had taught for 3 years and the other had only been teaching for six months at the time of the first interview. The diversity of the six participants (in regard to primary/secondary and beginning/experienced) was welcomed in this study to provide a wide range of cross-sectional data that might represent the different levels of science teaching.

Each participant contributed to creating one CoRe either individually or within a group. Delta and Gordon (each from different primary schools) completed individual CoRes. While both focussed on Space as a topic, Delta's CoRe was aimed for Grade 3/4 students while Gordon's was for Grade 5/6. Jerry also worked individually on the topic of Interactions of Light and Matter for Year 12 Physics. Julie, Rani and Samantha worked together in creating a CoRe on the topic of Genetics for Year 10 Science. It should be noted that all interviews were conducted individually and in a quiet location and did not extend beyond a sixty minute time allocation. All interviews were audio-recorded and fully transcribed.

Results

Pre-intervention Views on PCK, CoRes and PaP-eRs

PCK was an unknown construct to each of the participants at the beginning of the study. When introduced, the concept of PCK was well-received by all participants, and they all

were of the view that it offered worthwhile contributions to teachers' professional knowledge: '[PCK appeared to be useful because] it's about informing [teachers about] effective methods of facilitating learning' (Jerry, pre-intervention). Interestingly, one participant picked up on the complexities around articulating PCK and was concerned that it might be too elusive to be uncovered: 'you might be trying to quantify the unquantifiable' (Samantha, pre-intervention). However, she did suggest that it was a step forward in helping teachers to at least begin articulating some aspects of their practice.

From their initial responses their understanding of PCK was not very sophisticated. One participant (Julie) claimed that PCK was essentially a name for reflecting on teaching and that she was 'definitely doing it already' (Julie, pre-intervention) in an implicit manner. For two participants (Rani and Jerry) they felt that PCK was largely focussed on understanding their students; that it included 'recognising what [students] knew … and applying that understanding' (Rani, pre-intervention) and that it was the 'knowledge of the students … where they're at and how to … cater to them' (Jerry, pre-intervention).

CoRes and PaP-eRs were then introduced and were also well-received. All participants believed that CoRes offered a structured means of reflecting on practice and that they appeared to be useful in preparation for teaching. In terms of reflection before teaching a lesson, CoRes offered a way of setting up the teacher to consider their students' background, how they might learn best, how to structure the content appropriately to encourage that learning and illuminating areas of potential difficulty:

> I think that they [CoRes] would be really good at making sure that what … you're planning for the children is actually meaningful and will have value to the children and will also cater to those … unexpected things that you probably could have thought of before but you didn't spend the time to think of. So, I think that actually having to write it down will be very valuable because you have to think of it and not just sort of go, 'Oh, we'll deal with it when it comes'. (Delta, pre-intervention)

Similarly, PaP-eRs were generally viewed by all participants as post-reflection of a lesson and all supported the notion that they were a powerful exercise in shaping teachers' practice:

> In terms of providing a reflection tool … [for] pedagogical content knowledge, … I think [PaP-eRs are] very valuable because the teacher can reflect on their own learning about their students and they just go beyond knowing the content. (Gordon, pre-intervention)

As a combined instrument (i.e., a Resource Folio), all participants believed that CoRes and PaP-eRs could help teachers to formalise, provide structure and give meaning to how and what they taught in ways that might enhance students' understanding:

> I think they [CoRes and PaP-eRs] go hand in hand. … I think it leads to PCK because if you do a bit of reflection then there's this awareness of or an understanding of where students are coming from and what they're able to do in the future. So, I believe that that's your PCK moment—when students know how to learn. So, if you don't go back and reflect on, 'Mmm, have my students really understood anything? Can they now apply their skills?' Then you're not going to get your PCK moment. So, the way I see this thing—they really do go hand in hand. (Rani, pre-intervention)

The participants claimed that CoRes and PaP-eRs were not without limitations. All participants believed that a huge amount of time was required for their construction, and they were cautious about how it might be regularly sustained in a school environment. One

participant, however, acknowledged that 'you're not going to get a benefit without making an investment and so … the downside is that I have to make an investment in something that I wouldn't have normally done but if I get a benefit that's good' (Jerry, pre-intervention).

Mid-intervention Views on CoRes (directly following construction)

All six participants in this study stated that they found the CoRe to be useful or beneficial to their practice. Table 2 (below) presents a summary of these teachers' post-CoRe views (organised on the general views represented by the subheadings of each individual's study). Their views encompassed four broad areas (professional practice, student learning, content and improvements or suggestions). The last row of the table reports on the participants' views on the relationship between CoRes and PCK. It states whether there was, if any, an implicit or explicit statement made by the participant that the CoRe was useful in recognising or drawing out PCK.

In terms of professional practice, four participants (Julie, Samantha, Jerry and Gordon) claimed that the CoRe encouraged reflective practice and that using the CoRe had caused them to rethink how they could improve their teaching. One indicative comment is:

> [CoRes are] a very useful reflective tool … When you come to do this [topic] again … to have a look at your reflections and to have identified the problem areas and the areas that are really important for students to get a grasp on—absolutely, it's a good bit of reflective practice. (Samantha, mid-intervention)

At a big picture level, the CoRe essentially encouraged all participants to reflect and think about their teaching in a programmed and explicit manner. While reflection was very important in guiding and directing their future practice, an important subset of this process was also brought to light—that is, that in creating the CoRe, it forced these teachers to explicitly think about and connect with their tacit knowledge about teaching and learning. Thus, the process of working through developing a CoRe encouraged these participants to find ways of articulating that which they knew and how they developed their knowledge of practice. An indicative comment is:

> Well, it [the CoRe] certainly helped me map out what the students' prior knowledge and expectations were. … It did make that explicit whereas before I sort of would have vaguely known about it and not actually talked about it, had I not been asked about it. … I had to acknowledge that what the kids knew was different and less than what I knew. And if I'd stepped in and started talking to them at the level that I was at, then it wouldn't have worked well. (Jerry, mid-intervention)

In regard to student learning, interestingly, four participants (Julie, Rani, Delta and Gordon) commented on how the CoRe helped them to consider their audience—their students—in more meaningful ways. They listed such things as: questioning the purpose of the content and its depth and breadth; thinking about whom their specific students were; and, their individual learning abilities and limitations:

> Just knowing my students … and being more aware of their learning needs … were perhaps the biggest benefits of doing the actual programme [i.e., this study]. And the idea [of the study] was to have [or understand] the content knowledge of what you are teaching and how it is appropriate to your students. (Gordon, mid-intervention)

Table 2 List of participants' views on CoRes directly after its construction

	Julie	Rani	Sam-antha	Jerry	Delta	Gordon
Views on CoRes and professional practice						
Creating the CoRe helped the teacher to rethink how they could improve their teaching	✓	✓	✓			
Creating the CoRe helped the teacher to reflect on their practice	✓	✓	✓			✓
Creating the CoRe forced the teacher to explicitly think and connect with their intuitive and tacit knowledge about teaching and learning	✓	✓		✓		✓
The CoRe offered benefits to inexperienced teachers as well as experienced teachers	✓	✓	✓	✓	✓	✓
Limiting factors involved in creating the CoRe—time	✓					✓
Views on CoRes and student learning						
Creating the CoRe helped the teacher to think specifically about the importance of knowing their students	✓	✓			✓	✓
Creating the CoRe helped the teacher to think about how they recognised and evaluated student learning		✓				✓
Creating the CoRe helped the teacher to be aware of, and think about how to, approach drawing out and responding to students' alternative conceptions/misconceptions			✓			
Views on CoRes and content						
Creating the CoRe helped the teacher to recognise the range of teaching strategies they had expertise in for the teaching of particular content		✓				
Creating the CoRe helped the teacher to think specifically about the depth and breadth of content	✓			✓		
Creating the CoRe helped the teacher think about how to approach and plan for new or unfamiliar content					✓	
Improvements or suggestions						
The CoRe's prompts were good and none needed to be deleted	✓					
The CoRe should include specific prompts to cater to different learning styles			✓			
The CoRe only covered the minimum learning outcomes that would be examined and did not specially consider higher and lower functioning students			✓			
The CoRe could be revisited at the end of a topic as reflection and refinement for improving teaching	✓		✓	✓	✓	
The CoRe could be used as part of the regular curriculum documentation					✓	✓
Views on the relationship between CoRes and PCK: Was the CoRe useful in recognising or drawing out PCK?	Yes—implicit	Yes—Implicit	Yes—Explicit	Yes—Explicit	Yes—Explicit	Yes—Explicit

Four participants (Julie, Rani, Jerry and Delta) claimed that the CoRe developed their understanding of the content for teaching. These participants were able to consider more carefully the suitable depth and breadth of the content for their students, as well as recognising effective teaching approaches, and in particular, it provided them with a format to structure and plan for new or unfamiliar content:

> [The CoRe] made me realise as to whether we have actually addressed it [the content] carefully enough. Are we certain that we want this particular piece of information in the unit rather than 'it's just included because everyone else does' and have we actually taught something specifically to get it across. We intuitively … do that but not as a specific … 'tick the box' sort of criteria and sometimes things can slip through if we don't have a structure like this. (Julie, mid-intervention)

An overall and reasonable interpretation of all these participants' views about CoRes could be that it encouraged them to think about their practice in ways that effectively focussed attention on their knowledge of teaching particular content in particular ways, i.e., their PCK. Similarly, all of the participants' post-intervention views (discussed in more detail below)—after having had some time to use their CoRe in their practice—confirmed the claims that they had made directly after creating their CoRe. Every participant also reported that the CoRe, or aspects of it, had influenced their current practice to some degree. In this way, CoRes became a powerful tool for explicating PCK through insights into these teachers' teaching of science. Interestingly, all of the participants either implicitly (Julie, Rani) or explicitly (Samantha, Jerry, Delta and Gordon) suggested that CoRes had direct links to enhancing their practice based on thinking through a PCK lens or perspective:

> If we're talking about me understanding how I know something and how I can explain it and how my students are ready to accept it, to how much my students are ready to learn about it, then yes, definitely … it would help me improve [my] PCK [awareness]. (Jerry, mid-intervention)

Concerning improvements or suggestions to the CoRe, two participants (Delta and Gordon) suggested that CoRes could be adopted as a curriculum approach in schools:

> We could possibly use that as our unit planner. (Delta, mid-intervention).
> If you can work that [the CoRe's prompts] into the daily task anyway—and it's just an additional couple of questions—then it's going to be even more streamlined and it's going to succeed in the ideas of the study but it's also going to keep it much simpler [than doing a CoRe on its own]. (Gordon, mid-intervention)

In that way, they thought CoRes could then be sustained as a curriculum tool and encourage teachers to constantly use the approach to refine their practice.

Mid-intervention Views on PaP-eRs (directly after construction)

Table 3 presents a snapshot of the teachers' post-PaP-eR views. Again, as was the case for the participants' views on CoRes, similar themes began to emerge. These views were grouped thematically: professional practice; limiting factors; and, their relationship with PCK. Some views were further broken down more specifically. In Table 3, these sub-views are italicised and are indicated with bracketed check marks for ease of clarification.

Under the theme of professional practice, the following summary presents some of the specific views which stood out for individual participants. For Julie and Gordon, PaP-eRs were windows into the past which allowed comparison to the present. They claimed this

Table 3 List of participants' views on PaP-eRs directly after its construction

	Julie	Rani	Sam-antha	Jerry	Delta	Gordon
Views on PaP-eRs in regard to professional practice						
Encouraged self-reflection and self-evaluation of teaching practice:	✓	✓	✓	✓	✓	✓
• prompted re-evaluation or questioning of the effectiveness of the teaching approach used in a particular lesson	(✓)		(✓)	(✓)		
• deepened reflection (beyond normal) about: content; catering to specific students and carefully questioning and utilising the most appropriate teaching methodology to enhance students' understanding		(✓)			(✓)	
• prompted meaningful reflection on aspects of teaching practice and helped identify some areas of strengths and weaknesses						(✓)
Promoted deeper knowledge of students and catering to their particular learning styles:	✓	✓	✓	✓	✓	✓
• when teaching difficult content, understanding students and their learning styles was important				(✓)		
• prompted a better awareness of student misconceptions	(✓)	(✓)				
• reminded them to consider differing student groups and to shape the delivery of content especially for them				(✓)		
• promoted the purposeful engagement of students with the content						(✓)
Provided a way of viewing their practice from an observer's perspective	✓		✓	✓		
Provided opportunity to contrast their teaching between now and earlier lessons	✓					✓
Acted to affirm their beliefs and views of themselves as professional		✓			✓	
Explicitly stated that PaP-eRs offered valuable contributions to teachers because it could reveal insights and prompt meaningful consideration of their teaching practice	✓	✓		✓	✓	✓
Provided a way of identifying areas of teaching which could be improved:		✓	✓		✓	✓
• such as exploring students' prior knowledge, incorporating visual stimuli, and reminding them to cater to differing students' learning needs			(✓)			
Could be beneficial for beginning teachers and teachers who might not regularly reflect on their practice	✓					
Could influence teaching practice if used regularly	✓	✓	✓	✓	✓	✓
Limiting factors involved in creating and using PaP-eRs						
Time spent in its production	✓	✓	✓		✓	
Teachers must already know 'how' to reflect meaningfully	✓					
Could lose its effectiveness if teachers did not approach it with the right attitude			✓			
Should not be expected to yield similar depths of analysis of every time				✓		
To be wary of overanalysing teachers' practice unnecessarily				✓		
Views on the relationship between the PaP-eR and PCK						
PaP-eRs linked clearly to PCK:	✓	✓	✓	✓	✓	✓

Table 3 (continued)

	Julie	Rani	Sam-antha	Jerry	Delta	Gordon
• because it consciously connected the teacher to consider how they taught particular content to particular students	(✓)	(✓)	(✓)		(✓)	
• reminded the teacher of the individuality of their students and that they ought to be mindful of catering to their specific needs when structuring lessons						(✓)

was immensely beneficial to them as it allowed them to not only see how their practice had developed but how it might assist them in identifying areas to be improved. An indicative response is provided by Julie:

> [PaP-eRs] provided a tool and I could compare with what I did back then and what I would do next time. … But now, … I'm a little bit more sophisticated because from doing this a couple of times, I realised where kids have … got misconceptions and I would go through things a little slower …—just, sort of, [small] refinements. (Julie, mid-intervention)

For Rani and Delta, the PaP-eR affirmed them as teachers. This was a gratifying experience but also provided them with a view of themselves that they had not recognised before. From this perspective, they were both able to consciously connect to and meaningfully reflect on their practice and how they might improve it. In the case of Delta, there was excitement in her response:

> I actually read it and thought, yeah, I sounded like a really fantastic teacher (laughs). (Delta, mid-intervention)

Delta then went on to explain that she felt this way because her PaP-eR was evidence for her that she was indeed 'catering to [students'] needs—that's what it felt like' (Delta, mid-intervention). For Gordon and Samantha, the PaP-eR reminded them to focus (or see) the individuality of their students. In this way, the PaP-eR was reiterating what PCK stood for—that is, it was about teaching particular students and how best to manage the content in a way that enhanced student learning:

> As a result of reading the PaP-eR … I guess … that I don't always cater to different learning styles. I'm thinking maybe there are some learners in the class who would prefer to have … a whole picture I suppose, and then we come down and we fill in the details a little bit better. And even though that personally doesn't appeal to me and I don't know if it will work, it's possibly something that's worth giving a try. (Samantha, mid-intervention)

For Jerry, his PaP-eR was an intimate, personal document that provoked him to reflect on his practice with more consideration and structure. He felt that his PaP-eR 'documented' (Jerry, mid-intervention) reflection which prompted him to recognise when he reflected and to do so with more consideration:

> So, what I feel is—that this [PaP-eR] is articulating, documenting, making explicit— that kind of process which … on reflection, is a process … that I have going on in my head all the time, in relation to teaching and modelling. … It [PaP-eRs] certainly validates my process. (Jerry, mid-intervention)

It was awesome to come back and read [his PaP-eR]. … If you focus on it you could get some benefit from it and you feed that back into your routine teaching repertoire. … So, picking this up and looking at … this documentation and detailed reflection of what I thought about this whole process was really valuable. (Jerry, mid-intervention)

In summary, as the views (summarised in Table 3) illustrate, each participant clearly endorsed PaP-eRs as an effective, reflective tool. All participants believed that their PaP-eR offered valuable insights into their practice. They believed that PaP-eRs provoked meaningful consideration of their practice, helped them to know their particular students better and how to cater to their needs, and helped them to recognise strengths and weaknesses and areas that could be improved. When asked to rank his PaP-eR in terms of its effectiveness at drawing out his PCK Jerry stated that it would be high:

Look, I think it's probably fairly high. … It would be unrealistic to expect that the majority of PaP-eRs that were put together—if they followed the same process— would have the same high level. But that doesn't mean that they wouldn't be 'not' a valuable thing to pursue. (Jerry, Int. 5)

In many ways it could be suggested that PaP-eRs create possibilities for participants to value what they have done and invites them to develop insights into their professional knowledge and PCK. The participants' views offer evidence to support this suggestion. Their claims have demonstrated that PaP-eRs are a valid instrument for effectively stimulating teachers to meaningfully consider their teaching in ways that improves their professional knowledge and helps them recognise, enhance and more explicitly connect with their own PCK.

Post-intervention Views on CoRes and PaP-eRs (two years later)

Some 2 years later, participants were interviewed for their post-intervention views on PCK and the effect to which they believed this study, through CoRes and PaP-eRs, had developed or influenced this aspect of their professional knowledge. All six participants still endorsed CoRes and PaP-eRs as valuable tools which, as one participant (Julie) stated, had made her consider the 'why' and 'how' of her practice rather than just focussing on the 'what'. All participants felt that CoRes and PaP-eRs provided a framework for meaningfully examining content and the planning of its delivery; and provided a reflective tool that could help teachers evaluate and analyse their lessons and identify areas for improvement:

I think people are very good at 'what' … but I think this really gets you to think deeply about the actual delivery of the lesson itself. … And gives it respect. And makes you think of the various people in the room. … So, it helps you to differentiate the curriculum. It's the best tool I have come across so far. (Julie, post-intervention)

I think it [CoRes and PaP-eRs] would help you. … It would help you to identify any strengths or weaknesses in your teaching and perhaps whether if you were just going through the motions or … what [the] motivation was behind your use of certain instructional strategies in the classroom. If somebody was struggling with motivation or classroom technique, for want of a better word, then asking yourself, 'Well, what am I doing? And why am I doing it like this?' If I can't think of some good answers then maybe I need to change some of my teaching strategies. (Samantha, post-intervention)

Five of the six participants (Rani, Samantha, Delta, Jerry and Gordon) explicitly stated that they believed both CoRes and PaP-eRs were complementary and reinforced each other. An example is provided here by Rani. She viewed CoRes and PaP-eRs as symbiotic—CoRes provided a means of framing content with purpose and PaP-eRs forced meaningful reflection on how practice could be improved:

> CoRes helps you to structure your lessons. … Whereas your reflection [i.e., PaP-eRs] will help you develop the content of that lesson. … They depend on each other. … Can I say it's like a cycle? … The PaP-eR helps you to develop your CoRes and so that helps you to think about the content representation. … And, of course, … you can't have a PaP-eR until you've done some content. (Rani, post-intervention)

In terms of CoRes and PaP-eRs, all participants—either explicitly (Julie, Samantha, Jerry, Delta and Gordon) or implicitly (Rani)—felt that they were effective in drawing out and elucidating teachers' PCK. Some participants (Julie, Samantha, Jerry, Delta and Gordon) implied that CoRes and PaP-eRs offered a way of viewing their practice specifically through a PCK lens.

> PCK, [through the tools of CoRes and PaP-eRs], …contributes to your awareness of your ability as a teacher and it would sort of deconstruct your philosophies and concepts of being a teacher. And if the person is open to the experience it would give them the opportunity to reflect upon their teaching and go, 'Well, look. I have some gaps here. I need to work on this'. … And so PCK in my view is [the teachers'] … way of describing how they teach effectively and what they think is good teaching. (Gordon, post-intervention)

In particular, five of the six participants (Julie, Samantha, Jerry, Delta and Gordon) mentioned that their PCK developed because CoRes and PaP-eRs offered a structured way to reflect in a meaningful and purposeful manner. All participants suggested that CoRes and PaP-eRs were important for teachers to include in their 'professional arsenal'. Some endorsed its use as an important way of shaping their teaching of science at the faculty level in a school (Julie, Rani, Delta, Jerry and Gordon).

> I'd love to see this being implemented in the next few years [in schools]. I'd love to see a teacher come back to me and say I've heard of PCK and I want to try it. (Rani, post-intervention)

> I would think that [CoRes and PaP-eRs] would be an ongoing process [for teachers]. And I would actually be interested … you developed those elements for schools. (Gordon, post-intervention)

Others endorsed its use specifically as a way for beginning teachers to conceptualise the development of their science teaching practice (Julie, Rani, Samantha, Jerry and Gordon):

> I think those new to the profession who perhaps don't yet have the appreciation for the intricacies of the profession and the art and the craft of teaching, would do well to engage with the idea of PCK. (Samantha, post-intervention)

Overall, each participant claimed that PaP-eRs had left them with a lasting impression.

Participants' Views on the Limitations of CoRes and PaP-eRs

Upon considering the participants' views on CoRes and PaP-eRs, a number of possible limitations came to light. The most obvious of these, as reported many times by the participants, was the investment of time required in the production of CoRes. While this is clearly a limitation, a few participants (Delta, Gordon and Jerry) claimed that it was also a necessary feature of thinking about the nature of PCK. It could be argued that if participants were to pay due respect to understanding their PCK, then it was essential to spend the appropriate amount of time in the construction of the CoRe.

The impact of time as a limitation affected how the participants believed they would use CoRes and PaP-eRs in the future. Even though all participants claimed that CoRes were beneficial, they would not use them on their own initiative in their practice. Only two participants (Delta and Gordon) suggested that CoRes perhaps could be worked into the regular curriculum or enforced by their head of faculty. Three participants explicitly claimed that CoRes would be unsustainable if incorporated regularly into practice due to time. Two participants (Rani and Jerry) claimed, however, that they liked the notion of PCK that CoRes embodied and that they would 'informally' reflect on the CoRe's prompts.

Aside from time, in regard to PaP-eRs, three of the six participants (Julie, Samantha and Jerry) expressed their concerns about some possible limitations. Samantha felt that some teachers might skew their data to portray their teaching in a positive light ('window dress' (Samantha, post-intervention)) or that it could become too familiar (like a form to fill in) to offer any new insights. Jerry believed that there was a risk of over-analysing which might make the teacher 'read more depth into things than there really is. That's not going to do much harm but it mightn't be very productive' (Jerry, post-intervention). Finally, Julie was cautious that teachers needed to have modelled how to reflect effectively if the PaP-eR was to be helpful to their practice.

Overview of Results

This study has demonstrated that the participating science teachers were of the view that CoRes and PaP-eRs were worthwhile and valid tools which improved their understanding of their own practice and in particular, how they came to understand and recognise their own PCK. In regard to CoRes, all participants drew attention to the fact (four explicitly and two implicitly) that they believed it was effective at highlighting significant aspects of their PCK. These included areas such as: professional practice; student learning; and, content in the following ways:

- professional practice:

    ○ helped teachers to rethink how they could improve their teaching;
    ○ helped teachers to reflect on their practice;
    ○ 'forced' teachers to explicitly think and connect with their intuitive and tacit knowledge about teaching and learning; and,
    ○ offered benefits to inexperienced teachers as well as experienced teachers.

- student learning:

  ○ helped teachers to think specifically about the importance of knowing their students;
  ○ helped teachers to think about how they recognised and evaluated student learning; and,
  ○ helped teachers to be aware of, and think about how to, approach drawing out and responding to students' alternative conceptions/misconceptions.

- content:

  ○ helped teachers to recognise the range of teaching strategies they had expertise in and using these for the teaching of particular content;
  ○ helped teachers to think specifically about the depth and breadth of content; and,
  ○ helped teachers think about how to approach and plan for new or unfamiliar content.

In regard to PaP-eRs, all participants claimed that it was effective at highlighting significant aspects of their PCK and professional practice. These included:

- encouraging self-reflection and self-evaluation of teaching practice;
- stimulating teachers to consciously connect with knowing their students and catering to their particular learning styles;
- allowing teachers to see themselves from an observer's perspective;
- providing teachers with the opportunity to contrast their teaching between current and earlier lessons;
- acting to affirm teachers' beliefs and views of themselves as professionals;
- explicitly stating that PaP-eRs offered valuable contributions to teachers because it could reveal insights and prompt meaningful consideration of their teaching practice;
- providing a way of identifying areas of teaching which could be improved;
- being beneficial for beginning teachers and teachers who might not regularly reflect on their practice; and,
- influencing teaching practice if used regularly.

In considering both CoRes and PaP-eRs together (i.e., as a Resource Folio), the participating teachers all claimed that both instruments were complementary and necessary. As one participant stated, 'they depend on each other' (Rani). 'CoRes helps you to structure your lessons. … Whereas your reflection [the PaP-eR] will help you develop the content of that lesson' (Rani). Participants also claimed that Resource Folios were effective at building their PCK, and as a consequence, improving their professional practice. Evidence of this improved understanding of PCK could be observed through their more developed and refined definitions of PCK which they made as part of the larger study (not specifically reported here).

Many of the claims about the applicability, use and value of CoRes and PaP-eRs have now been verified. The participating science teachers have claimed that they have 're-conceptualised' their practice through professional learning, particularly the CoRe; that their awareness and understanding of PCK became more accessible through a CoRe and PaP-eRs approach and therefore their valuing of PCK was enhanced; and that they provided explicit, concrete portrayals of their PCK.

In answering the research question which was the focus of this paper, the main finding could be succinctly reported that 'participating science teachers believed that CoRes and

PaP-eRs were worthwhile and valid tools which improved their understanding of their own science practice and in particular, how they came to understand and recognise their own PCK'. In general, the idea of PCK allowed these teachers to gain insights into their science teaching in ways which they had not done previously. CoRes and PaP-eRs also provided a framework on which they could begin to access their tacit knowledge and use it to improve their practice:

> Yes, it's [this study] confirmed it [my practice] … and strengthened it, … and given me a good scaffold. … If I find a good scaffold then I'll refer to it often. And this is a scaffold that I would refer to often. (Julie, post-intervention)

Recommendations and Implications

The study set out to examine the views of practicing science teachers' on how the instruments of CoRes and PaP-eRs might influence their understanding and valuing of PCK as a legitimate part of their professional knowledge. Essentially, this study tested the value and applicability of CoRes and PaP-eRs with teachers in the real world of practice. The findings (as presented in this paper) have illustrated that practising science teachers were of the view that CoRes and PaP-eRs can indeed be of value in their practice and foster the development of their professional knowledge of teaching. However, all participants also noted the large investment of time required to complete a CoRe and PaP-eR and they all agreed that they would not actively create their own. Two participants suggested that the use of CoRes and PaP-eRs might be sustained if they were incorporated into regular curriculum practices.

In using CoRes and PaP-eRs, it was revealed that the teachers themselves developed an understanding of the way their knowledge of science teaching developed in teaching particular content in a particular way for a particular reason—that is, their PCK. This study has also shown how CoRes and PaP-eRs can help demonstrate (and possibly develop) deeper understandings of the complex nature of the work of science teachers and bring to the surface their specialist knowledge of teaching specific content.

At a more general level, CoRes and PaP-eRs could be explored in enhancing pedagogical models that might be of assistance to all science education stakeholders. These include: experienced science teachers (including teachers as readers of other teachers' CoRes and PaP-eRs); beginning science teachers; pre-service science teachers and their science teacher-educators (see for example, Hume & Berry, 2010); and science education researchers. With this in mind, recommendations for further research could include studies that might investigate how practising teachers might benefit from CoRes and PaP-eRs in longitudinal studies or when preparing for and teaching unfamiliar content. Other studies could examine how teachers, as end-users of CoRes and PaP-eRs (i.e., teacher-readers), might enhance their professional knowledge of practice. In addition, studies could explore how CoRes and PaP-eRs might be incorporated and used in regular and ongoing curriculum practises within science faculties and/or schools. Lastly, it would also be interesting to continue the research initiated by Woolnough (2009) that is beginning to explore how CoRes and PaP-eRs might benefit pre-service science teacher education (cf. Hume & Berry, 2010; Nilsson, 2010).

Shulman created a construct that has attracted sustained attention for a considerable period of time. CoRes and PaP-eRs have contributed to a platform from which the abstract concept of PCK may be realised in practice (thus offering a bridge between theory and

practice). As this study demonstrates, for science teachers, the use and development of PCK as a construct in shaping their practice is now realisable, applicable and meaningful, that must surely then offer new ways of highlighting the importance of professional knowledge of practice and bring to the fore new ways of recognising the specialist skills and knowledge at the heart of expert practice.

References

Abell, S. (2007). Research on science teacher knowledge. In S. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1149). Mahwah: Erlbaum.

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

Baxter, J. A., & Lederman, N. G. (1999). Assessment and measurement of pedagogical content knowledge. In J. A. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 147–161). Dordrecht: Kluwer Academic Publisher.

Bertram, A. (2010). Enhancing science teachers' knowledge of practice by explicitly developing pedagogical content knowledge. Unpublished Ph.D. thesis, Monash University, Clayton, Victoria, Australia.

Clandinin, D. J., & Connelly, F. M. (1996). Teachers' professional knowledge landscapes: teachers stories-stories of teachers-school stories-stories of schools. *Educational Researcher, 25*(3), 24–30.

Clandinin, D. J., & Connelly, F. M. (2000). *Narrative inquiry*. San Francisco: Jossey-Bass.

Conle, C. (2003). An anatomy of narrative curricula. *Educational Researcher, 32*(3), 3–15.

Connelly, F. M., & Clandinin, D. J. (1990). Stories of experience and narrative inquiry. *Educational Researcher, 19*(4), 2–14.

de Jong, O., van Driel, J., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching, 42*(8), 947–964.

Garritz, A., Porro, S., Rembado, F. M., & Trinidad, R. (2005, August). *Latin-American teachers' pedagogical content knowledge of the particulate nature of matter*. Paper presented at the European Science Education Research Association (ESERA): Symposium on understanding science teachers' PCK in the context of curriculum reform, Barcelona, Spain.

Gess-Newsome, J. A. (1999). Pedagogical content knowledge: An introduction and orientation. In J. A. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 3–17). Dordrecht: Kluwer Academic Publishers.

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

Hashweh, M. Z. (2005). Teacher pedagogical constructions: a reconfiguration of pedagogical content knowledge. *Teachers and Teaching: theory and practice, 11*(3), 273–292.

Hume, A., & Berry, A. (2010). Constructing CoRes: a strategy for building PCK in pre-service science teacher education. *Research in Science Education*. doi:10.1007/s11165-010-9168-3 (online frst).

Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. *Studies in Science Education, 45*(2), 169–204.

Korthagen, F., & Kessels, J. P. A. M. (1999). Linking theory and practice: changing the pedagogy of teacher education. *Educational Researcher, 28*(4), 4–17.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370–391.

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

Loughran, J., Berry, A., Mulhall, P., & Woolnough, J. (2006b). Understanding and valuing the development of pedagogical content knowledge in science teacher education. In I. Eilks & B. Ralle (Eds.), *Towards research-based science teacher education* (pp. 65–76). Aachen: Shaker Verlag.

Loughran, J., Berry, A., & Mulhall, P. (2007). Pedagogical content knowledge: What does it mean to science teachers? In R. Pinto & D. Couso (Eds.), *Contributions from science education research* (pp. 93–105). Dordrecht: Springer.

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

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

Marks, R. (1990a). *Pedagogical content knowledge in elementary mathematics.* Unpublished doctoral dissertation, Stanford University, Stanford, C.A., (Dissertation Abstracts International, 51 01A, p. 101).

Marks, R. (1990b). Pedagogical content knowledge: from a mathematical case to a modified conception. *Journal of Teacher Education, 41*(3), 3–11.

Nilsson, P. (2010). *The CoRe project. Understanding and assessing primary student teachers' pedagogical content knowledge.* Paper presented at the annual meeting of the National Association of Research in Science Teaching, Philadelphia, U.S.A.

Pekarek, R., Krockover, G. H., & Shepardson, D. P. (1996). The research-practice gap in science education. *Journal of research in Science Teaching, 33*(2), 111–113.

Polanyi, M. (1966). *The tacit dimension.* Garden City: Doubleday.

Ratcliffe, M. (2008). *Pedagogical content knowledge for teaching concepts of the nature of science.* Paper presented at the Nordic Symposium on Science Education, University of Iceland, Reykjavik, Iceland. Retrieved February 3, 2010, from http://eprints.soton.ac.uk/59177/01/PCK_NoS_Nordic_symp.pdf

Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: a case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education, 30*(10), 1365–1387.

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

Tamir, P. (1988). Subject matter and related pedagogical knowledge in teacher education. *Teaching and Teacher Education, 4*, 99–110.

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673–695.

Wiersma, W. (2000). *Research methods in education: An introduction* (7th ed.). Needham Heights: Allyn & Bacon.

Woolnough, J. (2009). *Developing preservice teachers' science PCK using Content Representations.* Paper presented at the European Science Education Research Association, Istanbul.