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Getting to the CoRe of it: A review of a specific PCK conceptual lens in science educational research

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Abstract Since its introduction, pedagogical content knowledge (PCK) has been widely written about in the science education research literature. It has served as an alluring concept amongst many of the discussions on the teaching and learning of science. This paper reviews and draws together empirical research on a specific PCK lens, consisting of two tools: a Content Representation (CoRe) and Pedagogical and Professional Experiences Repertoires (PaP-eRs). Both tools were originally developed by Loughran et al. (2006) and have since been used by a variety of educational researchers and practitioners within their own contexts. This paper seeks to present how CoRes and PaP-eRs have helped conceptualise and advance PCK research, including the impact this has had on the professional practice of teachers. This paper, in so doing, also demonstrates how this PCK lens can facilitate effective teaching and learning in science education.

PALABRAS CLAVE
Conocimiento didáctico del contenido;
Representación de un contenido;
Aprendizaje y enseñanza de las ciencias

Conociendo ''CoRe'': revisión de un concepto específico de investigación en ciencias de la educación

Resumen Desde su aparición, la expresión conocimiento didáctico del contenido (PCK, por sus siglas en inglés) ha sido ampliamente citada en la literatura sobre investigación en las ciencias de la educación, y ha protagonizado muchos de los debates sobre la enseñanza y el aprendizaje de las ciencias. Este artículo revisa y perfila con una mirada específica los PCK, que constan de 2 herramientas: una representación del contenido (CoRe), y un repertorio de experiencias profesionales y pedagógicas (Pap-eRs). Ambas herramientas fueron desarrolladas

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originalmente por Loughran et al. (2006), y desde entonces han sido empleadas por muchos investigadores y docentes en su contexto particular. El objetivo del presente artículo es mostrar cómo el uso de CoRes y PaP-eRs ha ayudado a conceptualizar y avanzar en la investigación del PCK, incluyendo el impacto que este ha tenido en la práctica profesional de los docentes. Al hacerlo, también se muestra cómo el PCK puede facilitar una enseñanza y un aprendizaje eficaz en educación científica.

Introduction

Pedagogical content knowledge (PCK) has served as an alluring theoretical construct since it was originally defined by Shulman (1986) as he attempted to grasp the knowledge bases that a teacher possesses. From his research he concluded that there were seven knowledge bases associated with teaching; one of these was PCK. Shulman defined PCK as:

> ''for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations- in a word, the ways of representing and formulating the subject that make it comprehensible to others'' (Shulman, 1986, p. 9).

PCK would distinguish the knowledge that a science teacher has from that of a scientist, a scientist would have considerable knowledge of the subject but would not necessarily have the knowledge associated with the effective instructional strategies for teaching the subject (National Research Council, 1996). In other words, it is a knowledge that is unique to teachers and is the essence of teaching (Cochran, King & deRuiter, 1993). A scientist's knowledge is structured from a research perspective whilst a teacher's knowledge is structured for the purpose of student learning (Cochran et al., 1993).

Shulman (1986) describes PCK as an amalgamation between knowledge of content and pedagogy allowing for more effective teaching of a particular concept. PCK revolves around both a teacher's understanding and the enactment of their knowledge (Park & Oliver, 2008). PCK develops over time, through experience of how to teach a particular concept in a specific way so that there is enhanced student understanding (Loughran, Mulhall, & Berry, 2006). It is a result of the many classroom experiences that a teacher has with many different students (Cochran et al., 1993). It can be assumed that such varied experiences and understandings of what enhances student learning results in difficulties around how PCK can be conceptualised in the classroom.

In discussions at a worldwide PCK summit in 2012, an attempt was made in coming to a general consensus of a description and conceptualisation of PCK. The attendees, all of which had experiential and expert knowledge into the construct of PCK, believed PCK (personal PCK) to be representative of a teacher's knowledge of, reasoning behind, and purposeful planning for teaching a particular topic in a certain way for enhanced student learning (Gess-Newsome, 2013). Making the material comprehensible to others is crucial behind the effective teaching and learning of scientific ideas. Once such way that has become recently widely investigated is that of CoRes and PaP-eRs. This paper now draws together this research and presents a review and implications of these instruments and their impact on science teacher education. This conceptualisation of PCK and review of the literature encompasses research from around the globe and is not specific to any one country or region.

Capturing and measuring PCK

Perhaps the most important message in Kind's 2009 review of PCK (Kind, 2009) was the ''strong evidence that PCK is a useful concept and tool for describing and contributing to our understanding of teachers' professional practice'' (p. 198). She summarised the empirical studies that reinforced the idea that PCK is indeed important to science teachers as well as being crucial in science teacher preparation programmes. Moving PCK research forward then requires investigations into capturing and portraying PCK and then making this more explicit both with practising teachers and student−teachers.

A teacher's professional knowledge is difficult to categorise and because of this is very difficult to articulate and record (Loughran, Mulhall & Berry, 2004). Whilst Baxter and Lederman (1999) believe PCK to be a highly complex construct that is not easily assessed, in order to ''capture'' PCK, it requires a combination of approaches which can invariably portray a teacher's beliefs about what teachers know, what beliefs they hold, what they do together with their justification for what they do. The authors of this current paper believe that the complex nature of PCK requires instruments which can adequately portray instances of PCK.

Two instruments have gained significant attention in the science education research literature: these are a Content Representation (CoRe) and a Pedagogical and Professional-experiences Repertoires (PaP-eRs), both developed as complimentary tools by Loughran et al. (2006) from which PCK could be captured. Kind (2009) believed that the CoRe tool offers the most useful technique devised to date in science education research for eliciting and recording the PCK from teachers directly. Indeed both the authors in this current paper have used these tools in their own research and that is why the remaining discussion will focus on these and provide insight into how they have been used in various research contexts. The extent to which mainly the CoRe has been used in a variety of research contexts gives substance to the authors assumption that it is the most widely used instrument for PCK related purposes.

These pedagogical tools (CoRes and PaP-eRs) not only help capture the teachers' PCK but can also be seen as a way of portraying this knowledge to others. These two tools offer a topic specific orientation as opposed to a general PCK representation (Lee & Luft, 2008). The teachers' PCK can be detected through such things as content specific teaching procedures, e.g. laboratory work, observations, questionnaires and discussions.

A CoRe is a research tool for accessing science teachers' understanding of the content as well as a way of representing this knowledge (Loughran et al., 2006). A CoRe can be used as an interview tool whose function is to draw out teachers' understandings of important aspects of the content under consideration. The main purpose of CoRes is to codify the teachers' knowledge across the content area that is being examined, which allows one to see what level of understanding each teacher has (Loughran et al., 2006). CoRes are mainly developed in groups (but can be done individually) and PaP-eRs are individual representations (Loughran et al., 2004). The reason for this difference is due to the fact that complementary aspects of PCK can be examined through group exploration as well as individual exploration, PCK can be a socially constructed phenomenon (Loughran et al., 2004). Abell (2008) advises that PCK can be held at both an individual and group level and suggest that the CoRe matrix can help teachers define PCK for teaching a particular topic. Teachers construct a CoRe on a particular topic by answering a number of framed questions but before this, need to consider the big ideas around the teaching of the chosen topic. These big ideas are the fundamental ideas that teachers view as crucial for students to develop their understanding of a topic (Loughran et al., 2006). There is no defined number of big ideas but Loughran et al. (2006) found there to be typically 5–8 big ideas within a given topic.

PaP-eRs connect the teachers' actual practice with their CoRe and offer a structure for reflection and evaluation of the teaching. The PaP-eRs are about reflecting on the teaching of the content within the classroom context and help to illustrate aspects of PCK in action. A collection of PaP-eRs are attached to different areas of the CoRe to highlight the different elements of PCK in that content area (Loughran et al., 2004). Together with its associated set of PaP-eRs, the CoRe must be conceptualised as necessary to codify and categorise the knowledge and content under consideration. PaP-eRs are developed from detailed descriptions offered by individual teachers, and/or as a result of discussions about situations/ideas/issues relating to the CoRe, as well as classroom observations (Loughran et al., 2006). A PaP-eR is further developed through the interaction between ''prompts, questions, issues and difficulties that influence the particular approach to teaching that content to which the PaP-eR is tied and reflects the richness of the teacher's understanding of science teaching and learning in that field'' (Loughran et al., 2004, p. 377).

The use of CoRes and PaP-eRs in science educational research

As suggested previously, many researchers have used the PCK instruments developed by Loughran et al. (2006) for their own research endeavours. The following section reviews the empirical research around the use of CoRes and PaP-eRs in recent science educational research.

Originally Loughran et al. (2006) developed the CoRe and PaP-eR to capture and portray the PCK of experienced teachers. They noted from their experiences that the act of describing ones' PCK through CoRe construction requires teachers to problematise the content and teaching and can facilitate to process of teachers to share with others their knowledge about how to teach particular content for enhanced student learning (Loughran et al., 2006). Hume and Berry (2013), Nilsson and Loughran (2012) and Lehane, O'Reilly and Mooney-Simmie (2013) and Bertram and Loughran (2014) focused their attention on using the CoRe with pre-service science teachers. When pre-service teachers were asked to construct CoRes, Hume and Berry (2011) noted that pre-service teachers found this task to be challenging and their lack of experimentation and classroom experience proved to be a limiting factor. In spite of this, Hume and Berry (2011) found that with appropriate and timely scaffolding, the process of CoRe construction could potentially aid pre-service teachers in their PCK development. They also concluded that if pre-service teachers continued to work together and practice their CoRes creation, they not only improved but were aided in their preparation for classroom teaching and learning (Hume & Berry, 2011). If the CoRe design process is carefully scaffolded and pre-service teachers work from experienced teachers' PCK, then it would allow the pre-service teachers to begin accessing and accumulating some of the knowledge of experienced science teachers and would help bolster feelings of confidence and competence when they begin to arrange their own knowledge for their model of PCK (Hume & Berry, 2011).

Lehane et al. (2013) focused their study on using the CoRe to capture and develop inquiry orientations of pre-service science teachers as part of a professional learning community (PLC). They adapted the CoRe slightly to include an inquiry focus, changing the pedagogical prompt ''teaching procedures (and specific reasons for using these to engage with this idea'' to ''teaching procedures (with specific reference to teaching through inquiry). Lehane et al. (2013) observed that the professional collaboration between the pre-service teachers resulted in the whole cohort developing a living educational theory (Whitehead, 1989) as to what they perceived inquiry to look like. Involvement in the CoRe workshops provided the pre-service teachers with an avenue to share ideas and work together to consider how they would teach a variety of topics through inquiry. The pre-service teachers struggled initially however they reported that the supportive, discursive environment created during the CoRe workshops acted as scaffold to enhancing their awareness of inquiry. The espoused developing inquiry orientations were seen to successfully translate into classroom practice.

Nilsson and Loughran (2012) found the CoRe to be a useful tool in planning for and assessing pre-service teachers own learning related to teaching elementary school science. Their study has shown that it is possible to introduce PCK to teachers of young children, not just for teachers of children at higher levels (where the majority of PCK research has been situated). Adadan and Oner (2014) focused their research on interpreting the changes in two pre-service science teachers' PCK representations of behaviour of gases over a semester long chemistry teaching methods course. The pre-service teachers' PCK representations increased over the course of the semester however the components of PCK did not progress to the same extent for each participant. Chordnork and Yuenyong (2014) also used the CoRe with elementary school teachers to facilitate them in developing a greater understanding of teaching global warming. Findings from their study suggested that teachers found that the CoRe offered a means to understand PCK and its influence on science teaching. Bertram and Loughran (2014) explored how PCK might begin to be developed in pre-service physics teachers. They used the CoRe as a frame for 'planting the seed'' (p. 151). They recognised that pre-service teachers would lack appropriate PCK since PCK is linked with classroom experience. Their research revealed, that by using a CoRe, the pre-service teachers ''shifted from a mostly transmissive content-focused delivery to one that considered more pedagogically-reasoned approaches ... thereby providing that some aspects of their PCK have begun to be developed'' (p. 151).

Indeed pre-service teachers, while lacking experience in the classroom as the facilitators of learning, have developed scripts for teaching based on their years in what Lortie (1975) refers to as the apprenticeship of observation and Abell (2008) believes that these scripts limit their views on teaching and learning. The CoRe provides a cognitive and reflective challenge for pre-service teachers as they continue to confirm or remove some of their pre-existing notions of teaching as they transition through their Initial Teacher Education programme. Nilsson (2013) again used the CoRe to facilitate pre-service teachers PCK. She noted from her study that developing a CoRe together with self-assessment and formative interactions with teacher educators and peers can potentially lead to PCK development. Loughran, Mulhall and Berry (2008) focused their studies on having a teacher educator introduce pre-service science teachers to ideas about PCK through the CoRe and the PaP-eR. They found that the use of PCK, through the medium of the CoRe and PaP-eR can offer another way of thinking about teaching that goes beyond the traditional range of ''tips and tricks'' about how to teach (Loughran et al., 2008). It encourages pre-service teachers to devolve into deeper understandings and link teaching and learning purposes (Loughran et al., 2008). The findings also showed that the pre-service teacher teachers adopted a particular language which the authors believed were as a result of the pedagogical prompts within the CoRe. This finding suggests that the barrier presented by Berry, Loughran, Smith and Lindsay (2009)related to the non-existence of a language resulting in the elusiveness of documenting teachers' knowledge, is indeed eradicated through the use of the CoRe.

Williams, Eames, Hume and Lockley (2012) used the CoRe as a lesson planning tool with early career teachers while others (Hume & Berry, 2013; Bertram & Loughran, 2012) have also advocated their use as a lesson planning tool. However Williams and Lockley (2012) expanded their use of the CoRe by using it with technology students as well as science students. This suggests that the CoRe can be utilised in a variety of general subject contexts beyond its ubiquitous use in the sciences. Williams et al. (2012) also used the CoRe as a tool for building the PCK of early career teachers and results showed that involvement in the CoRe construction helped these novices develop confidence in what they were teaching and to try new pedagogical strategies. Williams et al. (2012) also found that the support of expert teachers contributed hugely to the successful design of the CoRe. Williams et al. (2012) use of the CoRe as a lesson planning tool developed from an initial study carried out by Eames, Williams, Hume and Lockley (2011). They brought together science and technology experts in both content and pedagogy with early career science teachers and researchers to design a CoRe to assist the development of teacher PCK. This developed CoRe was then used by early career teachers' in the planning and delivery of a classroom activity. Eames et al. (2011) believed that CoRes had the potential to help early career teachers gain access to the content and pedagogical expertise of others. Also the process of developing the CoRe with experts was nearly as important as the product of the CoRe itself (Eames et al., 2011). This suggests that taking part in the construction of a CoRe can allow for experiential learning. This is vindicated by Lehane et al. (2013) who stated that the CoRe can act as a gateway for novice teachers to gain insight into expert teachers' knowledge and experience.

Padilla, Ponce-de-Leon, Rembado and Garritz (2008) used the CoRe to capture the PCK of four university professors on the topic of the ''amount of substance''. They classified and discussed the participants' PCK using Mortimer's conceptual profile model which analyses conceptual evolution in the classroom (Padilla et al., 2008). Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) also used the CoRe as a tool to facilitate the teaching and learning of the amount of substance, similar to Padilla et al. (2008) but included the topic of chemical equilibrium in their research agenda. The focus of this study was to investigate the effect of a teacher's subject matter knowledge on their PCK. Garritz and Ortega-Villar (2012) used the CoRe to capture four university professors understanding of ''condensed matter bonding'' and follow up interviews led the researchers to consider PCK to extend to having an affective element where students' interest and motivation should be a focus when considering the teaching of a topic. The success of the CoRe in these contexts illustrates how it can be used to facilitate teaching specific topics.

Davidowitz and Rollnick (2011) used the CoRe to portray the practice of a university lecturer as they believed that the strength of the CoRe was in its ability to focus the lecturer's understanding of the aspects of teaching that represent and shape the content. Barendsen, Dagiene, Saeli and Schulte (2014) would have used the CoRe to capture the PCK of both experienced and novice teachers and in doing so gain understanding of the differences between their respective PCKs. The findings suggested that experienced teachers stressed higher order skills while the novice teachers focused on more simple applications of learning.

Donnelly and Boniface (2013) made the accessibility of the CoRe more interactive by creating an on-line Wiki in response to the potential issues in having teachers meet face to face to design a CoRe. It was also in response to the proclaimed issue of CoRe construction being a labour and cost intensive affair (Donnelly & Boniface, 2013). They consider the fact that CoRes can be developed individually and shared online (Donnelly & Boniface, 2013). Even though the CoRe was originally constructed to represent group PCK,

Questions/inquiry pedagogical activities	A Identify and consider questions that can be answered through inquiry	B Define and analyse properly the question to be solved and identify its relevant aspects	C Gather bibliographic information to be used as evidence	D Develop explanations to set out question, from evidnce	E Think about everyday problems and display relevant historical aspects	F Design and conduct a scientific investigation	G Communicate by means of argumentation what has been learned through inquiry
1. Why do you consider impportant for students to develop this activity?							
2. Whare are the difficulties or limitations of teaching this activity?							
3. What are the difficulties or limitations of students related with learning this activity?							
4. What teaching examples and procedures do you use for engaging students with this activity?							
5. What are the specific ways for ascertaining students' undersanding or confusión around this activity?							

Figure 1 Espinosa-Bueno et al. (2011) I-CoRe.

others have found use in the individual construction of CoRes (Lehane & Bertram, 2013). While the group construction and the professional learning community created does have its own benefits, studies have shown that teachers can also gain professional learning from creating a CoRe individually.

Grgurina, Barendsen, Zwaneveld, van Veen and Stoker (2014) focused on exploring the computational thinking skills of teachers namely their skills in data collection, algorithms and procedures and simulation. From the analysis of a series of CoRes the authors determined that the teachers in question had varying knowledge of learning objectives and completeness of their respective PCK.

Espinosa-Bueno, Labastida-Pina, Padilla-Martinez and Garritz (2011) used the CoRe to document teachers' pedagogical inquiry/content knowledge (PICK) and were more focused on getting the participants to consider the implications of including the features of scientific inquiry in their lesson. However the CoRe scaffold, named I-CoRe, was so significantly adapted that its resemblance to the original CoRe designed by Loughran et al. (2006) was minute as Fig. 1 reveals.

The purpose of the I-CoRe was to consider the complexities of including the features of inquiry within a classroom and does little to suggest how inquiry is embedded within a teacher's PCK as in its description; it does not integrate the components of PCK within the I-CoRe scaffold.

Park Rogers et al. (2012) have used the CoRe to facilitate in the development of science curriculum by introducing aspects of PCK into curriculum documentation. This use is far removed from the originally intended use of the CoRe but it does again confirm the flexible nature of the CoRe for individual educational purposes.

The above section has provided an insight into the varied interpretations and uses of the CoRe in particular in science education research. However the question remains, does such illustration of use provide adequate response to the contentious construct that is PCK? The next section will explore this inquiry.

Future research

Kind's (2009) review ended with her view:

> ''Education courses should make explicit what PCK is, for example, by introducing CoRes as a way of describing current practice and/or using completed CoRes as exemplar material. CoRe completion promotes develop- ment of reflective practice skills, offering a means of acknowledging changes in PCK through application of classroom experience. Use of vignettes and other prompts may also be useful ways of highlighting and devising instructional strategies'' (p. 200).

The authors agree with Kind's views and believe that the development of the CoRe and PaP-eRs and the contribution that the instrument has made to science education research is not something that should be ignored or forgotten. The diversity of contexts in which it has been used suggests that imaginative applications of these instruments can continue to contribute to research in science education. Future research may lie in the continued development of CoRes and PaP-eRs and the publishing of examples of developed CoRes and PaP-eRs within a resource folio.

Loughran, Mulhall and Berry (2012) have published specific examples of developed CoRes and PaP-eRs related to the topics of the Particle Theory, Genetics, Chemical Reactions, Electric Circuits, Force and the Circulatory System. These provide exemplars of expert teachers espoused and enacted PCK and are a valuable professional development resource. As well as the Particle Theory, Chemical Reactions and Genetics, pre-service science teachers within the study conducted by Lehane et al. (2013) developed a number of CoRes on the topics of Heat, Mechanics, the Immune System, Respiration, the Nervous System and Modern Physics. Further research would involve experts reviewing these CoRes, making suitable changes and disseminating them to other cohorts of pre-service science teachers within the Initial Teacher Education programmes in Ireland.

To date, the CoRe has been the more widely used of the two in the literature. While the CoRe does provide a unique portray of PCK, it is reflective of espoused PCK. A greater focus on reporting enacted PCK is needed to compliment the CoRe. Therefore the authors would suggest the need to provide narrative accounts of a teacher's PCK in their actual classroom context. Having a repository of enacted PCK from actual and varied classroom settings would broaden the appeal of using these tools to facilitate teachers' professional development.

Other possible research may lie in using the CoRe for specific research purposes, for example Lehane et al. (2013) used the CoRe to develop inquiry orientations, so the potential is there to develop alternative teaching methodologies using the CoRe scaffold. Also the non-specific nature of the CoRe means that its design could be extended to other subject areas.

Conflict of interest

The authors declare no conflict of interest.

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