What do we know about effective CPD for developing science teachers' pedagogical content knowledge?

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While a great deal of research has been conducted into pedagogical content knowledge (PCK), much of that research to date has focussed on efforts to define, describe or measure it. Little of this research has focussed on ways of explicitly promoting PCK, and rarely in the context of professional development programs. One reason for this situation may be because PCK research is still in its "formative phase" (Abell, 2007) in terms of developing a robust understanding of what constitutes PCK and how it develops. At the same time, it is clear that the construct of PCK offers much that is worthwhile in promoting the development of teachers' professional knowledge and practice in facilitating student learning and understanding in science. This paper summarises research on PCK and discusses implications of that research in the context of continuing professional development (CPD) of science teachers. In particular, the paper considers implications from research conducted by the authors on potentially effective approaches to the development of science teachers' PCK, and more generally, in better valuing teachers' professional knowledge of practice and creating a vision for their ongoing professional learning.

Keywords: pedagogical content knowledge, science teachers, professional learning, professional knowledge.

There have been longstanding calls for change to how science is taught in schools (Russell & Martin, 2007). This situation has resulted in an array of responses aimed at changing teachers' practices so that more effective student learning/interest in science might be promoted. While the aim of such professional development activities has been to promote more effective teaching practice that, in turn might lead to improvements in students' understanding and/or appreciation of science, it is clear that such approaches have done little to change teachers' practices in any lasting way. One reason for this lack of change is due to the fact that "teaching practices are far more stable (Sarason, 1996) than those who call for change (see Handelsman et al., 2004) seem to realise" (Russell & Martin, 2007, p. 1152).

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Moreover, the ways in which professional development activities have typically been organised have contributed to this situation. Traditional notions of professional development are often interpreted as the supply of pre-packaged knowledge that is distributed to teachers in easily digestible 'bite-sized pieces'. Such approaches have positioned teachers as passive receivers of knowledge whereby they are expected to attend a 'PD day' in order to return to school to implement the PD ideas in their own practice. Although it is not often described that way in the literature, it is very much akin to a training model of development. More recently, the complex nature of change and the central role of the teacher in changing practice has been better recognised and programmes of professional development are now beginning to attend to these features, for instance, in making connections between teachers' own contexts and their learning needs (Garet et al., 2001; Hewson, 2007).

An important feature of changing views of professional development is in recognising teachers' "central key role" (Hewson, 2007) in constructing their own professional knowledge, and recognising and valuing the range of experiences, skills and knowledge that teachers bring to their learning. In his review of Science teachers' professional development Hewson noted, "What teachers do not do is a formulaic following of rules, but nuanced professional practice in which teachers constantly make important decisions and judgements in how they interact with their students to facilitate their learning" (Hewson, 2007, p. 1180). The notion of teacher as pedagogical decision maker within a specific context has come to be recognised as a vital centrepiece to new understandings of professional development.

It has also been long been recognized that teachers' knowledge of practice is largely tacit (Clark & Peterson, 1986; Richardson, 1996). Teachers are not used to articulating their knowledge of practice and typically, know more than they can say about what they do. Some of the tacit features of teaching include such things as: the reasons for approaching teaching in a particular way; knowledge of teaching procedures and their influence on students' learning; the ability to interpret teaching situations in different ways; and, ways of recognising and responding to student learning difficulties, to name just a few. These (and many more) aspects comprise teachers' professional knowledge of practice (see for example, Loughran, 2010). However, because many of these features are tacit or implicit within practice they are not always obvious to teachers themselves and therefore are not central to the ways in which teachers talk about the complex work of teaching and learning. This problem is exacerbated by a lack of shared language or structure to adequately discuss that knowledge (Carter, 1993). This means that what might be described as their professional knowledge of practice is often neither recognised nor seriously valued by teachers - even though making the tacit explicit offers possibilities for developing new insights into practice, individually as well as across the profession.

Re-imagining traditional notions of professional development to create a focus on professional learning puts teachers forward as actively involved in exploring their individual experiences and contexts and "becoming articulate about what they have learnt" (Lieberman, 1995, p. 591). Conceptualised in this way, Professional Learning involves the sharing of insights about teaching and learning between teachers in order to gain a sense of professional control and ownership over their learning, and concomitantly, a responsibility for the learning and teaching environment that they actively create in their classes. We would therefore argue that an emphasis on professional learning is important for empowering teachers through valuing their voices and perspectives (Gore & Gitlin, 2004); a process that is now recognized as developing throughout their whole career (Feimen-Nemser, 2001).

Munby et al. (2001), in their review of *Teachers' knowledge and how it develops*, drew attention to a basic tension within the research literature on teachers' knowledge that emerged from "different views of what counts as professional knowledge and even how to conceptualize [that] knowledge" (p. 878). This tension is manifest in the commonly reported 'theory-practice divide' that stereotypes teachers' knowledge as experiential and practical, and knowledge produced by academic researchers as general propositions and abstract theories. Such a dichotomous perception of knowledge types has reduced the usefulness of each form in the work of teaching and created an unspoken tension between teachers and academics. Recognising the importance of highlighting and promoting teachers' professional knowledge, Shulman's (1987) views of teacher knowledge focused attention on understanding not only what such knowledge might be but also how it might be developed. He did so, in part, through introducing the construct of Pedagogical Content Knowledge (PCK).

Pedagogical content knowledge

Shulman (1986, 1987) proposed that teachers' professional knowledge is comprised of a variety of categories, with one of the categories being "pedagogical content knowledge". Shulman conceptualised PCK as including "the most powerful analogies, illustrations, examples, explanations and demonstrations – in a word, the most powerful ways of representing and formulating the subject that makes it comprehensible for others" (1986, p. 9). In advancing the notion of PCK, Shulman drew attention to a unique and specialised form of teacher knowledge, that is, "the category [of teacher knowledge] most likely to distinguish the understanding of the content specialist from that of the pedagogue" (1987, p. 8).

Shulman asserted that teachers needed strong PCK to be the best possible teachers in order to structure the content of their lessons, to choose or develop specific representations or analogies, to understand and anticipate particular preconceptions or learning difficulties of their students, and so on. Viewed in this way, pedagogical content knowledge is a category of teachers' professional knowledge that is fundamental to facilitating learning of science content knowledge in a comprehensible form by learners.

When Shulman introduced the notion of PCK to the educational community, it was particularly appealing to academics and generated an extensive research agenda. However, the outcomes of this research tended to speak more to academic researchers than to teachers who are surely not only the producers of such knowledge, but also important end users. Although PCK offers opportunities to explore interesting ideas about that which successful teachers know in order to teach in ways that achieve student understanding, its general "fuzziness" (Marks, 1990), has meant that that which is searched for and uncovered is variable.

What much of the research on PCK suggests then is that interest in the construct is not necessarily linked with finding ways of helping teachers (whether pre-service, beginning or experienced) to improve their practice. Rather, much time and energy has been expended evaluating PCK as opposed to exploring concrete examples of how teachers teach particular content topics in particular ways that promote understanding (Loughran, Mulhall, & Berry, 2004). Therefore, unfortunately, PCK has not been developed through the research literature in ways that necessarily directly correlate with enhancing the practice of science teaching. Nor has PCK research been developed in ways that might encourage the construct to be widely used by teachers as a central aspect of their practice; a crucial issue in making the tacit explicit and leading to a purposeful refining of one's expertise i.e., professional learning. This point has been highlighted in the work of Van Driel et al. (1998) who concluded that research on science teachers' PCK should enable useful generalizations to be made. Despite these few instances of generalizability, literature of topic specific PCK that might be informative and applicable in the work of science teachers is largely lacking. Reasons for the sparse offerings of topic specific PCK may be related to the approach of researchers in this area.

By and large, researchers have tended to: compare and contrast particular aspects of PCK of individual teachers (Magnusson & Krajcik, 1993, heat energy and temperature) and of groups of teachers (Clermont, Borko, & Krajcik, 1994, density and air pressure); use case studies of novice and/or practising teachers to explore aspects of their topic specific PCK (Geddis, Onslow, Beynon, & Oesch, 1993, isotopes); and, to explore the effect on science teachers' topic specific PCK of programs that relied on the researchers' own PCK in that particular content area (Parker & Heywood, 2000, forces in floating and sinking). Hence, building up strong portrayals of what PCK in particular content areas might look like, and how it might be enacted in practice, has not been a common research agenda (let alone how PCK might effectively be developed in pre-service or continuing teacher education).

Given the value to teachers of some form of generalization about topic specific PCK it is somewhat disappointing that research efforts have not yet provided detailed overviews of successful teachers' PCK so that some overarching and meaningful synthesis might be available for others to consider. One interesting exception though is the work of Van Driel et al. (1998) who offered descriptions of what teachers know and do to help students understand the dynamic nature of chemical equilibrium. At the heart of this concern about the research into PCK and its applicability in the work of teachers is of course teachers themselves. One of the difficulties is that since this specialized form of professional knowledge is embedded in individual teachers' classroom practice (Padilla et al., 2008) it is rarely articulated by teachers themselves or within the teaching community of practice, as noted earlier in this paper.

Although Shulman's notion of PCK has created many and varied responses it has, nonetheless, become a way of understanding the complex relationship between teaching, learning and content that underpins the professional knowledge of expert science teachers. For this amalgam of pedagogy and science content understanding to be foundational to a vision for the development of experienced teachers' views of their own professional learning, PCK must be concrete and clear so that it can be interrogated and better understood as a way of valuing and directing their own professional knowledge development. However, as the literature continually demonstrates, making PCK concrete has been a major problem.

CoRe and PaPeRs: a framework for representing concrete examples of PCK

Over the past years we (authors) have been involved in a longitudinal research project that has sought to address the issues discussed above through efforts to capture the PCK of expert science teachers and to explore how PCK might be portrayed in ways that are meaningful and applicable for teachers' practice. In essence our research has been designed in order to help demonstrate the value and importance of such knowledge to science teachers (see Loughran, Milroy, Berry, Gunstone & Mulhall, 2001; Loughran, Mulhall & Berry, 2004; Loughran, Berry & Mulhall, 2006). Our research approach was based on interviews with experienced high school science teachers about how and why they taught particular science content to their students in a particular way (i.e., what knowledge of teaching, learning and specific content influenced their pedagogy) to promote student understanding. In so doing, we were attempting to help make the tacit nature of expert science teachers' practice explicit. Over time, and through experimenting with different formats and approaches, we came to develop particular representations called CoRes (Content Representations) and PaP-eRs (Pedagogical and Professional-experience Repertoires) that were designed to capture and portray concrete examples of PCK. A summary description of these representations follows, and an example of a CoRe and PaP-eR are included as appendices.

CoRes represent conceptualisations of the collective PCK of expert teachers around a specific science topic, including "the key content ideas, known alternative conceptions, insightful ways of testing for understanding, known areas of confusion, and ways of framing ideas to support student learning" (Loughran, Mulhall & Berry, 2008, p. 1305) that are encapsulated as a set of prompts in the left hand column of the CoRe (see, for example, Appendix 1, column 1). CoRes attempt to portray holistic overviews of teachers' PCK related to the teaching of a particular science topic (e.g., chemical reactions) to make the tacit nature of this expert PCK explicit to others. Importantly, a CoRe is not intended to represent a prescription of what to teach, or the 'best' or 'only' ways to teach a topic, rather it offers a basis which can be added to or changed as further insights are gained or clarified. Also, it is not intended that there is one CoRe for each topic. Different groups of teachers may develop different CoRes for the same topic, as factors such as experience and context (e.g., curriculum, target group of students), invariably influence teachers' understandings of, and actions in, practice.

CoRes are accompanied by *Pa-PeRs*; descriptions of how specific aspects of a topic aligned to the CoRe have been taught by expert teachers (see Appendix 2 for an example of a PaP-eR.) PaP-eRs are narrative accounts designed to illustrate specific instances of that PCK in action. PaP-eRs include a variety of narrative types, for example a dialogue between two teachers exploring their approach to the teaching of particular content and students' responses to it, a teacher's annotated curriculum document, or a student's perspective of a teaching/learning situation. The function of PaP-eRs is to give insight into the various interacting elements that comprise a teacher's PCK (such as subject matter, known student difficulties, teaching approaches) and make explicit the teacher/s' pedagogical reasoning in a specific situation.

A CoRe(s) and its associated PaP-eRs together comprise a Resource Folio for a given content area (e.g., forces). A Resource Folio is therefore a collection of two kinds of complementary representations that are intended to portray the PCK as developed and articulated by a given group of science teachers. In some cases this portrayal has been constructed as teachers' collective understandings (more common in the CoRe) and in other cases, as individual illustrations of specific practice (more common in PaP-eRs). Therefore, Resource Folios are intended to begin to address the problem of the theory-practice gap by offering generalisable instances of teachers' PCK about teaching of particular science content (while still being complex and quite specific) and offer other science teachers new and valuable ways of accessing that (typically tacit) aspect of knowledge of teaching.

The remainder of this paper discusses insights and implications of our CoRe and PaP-eRs approach for promoting the professional learning of science teachers and, more generally, in building and valuing teachers' professional knowledge of practice and a creating vision for their ongoing professional learning.

Building and promoting teachers' PCK through professional learning

In striving to develop Resource Folios we found ourselves both researching and workshopping ideas of PCK with experienced science teachers. On the one hand, our research uncovered interesting issues about the nature of PCK while on the other, it also brought to the surface a wealth of previously untapped knowledge of science teaching and learning for many of the science teacher participants with whom we were working.

Through our research, it became obvious to us that science teachers appreciated the opportunity to pursue understandings of PCK as they began to recognize and respond to the various alternative approaches to enhancing students' understanding of particular science topics and concepts. As they unpacked their own and their colleagues' knowledge and practice of science teaching, the strength of their own professional learning was constantly being highlighted which helped to build a sense of confidence in shaping their views of the nature and expectations of teaching.

Through this process of exploring science teachers' PCK, the complexity of such knowledge as well as the rich variation that contributed to a recognition of the skills and expertise so fundamental to good science teaching and learning continually emerged. The value then, in encouraging science teachers to use the ideas, prompts, structures and organisation of CoRes and PaP-eRs, we suggest, creates an impetus for using this approach as a professional learning tool for science teachers more generally.

As noted earlier, it is difficult for individual science teachers to recognize how their understanding of specific content has changed from the time they first started teaching. Yet being able to explain how one's understanding of particular subject matter content has changed and developed offers insights into how one's professional knowledge and practice may have been refined over time. For example, how one came to understand why a particular concept was difficult for students to grasp can be a catalyst for teaching in ways that better helps students to learn how to overcome these difficulties. Such teaching is clearly very different, much more skilful and indeed more specialized and sophisticated than simply presenting propositional knowledge as constituent parts of the given subject matter content.

We recognised that as science teachers used the ideas, prompts, structures and organisation of CoRe and/or PaP-eRs, they were concomitantly exploring how their understanding of practice had changed and developed, the factors that influenced that development and, how teaching particular content altered their understanding of the concepts over time. Doing so also leads to possibilities to link that knowledge and the subsequent teaching approach in ways that makes it much more explicit for themselves and others. In this way, discussions of science teaching using a CoRe and PaP-eRs approach leads to a major shift in that which is typically done through the common sharing of activities and ideas, toward richer explanations of content related pedagogy. It also highlights the underpinning pedagogical reasoning because it is the link to these deeper understandings of both subject matter content and pedagogy that, when combined, are crucial to understanding the amalgam that is PCK.

Workshopping the development of a CoRe and/or PaP-eRs is one approach that can be used to help teachers think about, and share with others, their knowledge about how to teach particular science subject matter. For example, in science faculty meetings, working through existing topics in the curriculum by attempting to populate a blank CoRe offers a very different way of thinking about the nature of the content to be taught than is common in many curriculum documents and syllabi. The notion of Big Ideas and the prompts in the left hand column helps to unpack exemplary practice in new and different ways through the lens of PCK. It also helps to make clear how important PCK can be in addressing the tendency to oversimplify complex subject matter as opposed to teasing out the central concepts and the associated implications for teaching and learning.

We have seen that using a CoRe and PaP-eRs approach as a way of reconsidering practice can help science teachers to address some of the teaching and learning issues created through subject specialisation, (i.e., the difference in content familiarity between, for example, a physics specialist and a biology specialist). The idea underpinning this issue was identified by one of the science teacher research participants who explained, "Knowing the content is extremely important but knowing how to teach the content to particular students is also extremely important. It is necessary for me to have a large repertoire of various ideas (or different ways of teaching the same idea) so that students learn/understand the content". We see this type of response as illustrative of the fact that high quality science teaching is enmeshed within the notion of PCK. Therefore, encouraging science teachers to find ways of making their PCK explicit matters if high quality practice is to not only be affirmed, but also more carefully analysed and understood, across different subject area specializations, and effectively developed throughout a teacher's career (a tangible demonstration of professional learning).

As we have pursued our research agenda we have come to understand that the science teachers we have worked with have in fact recognised important insights into their own practice and experienced a genuine sense of their own professional learning. This professional learning has been evident in the manner in which teachers have negotiated a professional language of practice through which to share their knowledge of teaching as well as the subtleties of their constructions and understandings of particular science content knowledge. In essence, through better valuing high quality science teaching, by documenting, exploring and analysing such practice, we believe that PCK (as conceptualized through a CoRe and PaP-eRs approach) offers science teachers new and more meaningful ways of learning about teaching particular subject matter content. And, that this occurs at not only an individual and personal level in respect to one's own practice, but also at a collective level by creating an expectation for sharing PCK within the profession itself.

An interesting issue that has emerged for us as we have worked with teachers in this approach to capturing and portraying PCK is linked to the notion that while we, as researchers, value the idea of science teachers' professional knowledge and have endeavoured to develop meaningful ways of explicitly sharing that knowledge through representations such as CoRes and Pap-eRs, the value that teachers see in their experiences of working with these tools tends to focus more on their learning through the processes of discussion around their creation, compared with actually making the end product/s themselves. In fact, we have found that teachers typically have a rather limited interest in the end product/s (particularly PaP-eRs) beyond serving as a resource for ideas that link with their own situations and needs. This raises a paradox: teachers don't want to make the product but quite like the process of being involved in making it; and they appreciate having the product to adjust and adapt in order to take ideas from and work with in ways that suit their needs. We would argue that it is this type of paradox that leads to the much maligned theory-practice gap perspectives on teaching that so often dominate debate about that which matters in and for practice.

Academics tend to seek understandings of knowledge of practice that requires a perspective in terms of development and conceptualization that is sometimes at odds with the concrete and immediate demands of classroom practice. PCK is a case in point. PCK is an abstract construct that is seductive to academics but, to date, has offered little advice or practical applications to teachers. Although we developed Resource Folios (CoRe and PaP-eRs) as a way of capturing and portraying PCK, teachers interpreted this work in terms of its implementable value in their practice. That meant that the ideas for practice derived from the CoRes and PaP-eRs products mattered more to them than the construct underpinning their conceptualization. Recognizing and responding to this situation is what we are now arguing is important in differentiating between professional learning and professional development.

Typically, research outcomes (such as that of CoRes and PaP-eRs) might be packaged up for science teachers who would then have it imposed upon them as ‘the way of developing their PCK’ or ‘enhancing their science teaching’. That would mean that they would typically experience a professional development program designed to teach them how to develop and use CoRes and PaP-eRs. However, as we are attempting to argue in this paper, by adopting a professional learning approach, working through the process and working with the product (rather than necessarily becoming expert at making it) is what really makes a difference for teachers’ understandings of their *own* practice and *their* students’ learning. In so doing, they are able to adapt and adjust a CoRe and PaP-eRs approach to suit their context and to develop their science pedagogy in ways that are responsive to their needs. That is a crucial aspect of responding to Sarason’s (1990) lament about the inevitable failure of change in schools and, we suggest, offers real possibilities for positive developments in the way teachers’ work might be understood – by themselves and the educational bureaucracies that attempt to direct their work.

Conclusion

In reflecting on PCK research in science education, Abell (2008) questioned whether PCK is still a useful construct 20 years after its introduction by Shulman. She convincingly gave an affirmative answer to this question stating, “We still do not know enough about what PCK science teachers have, how they come to have it, or what they do with it” (p. 1413). Abell highlighted a range of research areas and questions for further study using PCK as a theoretical framework. These areas include examining PCK across different grade levels, career stages, disciplines and topics; investigating the quality of teachers' PCK in addition to measuring the amount of PCK; understanding more about PCK development, particularly at critical points in a teacher's career, and generating models of PCK development; and, the need for systematic, long term programmes of study.

As we have outlined in this paper, adopting a professional learning stance to working with teachers is crucial to creating new and engaging ways for teachers to be able to take more control over their careers and the very nature of their professional knowledge. PCK is an academic construct that when viewed through the lens of CoRes and PaP-eRs allows the theory-practice gap to be bridged in innovative and exciting ways and offers teachers an invitation to take more control of that which they might value in relation to their knowledge of practice.

When we set out to study PCK through our work with expert science teachers, we were concerned to document and portray their professional knowledge in ways that might be useful and applicable in their practice, and offer insights and be useable by others. Articulating what expert science teachers know and are able to do quickly emerged as a catalyst in pursuing our aims and, for those teachers with whom we worked, helped them to make the tacit explicit in ways that developed their understanding and valuing of their professional knowledge.

In reflecting on our learning from a CoRe and PaP-eRs approach to documenting and portraying science teachers' PCK, we have come to better understand the nature of teachers' professional learning and to recognize the value of being responsive to their needs and concerns rather than focusing solely on the aims of the research project. We would argue that although it seems simple and obvious, it is that fundamental shift in understanding that matters most (but is frequently overlooked) if we are to use research findings in meaningful ways to support the development of richer understandings of science teaching. Ultimately, in so doing, theory and practice can work together to create genuine opportunities for developing and sharing knowledge of practice in ways that can be used by teachers and therefore lead to real change in science pedagogy in schools. In so doing, students' learning of science might be enhanced, and that surely, is the goal of this work.

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APPENDIX 1: CoRe for Particle Theory

Introduction: ***This table offers some of the range of ideas that might be covered in teaching Year 7 –9 Science students on the topic of* Particle Theory*. The list of important science ideas/concepts are not designed to imply that they are the 'only' or the 'correct' ideas/concepts for this topic. They are, however, those important science ideas/concepts that teachers in this project suggested and discussed as pertaining to* Particle Theory.**

	IMPORTANT SCIENCE IDEAS/CONCEPTS						
1. What you intend the <u>students</u> to learn about this idea.	**A.** That matter is made up of small bits that are called particles.	**B.** That there is empty space between particles.	**C.** That particles are moving (their speed is changed by temperature) and that they appear in a certain arrangement.	**D.** That particles of different substances are different from one another.	**E.** That there are different kinds of particles that, when joined, are different again. There are different 'smallest bits'.	**F.** That there is conservation of matter. Particles don't disappear or get created, rather, their arrangements change.	**G.** That the concept of a model is used to explain the things we observe.
2. Why it is important for students to know this.	Because it helps to explain the behavior of everyday things e.g. diffusion.	Because it explains the ability to compress things and helps to explain events such as expansion and dissolving.	Because it explains what happens in phase changes, e.g. the need to contain gases is evidence the particles are moving.	Because it explains the observable behaviors of different substances.	Because it explains why there are a limited number of elements, but many different kinds of compounds. It also accounts for the concept of atoms and molecules.	Because in any reaction involving matter, all of that matter must be able to accounted for.	Because the use of models links to important ideas about the way we explore and express views about the nature of science, e.g. the particle theory was constructed rather than discovered.
3. What else <u>you</u> know about this idea (that you do not intend students to know yet).	Subatomic structure. Chemical reactions. Ions (links to electricity). Generalizations about properties of materials. More complicated models of matter. Links to diffusion and thermal properties of matter.				That the bits themselves are different when combined (e.g. ionic and molecular formation).		
4. Difficulties/ limitations connected with teaching this idea.	Particles are too small to see. The use of models is not necessary to comprehend science in every day life.	There is a big difference between macro (seen) and micro (unseen) levels, e.g. wood seems solid so it is hard to picture empty space between the 'wood' particles.	That macro properties are a result of micro arrangements is hard to understand. The term *state* implies that things are separate and fixed.		Students can come to think that molecules 'disassociate' in boiling water (the confusion between atoms and molecules).	Bits are rearranged to create a different substance from existing bits (integrity of particles).	

Difficulties/ limitations connected with teaching this idea (continued).	Substances ‘appear’ to disappear when dissolved. What holds particles together? Why don’t substances automatically become a gas?		It is difficult to imagine particles in a solid moving. There are problems with some representations of liquid, e.g. particles are often shown as being much further apart than they are in solids. ‘Melt’ and ‘dissolve’ are often used interchangeably in everyday life.				
5. Knowledge about students’ thinking which influences your teaching of this idea.	Many students will use a continuous model (despite former teaching).	The notion of ‘space’ is very difficult to think about – most students propose there is other ‘stuff’ between the particles. Students think that particles get bigger during expansion.	Students have commonly encountered states of matter but do not understand it in terms of particle movement. Students can be confused by the notion of melting and think a particular particle melts.	Students tend to internalize a model from textbooks that shows circles all of the same size.	Students use the terms molecule and atom without understanding concepts. They simply adopt the language.	Students believe that new stuff can appear.	
6. Other factors that influence your teaching of this idea.	Maturity – stage of psychological development, readiness to grapple with abstract ideas. Dealing with many different student conceptions at once. Knowledge of context (students’ and teacher’s). Using the term *phase* suggests the idea of a continuum and helps to address the difficulties associated with the term ‘state’.						

7. Teaching procedures (and particular reasons for using these to engage with this idea).	**Probes** of student understanding, e.g. students draw a flask containing air, then re-draw the same flask with some of the air removed. Probes promote student thinking and uncover individual's views of situations. **Analogies**: Use of analogies to draw parallel between new ideas and specific/similar situations. For example, although something may appear to be made up of one thing – like a pipe is made up of one piece of metal – it is really the combination of lots of small things. This can be analogous to a jar of sand. From a distance it looks like one thing, but up close you can see the individual grains of sand.	**POE** (Predict, - Observe, Explain) e.g. squashing syringe of air (ask students to predict the outcome based on different models of matter). **Mixing activities** e.g. methylated spirits and water or salt and water (the outcome can be explained by empty space between the bits). **Comparing models**.	**Translation activities** e.g. role-play, modeling, drawing. **Creative writing**. Compare pieces with & without misconceptions, i.e. share student's work around the class and encourage students' comments on aspects of understanding in them. **Using models & demonstrations**, e.g. a jar of marbles as model: packed tight to illustrate a solid; remove one & shake to demonstrate movement in a liquid. **Observation**: dry ice sublimating- what's happening?	**Mixing activities** - it can be helpful to model the mixing of different substances by, for example, using different sized balls for the mixing of water and methylated spirits.	POE (Predict, Observe, Explain) e.g. water boiling (this can create a need for different kinds of smallest bits). **Modeling with specific materials**, e.g. explore the possible combinations in new things.		

Teaching procedures **(and particular reasons for using these to engage with this idea) (continued).**	**Linking** activities: Behavior of everyday things, e.g. putting a marshmallow in a gas jar and changing the pressure so the behavior of the marshmallow is affected. It helps to illustrate the point that small bits move or act differently in response to changes in conditions. The marshmallow is good because it is an example something they are familiar with – it links to their everyday experience.						
8. Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Explaining thinking and defending views. Making predictions about new situations. Tracking one's own learning, e.g. "I used to think." Ask questions such as, "What is something that has been bothering you from yesterday's lesson?" Questions such as, "Explain why popcorn pops", "Why when popcorn is pierced does it not pop?", "Why can we smell onions being cooked when we are at a distance from them?", "Why does a syringe containing NO_2 appear darker when it is compressed?"		Concept Map using the terms: solid; liquid; gas; particles; air; nothing. Questions such as, "Explain why popcorn pops", "Why when popcorn is pierced does it not pop?", "Why can we smell onions being cooked when we are at a distance from them?", "Why does a syringe containing NO_2 appear darker when it is compressed?"	Questions such as, "Explain why popcorn pops", "Why when popcorn is pierced does it not pop?", "Why can we smell onions being cooked when we are at a distance from them?", "Why does a syringe containing NO_2 appear darker when it is compressed?"	Draw a picture to show what happens to water particles when water boils.		
	Put on your "Magic Glasses" (which are glasses that enable you to see the particles in substances) – What do you see? (i.e. discuss what might be seen through the magic glasses), OR, Draw what you see (then compare and discuss these drawings).						

APPENDIX 2: PaP-eR "Seeing things differently"

A PaP-eR on the Particle Model

Seeing things differently

Introduction

This PaP-eR illustrates how important the teacher's understanding of the content is in influencing how she approaches her teaching about the Particle Model of Matter. In this PaP-eR, the teaching unfolds over a number of lessons and is based on the view that understanding how a model can help to explain everyday phenomena requires continual revisiting and reinforcement with students. The PaP-eR closes with an illustration of how inherent contradictions in teaching resources need to be recognized and addressed in order to minimize their level of 'interference' in learning specific concepts and how important that is in teaching about models.

Rhonda is a Chemistry major with a commitment to making science meaningful for her students. She enjoys teaching about 'States of Matter' and has developed a number of important 'frames' for approaching the content so that her students will better grasp the ideas rather than simply learn how to 'parrot' the appropriate 'science' responses in a test.

Rhonda's framing in the interview – the content

At Year 7 level it really is only a very limited particle theory that I teach - I don't go into atomic structure in any serious way. I try to introduce the students to the idea that everything around them is not continuous but is made up of small particles that fit together. I don't try to give any detail about how they fit together but I do talk with them about the particles being roughly spherical objects that are very, very, very, very tiny.

I know that getting students to use a particle model is not going to fully happen: they will revert to a continuous model when they are pushed. But it is important to start moving them some way along the path – to get them to consider that there may be another way of looking at the things around us. The ideas of the particle model also need to be linked to what is happening during phase changes (melting, freezing etc.) and that link needs to be at the very tiny level rather than at the macroscopic level. So these two ideas influence how I approach the teaching.

It's important to continually remind yourself that particle theory at year 7 and 8 needs to be presented in helpful ways. I believe that maturity plays an important part in what students can actually grasp at a certain age. It's easy, as the teacher, to forget how conceptually difficult and conceptually abstract this topic is. It is an important topic to teach about though, because it's one of those building blocks of chemistry that you can build on in layers over the years in science classes rather than trying to do it all at once. It's conceptually meaty so I enjoy teaching it!

So what do I do? Well I suppose the first issue is helping the students to start thinking differently about what they're looking at. It's important to help them realize that although the things they are looking at appear to be made up of one thing – like a piece of pipe is made up of one piece of metal – you can break it down until it is made up of lots of small things combining together. A simple analogy is a jar of sand. From a distance it looks like one thing, but up close you can see the individual grains of sand.

From this, you can begin to explain the behavior of everyday things in terms of movements of particles. This is a big shift in thinking for students. Again, you can play with this idea by getting something like a marshmallow and putting it in a gas jar and changing the pressure so the behavior of the marshmallow is affected[1]. It helps to illustrate the point about small bits moving or acting differently in response to the conditions. The marshmallow is also good because it is an example of something they are familiar with - it links to their everyday experiences and that really matters. I've built up quite a few of these examples in my teaching over the years; it's good fun too.

The other idea to try and aim for is the idea of space, nothing, between the particles: it's really hard. One way of helping to address this is by using the demonstration of mixing water and methylated spirits. You add equal volumes of them together, if each liquid is one big block of water or metho, then the volume should be double, but it isn't so - how come? That helps to make the point about the spaces, so that in this case things can fit between the spaces.

So overall I suppose really I'm only concentrating on three things:

1. Things are made up of tiny little bits
2. There is space between the tiny little bits
3. You can use the model to explain phase changes, etc.

But I don't mean to make it sound as simple as that because really what I do is respond to what's happening in the class. Last year I went 'down the density path' even though I wasn't intending to. But, because it was students' questions that took us there, I let it go on and followed it for longer. The point really is that the use of the particle model is a *way of thinking* and it's something that the students have to be reminded of so that they think about things from that perspective, rather than reverting to their continuous model perspective.

Rhonda's framing in the classroom – "imagine"

The unit starts with Rhonda asking the students to imagine that they have been shrunk down so that they are very tiny and then they fall into a droplet of water on the lab bench. They have to imagine what the droplet looks like from the inside, and then they write a short adventure story and draw a picture of what they can see. The students' pictures show a range of responses, a handful contain dots but most of these are explained as being "the dirt and stuff in the water". Through a number of activities and discussions over several lessons Rhonda introduces the class to the content ideas that she outlined in the interview.

Then Rhonda gets all of the students to make a pair of cardboard glasses. They decorate these in whatever way they wish. She encourages them to use their imagination in designing their "magic glasses". Putting the glasses on is a cue for them to think in terms of particles.

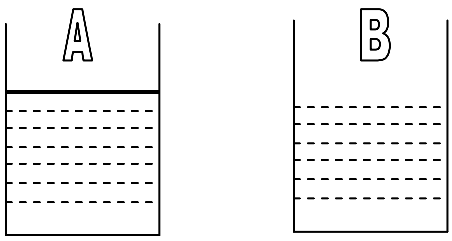
> "One of the problems I find is that they easily revert back to a continuous model, so putting them in a situation where they wear the glasses and look at something helps them to better understand how the model works to explain what they are seeing. You can get them to put them on at different times throughout the unit and it helps them make the transition to particle model thinking."

In one lesson Rhonda fries onions on the front bench in the laboratory. The students call out from their seats when they start to smell the onions. They track the progress of the smell towards the back of the lab. Rhonda asks them to put on their glasses and look around the room. Can they explain the smell through particle theory? She asks them to think about when they mixed the methylated spirits and water together. With their glasses on they need to describe what is happening as the two liquids combine.

Rhonda shows the class a marshmallow inside a gas jar. By reducing the air pressure in the jar she causes the marshmallow to swell up and then eventually collapse. She asks the students to think about the air inside the marshmallow. If they could 'see' it through their glasses how could they explain what was happening to the marshmallow?

The class revisits their shrinking adventure in the drop of water. Rhonda asks them to think carefully and draw what the inside of a drop of water would be like with the 'magic glasses' on. Later in the unit, Rhonda will introduce a new activity based around the way that textbooks represent water as a liquid.

[1] The behavior is described later.



> "If you look at the pictures in books they often show liquid as particles but the liquid is capped by a continuous line (diagram A), which inadvertently undermines what we're trying to get students to understand by these representations of a particulate model. The students end up thinking that the water is the clear stuff and the particles are just dots in the water."

Rhonda decides that this year she will ask the class to look at a beaker of water through their glasses and to decide which of the two diagrams best represents water and why they think so.

"If the students are wearing their glasses when they look at a beaker of water they should see diagram B rather than diagram A. And be able to explain why they do!"