DOCUMENT RESUME

ED 442 631		SE 063 550

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TITLE	Documenting Science Teachers' Pedagogical Content Knowledge through PaP-eRs.
SPONS AGENCY	Australian Research Council.
PUB DATE	2000-04-00
NOTE	27p.; Paper presented at the Annual Meeting of the American Educational Research Association (New Orleans, LA, April 24-28, 2000).
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Documentation; Elementary Secondary Education; Foreign Countries; *Knowledge Base for Teaching; *Pedagogical Content Knowledge; Research Problems; *Science Teachers; Teacher Education; Teacher Effectiveness; *Teaching Skills
IDENTIFIERS	Australia

ABSTRACT

In coming to better value teachers' knowledge and practice, there is a need to be able to articulate and document what teachers know and are able to do. This is central in coming to understand pedagogical content knowledge (PCK). This paper presents a working understanding of PCK as it has emerged through a research project and describes the development of a method of documenting PCK, the Pedagogical and Professional-experience repertoire (PaP-eR). (Contains 14 references.) (WRM)

Documenting Science Teachers' Pedagogical Content Knowledge through PaP-eRs

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The Research reported in this paper was supported by an Australian Research Council Large Grant (Loughran and Gunstone, 1999).

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Introduction

Shulman's (1986; 1987) notion of Pedagogical content knowledge (PCK) has long been an accepted academic construct and as such, it has been closely linked to views associated with the professional knowledge base of teachers. In many cases, the view of PCK is that for (in this case) science teachers, their PCK is bound up – and recognisable - in their approach to teaching particular content. The amalgam between their pedagogy and their understanding of content is thought to be the foundation of their PCK so that their PCK influences their teaching in ways that will best engender students' learning science 'for understanding'.

Understanding how science teachers organize and conceptualize their teaching in order to enhance student understanding of the concepts being taught is a field of research which probes the very essence of teaching itself and may well be described in terms of the search for the expert pedagogue (Berliner, 1988). "What does a science teacher consider when determining how to teach a particular concept?" "Why does the science teacher use teaching strategies for some concepts and not others?" "What reasoning underpins the science teacher's practice?" "How does a science teacher's understanding of learning influence their pedagogical reasoning and thinking?" These questions are at the heart of understanding the specialist knowledge of science teaching and are important in determining how knowledge about science teaching is developed and refined. We have been attempting to capture this knowledge through an *adaptation* of the use of 'cases' (Shulman, 1992; Mitchell and Mitchell, 1997).

In this project we have been attempting to address many of the questions germane to the codification of pedagogical content knowledge of science teachers, and hence to help to demonstrate the value and importance of such knowledge.

In this paper we will not pursue the development of arguments surrounding PCK in detail (see Loughran et al, 2000 for elaboration of these arguments), rather we will present our working understanding of PCK as it has emerged through our research and how that has influenced our approach to developing ways of articulating and documenting science teachers' PCK for others.

Our developing view of science teachers' Pedagogical Content Knowledge (PCK) has been refined through our attempts to uncover and document that which we initially conceived to be a recognisable and articulable body of knowledge that experienced science teachers possessed.

Loughran, Gunstone, Berry, Milroy and Mulhall. A paper presented at the annual meeting of American Educational Research Association. New Orleans. April, 2000.

It has become increasingly clear to us through our research that although PCK may well exist, it is not quite so straightforward a process to recognise or articulate as we originally expected. There are numerous reasons for this realisation, but suffice to say that PCK is not confined to one lesson or teaching experience, it may well extend over a considerable period of time (a unit of work for example). It is also clear that PCK is a complex notion and that science teachers themselves do not use a language that includes (nor necessarily resembles) the construct of PCK as much of their knowledge of practice is tacit and therefore difficult for them to articulate. We also now better recognise that the development of PCK is closely tied to the changes in one's understanding of content and how that has been influenced by teaching that content – yet this is very difficult for teachers to reconstruct as the changes become incorporated into existing conceptions without easily distinguishing them as new or different.

Our research has now led us to contend that to "see" PCK is not to see PCK at all but rather to see a mixture of interacting elements which, when combined, help to give insights into PCK. However, as the mixture of elements invariably vary, so PCK itself is variable in that the different mixtures of elements influence the richness of the PCK and changes in any of the elements inevitably influences the nature of the PCK that is being portrayed. Some of these elements include: views of learning; views of teaching; understanding of content – how that understanding has developed and changed; knowledge and practice of "Children's Science/alternative conceptions"; time – teaching time/length of unit/unit of work; context – school, classroom, year level; understanding of students; views of scientific knowledge; pedagogical practice; decision making; reflection; and, explicit vs. tacit elements of knowledge of practice/beliefs/ideas.

With these elements in mind, the overlap of each clearly influences what the PCK actually looks like such that elements influence each other through the nature of their overlap, hence PCK is the amalgam of all in the mixtures available and presented. One other important factor is what we have termed the 'Destination'. By destination we mean how a teacher envisages where they want the content/concepts under consideration to lead in terms of conceptualisation for the learners, for it is this destination that influences the rich tapestry of PCK that is called upon by experienced science teachers to teach about the science with which they are involved.

In essence then, we would argue that no one element is PCK and that the nature of PCK is as a result of the different ways the elements can overlap and be portrayed, and this portrayal varies through the variations in the overlap of the elements.

In Search of PCK

Throughout this study we have slowly been developing ways of attempting to recognise and capture PCK. PCK, whilst being an exceptionally seductive academic construct, has proved to be quite elusive. Part of the difficulty associated with 'finding' PCK is embedded in the 'frame' (Schön, 1983; 1987) that researchers bring to the 'problem' and our framing has certainly been challenged (and has changed) throughout this project.

In the first instance, the notion of PCK was such that we envisaged finding expert science teachers who more than likely had well developed PCK, but were perhaps unable to personally articulate it. Hence, we thought we might be able to see PCK through such things as content specific teaching procedures (eg. role plays, laboratory work designed and implemented with particular purposes in mind (Hart et al, (in press), demonstrations etc.), through discussions with teachers about their teaching, through classroom observation, and other 'traditional' approaches to seeing 'knowledge through the practice' of experienced science teachers. However, our hopes were not realised as PCK was neither easy to see nor simple to articulate. Our method for recognising and documenting PCK then has emerged through insights derived from our attempts to 'capture' PCK.

Our first attempt at 'capturing' PCK was through interviewing experienced science teachers and attempting to 'unpack' their understanding of their approach to teaching a particular content area in science (eg. electricity, states of matter etc.). Although the science teachers we interviewed certainly had a very good working knowledge of their teaching, there were noticeable difficulties associated with the articulation of their knowledge about their practice. This was in part due to a lack of a common vocabulary about teaching and learning, and also because the need to make the tacit nature of their practice explicit was not a normal expectation of being a teacher; it is not a cultural norm of the profession.

Attempting to talk about teaching particular content in a particular way was not helpful for the interviewee as they tended to move across a range of content areas and hence shift focus and not concentrate on any one particular field, thus offering summative views of classroom practice rather than 'rich' pictures of content related pedagogy.

We pursued ways of uncovering an individual's PCK by asking them to consider why they taught a particular content in a particular way ie what knowledge of teaching, learning and specific content influenced their pedagogy. Through this process we came to see the importance of placing emphasis on the teacher's understanding of the content: how it had developed and changed; the factors that had influenced this development; how teaching the content had altered their understanding of the concepts.

In pursuing this line of questioning we were hoping to help recreate in the teacher's mind the way they had come to know the content and hence make the link between that knowledge and their teaching approach more explicit.

Throughout this process of individual interviews, there was also a notion of PCK as an 'isolatable' item, hence a recognisable data source. In working with expert science teachers, we were partly searching for the 'markers' or 'triggers' (Kadar, 1998) of their practice. In helping the teachers to articulate these points, we felt it would be possible to then map out their PCK in relation to the trigger that caused them to teach a concept in a particular way, hopefully also designed to enhance student understanding. In one sense, we were attempting to find identifiable instances where a concrete pedagogic action was employed for a particular reason in response to, for example, a learning difficulty, or situation, need, or known point of confusion in the content being taught. In reality, we were perhaps searching for individual instances of PCK, or individual lessons where PCK was being used. Although we had insights into teachers' use of teaching procedures, we did not feel as though we were particularly uncovering PCK.

Throughout the process of working with individual science teachers we did however see what we considered to be elements of PCK in action. It was the development of these small insights that led to the view of PCK outlined in the first section of this paper whereby we could see the overlap of a number of elements influencing in different ways the nature of the pedagogy of the individuals we were working with. Thus the understanding began to emerge that PCK was not 'an individual item' but a mixture of items that were not necessarily 'fixed' but varied with the context of the teaching and learning situation. More importantly, the nature of PCK varied with the situation even if the content was the same.

Through this development it became strikingly obvious why there was such a paucity of concrete examples of PCK in the literature.

As our project had two main aims (to capture PCK and to create representations that portrayed it to others), our earlier thoughts about writing cases of PCK now seemed less viable. We came to see that the 'case approach', although excellent for portraying teaching dilemmas, was no longer as appropriate for portraying PCK as we had initially envisaged. The divergence of elements that could comprise PCK could not be confined to a 'stereotypical' case approach, and, some of the examples of elements of PCK that we had uncovered were not 'cases' of practice but insights into particular instances, ideas, shaping factors and so on that impacted on the academic construct that was still unable to be fully recognised or explained in a coherent holisitic manner. We then realised that our portrayals could not be full pictures of PCK in action but rather insights that illustrated the 'richness' of experienced science teachers' pedagogy and professional experience through their repertoires of practice. Thus the development of what we have termed a PaP-eR (Pedagogical and Professional-experience repertoire).

Attempting to Portray PCK

As we have come to understand PCK, it is very difficult to offer an example that is a neat concrete package, able to be analysed and dissected or used as a blueprint for practice by others. For science teachers, as noted earlier, there is little opportunity, time or expectation to engage in discussions that helps them to develop the tacit knowledge of their professional experience into explicit, articulable forms to share across the profession. Rather, they share activities, teaching procedures and clever insights into teaching and learning that have implicit purposes in practice from which others can interpret the implied – but rarely stated – meanings which underpin the practice.

The two main aims of the project were: to 'uncover' PCK; and, to create representations that portrayed it to other teachers. The early attempts at documenting PCK using a 'case approach' were not as successful as we had initially envisaged. Our attempts at cases often lacked a dilemma or a 'hook' to bring the reader into the case. In reality, they more resembled a discussion of teaching or an example of a teaching procedure, the sharing of an interesting idea or even a lesson plan. In hindsight, it is not difficult to see why this was the situation. There is a great divergence of elements that we believe can be 'indicators' of PCK. Hence the examples of 'PCK in action' that we encountered were not always 'cases' of practice, but rather various insights or 'windows' into particular instances, ideas, shaping factors.

We offer the vignette (one of many we worked on) as an example of these early attempts in an effort to illustrate how what we thought we could 'see' in the situation was not so easy to portray to others. The vignette describes the 'goings-on' in this teacher's classroom and offers some hints about the content or context, but offers little insight into the decisions being made. The vignette is really the teacher's response to our attempts to explore the relationship between content and pedagogy but as the vignette shows, this is not an easy task. Through a dissection of the vignette 'Inertia' and exploring what we found to be lacking, we can now illustrate what we believe is needed in a representation of pedagogical content knowledge. The callout boxes accompanying this vignette flag some specific questions that a reader might ponder when considering how this teacher went about her teaching of inertia with this particular class and illustrates some of the complexities of the issues associated with attempting to portray teachers' PCK. The callout boxes could be seen as marking the 'gaps' that this account needs to illuminate in order to better 'hear' the teacher's thinking, prior to, during and even after the class, as well as more of the likely student responses. In addition to this, the account must also carry 'what it is about the content' that the teacher knows and brings to bear during the teaching so that it impacts on students' learning in the ways intended/anticipated. The callout boxes help to question aspects of the subject matter, decision-making, students' thinking and the underlying intentions related to making sense of the subject matter. Similarly, it is important that we 'hear' how students comment about, and react to, the details of the subject matter and the way it is covered.

Inertia

There are four factors that decide how I'm going to approach a certain topic:

1) *The age level of the student.*
2) *Their prior experience is incredibly important as it affects what they already know or think they know. For example the technique I use to cover a topic that the kids are very well versed in is different to what I use for something they know nothing about.*
3) *The interest of the students is crucial. If it's a topic that I'm supposed to cover because it's in the CSF (Curriculum and Standards Framework – syllabus guide) and they absolutely abhor it, well I cover it as quickly as possible and get on with something else. On the other hand if they're enjoying it very much I do lots of different activities.*
4) *The fourth factor is student ability.*

The level of these four factors determines the sort of things I do.

*In addition, my teacher training taught me the value of practical work and Socratic questioning which has been reinforced by my experiences as a teacher. Practical work enables students to find things out for themselves, which they enjoy. It also helps them to remember content better. Socratic questioning encourages students to think. I make as few statements as possible in a lesson, I ask questions which prompt students to work out explanations for themselves. I feel that if a student can explain something to someone else they **have** grasped the knowledge.*

So my general approach to teaching is to include as much practical work as possible with the students working in small groups and working out their own explanations for what is happening. During a lesson I move around monitoring each group's progress and asking questions if necessary. Because the class sizes are 24 it is relatively easy for me to get around to each group during a lesson and provide help if necessary. It would be impossible if there were 30 in the class.

The topic of Inertia forms part of the Year 10 Science program at our school. When I first taught this topic I expected students would grasp the concept of inertia fairly easily. They had all seen the TAC (Transport Accident Commission) advertisements on television which demonstrate what happens to the occupants of a car when the car is involved in a road accident. So my approach was to discuss the idea of inertia and relate it to these ads. Yet I found that when I gave them a set of exercises involving different scenarios of cars colliding many students would wrongly predict the occupants' movements. Since then I have discovered that the key to helping students understand inertia is to get them to actually do experiments which simulate cars with people in them crashing into objects. Then the students have no trouble with what-if scenarios.

I begin the topic by trying to assess their prior knowledge of inertia. I'll ask questions like, 'Who's seen the TAC ads?' and 'Does anyone know what that is called?' From the kind of responses that students give I assess how much they already know about inertia. This determines what I do next. If inertia seems to be a concept with which the students are very familiar, I get them to start on the experiments straightaway. On the other hand, if the word 'inertia' is not forthcoming from the students I'll ask more questions like, 'Who feels like just sitting there for a while?' and, 'What do you call that when you don't feel like moving?' Usually there are one or two students who have heard of the expression 'inertia' and I structure my questioning to encourage them to explain what it is. When I am steaching I always try to avoid making statements. I believe it is more valuable to ask questions that encourage students to explain things themselves. So I'll only introduce the word 'inertia' myself if students do not use the word in their responses. Eventually when I am satisfied that the students have at least a reasonable idea of what inertia is, I set them the prac task.

> This is a most interesting start to talking about teaching. How much will these factors genuinely influence the teaching? How might we 'see' these in the teaching?

> It is interesting to ponder why 'content' is not a factor, or is it taken for granted by the teacher that it does matter?

> Views of learning are implicit in this statement, why does this account not explore these in more detail?

> Does practical work serve a purpose beyond being enjoyable for students? What is the nature of what they work out forthemselves?

> Why? What understanding of inertia influences this statement? How has her understanding developed/changed? Modelling first and then asking questions might be an important change

> This account does not make the link between these two clear. What did she discover?

> Is this assessing prior knowledge? Examples of students' responses would be very helpful here.

> Is it really only familiarity with the term inertia that is being

The task is to simulate 10 different collisions involving cars and to explore what happens to the cars and their occupants in these situations. I tell them they can use laboratory trolleys for cars and make dummies from plasticine to represent people. Because it affects the results and also because it makes students feel their experiments are more scientifically accurate, I get the students to shape their dummies in the same proportions as a human. If we had time I would get the students to actually work out these proportions for themselves. Usually though I ask them to guess what the various proportions are and then show them a list which has the correct values.

As the students are in Year 10, I expect them to make their own decisions about what measurements to make and how they will make them. I merely tell them that they should make detailed Year 10 results, which, from our work earlier in the year, they know means that diagrams etc should be recorded and measurements are sensible. If a group is struggling and says, 'I'm not sure how we should measure this', I might say, 'What would be sensible? If you were in a car that crashed, what might you see happen to the things in the car?' To which they might respond, 'Oh … distance! Distance might be good!' And then I would try to get them to explain to me or to each other why. If what they decide to measure is inappropriate, I say 'Maybe you need to rethink that'. I don't tell them, 'No that's wrong.' because I want them to figure this out for themselves.

Once all the groups have started their experiments a relative quiet descends on the room. I can tell that the students are really involved in the activity because there is none of the usual chatter about the latest movie or what they are doing this Saturday night. They behave as if they are enjoying interacting with the equipment and are treating their experiments seriously. They'll come up to me and say, 'Look at this Mrs D. The car moved 3cm but the person moved 5cm (say).' As I move around to the various groups I can see that each is recording sensible data which is precise and accurate. This is atypical and it is this which tells me that the activity is working (successful?).

Most students decide to measure distance because equipment for this is readily available. Time is also a possibility. All measurements are acceptable, even inappropriate ones, as long as they are sensible and intelligent. By this I mean that they have the right degree of accuracy and precision. This is where rounding off numbers correctly becomes an issue. A common error for students when using their calculators to find the averages of their measurements is to give too many decimal places in their answers. Rather than write rules on the board about significant figures, I find it more effective to carry a set of rulers with different degrees of precision around to each prac group while they are evaluating their data. When I come across a group who have recorded an average of say, 16.7451 cm, I say to them,

'Oh, that's really good. Show me the ruler that measured that.'

And they will point to the metre ruler:

'Oh it was this one'.

And I will say,

'What are these little marks?'
'Oh, they're just millimetres.'
'Did you measure to the millimetre?'
'Oh no, we just measured to the centimetre.'
'Oh, should we round?'
How come you measured to the centimetre and yet you gave this answer?

> Real classroom dialogue would be helpful here to illustrate the point. "Feel" like moving may be inappropriate, it implies choice.

> Is this an important element of the exercise that 'influences' the outcome? Is it a link with other concepts (mass for example)? This section could be important but it is unclear how constructing a plasticine dummy would help to improve the accuracy of the results.

> How is this linked to learning about inertia? Is this an important issue for the teacher/students or is it a matter of 'recording what the teacher really wants them to record?

> Does she ask them to rethink if they chose the correct quantity?

> It appears as though there is much more understanding and teacher interpretation about this situation than is apparent in the text. Why is it not better 'unpacked ' for the reader? How are these issues linked to the content?

> This is obviously an important issue for the teacher but is it necessary in this account for inertia? How does illustrating the teacher's ability to link students' skills across areas influence the reader's understanding of the situation?

'What do you think?'

And they say,

'Oh yeah because we didn't measure that precisely.'

When the students have completed the practical, I give them the set of exercises involving cars colliding in different ways that I mentioned before. Typically if the students have done the inertia practical they have no trouble predicting the motion of the people in a particular car and the sort of injuries they might sustain. If they haven't done the prac the students find it hard to imagine the effects of inertia. Actually seeing what happens to the plasticine person in a trolley when it gets hit gives them, enables them, to visualize what might happen in a car accident. The practical is a brilliant way of developing students' understanding of inertia.

There appears to be a lot of 'teacher understanding' in this explanation but little of it is made explicit for the reader. How is it that the practical can make such a difference to students' understanding? What does the teacher see in their learning that convinces her that the practical is so powerful and makes the students make such a shift in understanding?

But can the students translate the ideas to a new context? Is this an issue for the teacher?

Do the students see the practical as enhancing their understanding?

The vignette (above) begins to illustrate how difficult it is document PCK. We would argue that what is often offered as documentation of PCK lacks the ability to portray the diversity of ways that particular concepts and content are grasped by science teachers and consequently shape the manner of their teaching.

Science teachers' understanding of the content, their particular views of teaching and learning within a context, and the subtleties of their practice in response to the learning (and other) demands of their students are all insights into their PCK but may not, of themselves, be PCK.

We believe it is fair to assert that the vignette and the callout boxes illustrate that there are some important features of portrayal that are crucial in offering insights into PCK. These include:

- classroom reality (including a diversity of students' responses)
- teacher's thinking (about the content AND the responses from the students)
- students' thinking (the links they are/not making and why)
- 'what it is about the content' that shapes the teaching and learning and why

As our understanding of PCK has developed, we have realised that it is very difficult to offer a single example that is a neat concrete package, able to be analysed and dissected or used as a blueprint for practice by others (hence the lack of examples in the literature).

In grappling with these issues, we have come to the realisation that our initial conception of PCK being portrayed through Cases was flawed. Hence we have developed the notion of a PaP-eR (Pedagogical and Professional-experience Repertoire) as our way of addressing our perceived difficulties. A PaP-eR is 'of' a content area because it is the content that shapes the pedagogy, but it is not necessarily a concrete example of PCK in the way that a case may be an example of managing a dilemma such as students' questions (Fox, 1997) or the possibilities for using a new teaching procedure. However, the notion of a PaP-eR is not meant to exclude case methodology which itself may also be valuable in portraying some elements of PCK (see for example Ingvarson, et al., 1995; Kleinfeld, 1992), it is just that cases alone are not sufficient for the range of instances we have begun to recognise.

Constructing PaP-eRs

Our conception and development of PaP-eRs as a form for portraying PCK hinges on two important issues:

- PaP-eRs are 'of' a particular content area - and are therefore 'attached' to that content.
- One PaP-eR ***cannot alone carry PCK*** – a diversity of PaP-eRs helps to shed light on the different aspects of PCK.

If a representation of PCK is to help teachers to recognise, articulate and develop their understanding of that content, then clearly it must be based on an understanding of what it is about the content that the teacher knows (and has come to understand) in order to purposefully shape the pedagogy and the associated approach to student learning.

We therefore propose a central representation of content (but not that this be viewed as static or as the only/best/correct representation) that sets out and discusses the aspects of PCK 'most attached to that content' (such as, for example, an overview of the main ideas; knowledge of alternative conceptions; insightful ways of testing for understanding; known points of confusion; effective sequencing; and, important approaches to the framing of ideas). This we illustrate through Table 1.

It is crucial that we emphasise that this representation is what we have settled on at this stage as a methodology for accessing science teachers' understanding of the content. It is not ***the representation*** that must be accepted and followed by all. It is a necessary but incomplete generalization resulting from work with teachers. It is being used to help codify information so that the links between the representation and the PaP-eRs attached to that representation are meaningful and in accord with the perceived understanding of the particular content; it helps to make the complexity accessible and manageable, and is neither complete nor absolute. Similarly, as a methodology, it is also important to stress that all of the cells in the table do not/need not be 'filled in' and that the representation will vary in emphasis and understanding across different groups of science teachers.

Attached to this central representation are the PaP-eRs, with links to the aspects of this field that they 'bring to life' (see Table 1 and the two PaPe-Rs). Through our research we have come to see the value in putting this central representation together through the interaction of a group of teachers and researchers.

Science teachers' understanding of the content, their particular views of teaching and learning within a context, and the subtleties of their practice in response to the learning (and other) demands of their students are all insights into their PCK but are not, of themselves, PCK. A PaP-eR must be 'of' a content area: it must allow us to look inside a teaching/learning situation where it is the content that shapes the pedagogy. The PaP-eR's embedded questions (or other links) should help to connect the 'practice' seen, with the explicit body of knowledge about the content central to the particular representation. That link should illuminate the decisions underpinning the teacher's actions that are intended to help the learners make sense of the content.

The PaP-eRs are about teaching ***that*** content in ***that*** context and help to illustrate aspects of PCK. The more specific a PaP-eR is to a particular classroom (as opposed to a more generic, "This is how I always teach States of Matter"), the more the PaP-eR illuminates the important links between teaching and learning - this is brought about by inclusion of specific student responses and the particular actions by the teacher in light of those responses.

Including a collection of PaP-eRs attached to different areas of the content might also highlight some of the different blends of elements that jointly contribute to an individual's (or group of science teachers') PCK. Therefore, the overlap, the interplay, and the relationship between PaP-eRs in a content area is important in viewing the complex nature of PCK without any one PaP-eR being regarded as the nature of PCK itself. To illustrate this we offer the following central representation (Table 1) and two PaP-eRs on States of Matter.

Table 2: Central Representation Table to Accompany PaP-eRs on Particle Theory.

TOPIC: **Particle Theory**
YEAR LEVEL: 7 - 9

	IMPORTANT SCIENCE IDEAS / CONCEPTS						
What you intend the students to learn about this idea.	**A.** matter is made up of small bits (particles) $#	**B.** there is empty space between the particles	**C.** particles are moving and in a certain arrangement >> phase changes #	**D.** particles of different substances are different	**E.** different kinds of particles that, when joined, are different again ie. different 'smallest bits' #	**F.** conservation of matter: particles don't disappear or get created – they change	**G.** concept of a model to explain things we observe
Why it is important for students to know this.	Explaining the behaviour of everyday things (applies to whole topic) #$	Ability to compress things	Explains phase changes eg need to contain gases because of movement #$	explains behaviour of diff. substances	Explains why there are a limited number of elements, but many different kinds of compounds. Concepts of molecule & atom #	in any reaction involving matter must be able to account for all of the matter	concerned with ideas of nature of science but specifically particle theory is constructed rather than discovered
What else you know about this idea (that you don't intend students to know yet).	Subatomic structure Chemical reactions Ions (links to electricity) Generalisations about properties of materials (maybe) More complicated models Links to thermal properties of matter/diffusion				the bits themselves are different when combined (eg ions, change in subatomic arrangement)		
Difficulties/ limitations connected with teaching this idea.	Particles are too small to see. #$	big difference between macro (seen) and unseen eg. wood seems solid >> hard to picture empty space between particles.	macro properties are a result of micro arrangements. State implies separate and fixed while Phase gives idea of continuum. Difficult to imagine particles in a solid moving. #		stds.. can come to think molecules disassociate in boiling water #	bits are rearranged to create a different substance from existing bits (integrity of particles)	***CONTINUED OVER PAGE***

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Knowledge about students' thinking which influences your teaching of this idea.	Nearly all stds.. will use a continuous model (despite former teaching). #$	'space' hard to think about – most stds.. propose other 'stuff' between particles.	Stds.. Have commonly encountered states of matter but not understood it in terms of particle movement. #	stds.. tend to internalise a model from the text that shows circles all same size.	stds.. use terms molecule and atom without understanding concepts #	stds.. believe that new stuff can appear	

Other factors that influence your teaching of this idea.	Maturity – stage of psych development, readiness to grapple with abstract ideas. Dealing with many different student conceptions at once. Knowledge of context.						
Teaching strategies **(and particular reasons for using these to engage with this idea).**	Probe eg draw air removed from flask (promotes std. thinking; uncovers individual views). Analogies eg sand (represents small bits making up solid whole). $	POE eg syringe (asks stds.. to predict outcome based on different models of matter). Mixing activities eg meths and water / salt and water (outcome can be explained by empty space between bits). Comparing models.	Translation activities eg. Role-play, modelling, drawing. #$ #$	mixing activities (can model explanation of water & meths mixing using balls of different sizes)	*POE eg water boiling (creates need for different kinds of smallest bits).* Modelling with specific materials (explore possible combinations in new things). #		
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.						

Nb: $ indicates link to PaP-eR 1: Seeing things differently.

# indicates link to PaP-eR 2: What is the smallest bit?

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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. In this PaP-eR, the teaching unfolds over a number of lessons but 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 recognised and addressed in order to minimise the 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 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 (in Rhonda's voice)

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 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 them to 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 also need to be linked to what is happening during phase changes (melting, freezing etc.) and that link needs to be at the very small 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 you 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 and it helps you to build it in layers through science over the years 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 about what they're looking at differently. It's important to help them realise 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 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 behaviour 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 behaviour 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 and linking to their everyday experiences 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 their 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.

[1] The behaviour is described later.

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."

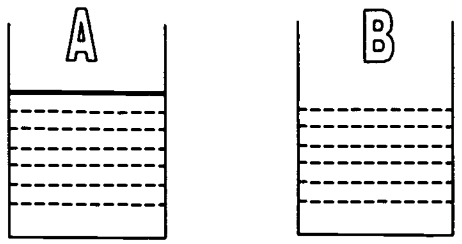
In one lesson Rhonda fries onions on the front bench in the laboratory. The students call out from their seats when they start to smell the onions. They track the progress of the smell towards the back of the lab. Rhonda asks them to put on their glasses and look around the room. Can they explain the 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 varying 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.

Rhonda shows the interviewers diagrams representing water from a couple of textbooks.



"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!"

A PaP-eR on Particle Theory

What is the smallest bit?

Introduction

This PaP-eR has been constructed as a result of two teachers (MB and PM) reviewing their learning during their team teaching whereby their approaches and ideas about the classes they taught and shared were documented through a journal that they maintained as an 'added' form of communication. The journal entries in the PaP-eR are highlighted through formatting changes.

As this PaP-eR 'opens' the class have already moved through several activities and discussions that have helped them to consider the ideas that matter is made up of tiny, tiny bits and that these bits have nothing between them. They have started to consider that these particles (the smallest bits possible) are moving and hence have a particular arrangement, and that these factors help explain what phase a substance will assume.

These teachers have, in essence, covered the content ideas that Rhonda described. In this account they attempt to create a need for different kinds of particles, by asking students to explain (using different media) what happens as water boils. This teaching sequence also revisits and reinforces the content ideas already covered.

MB - teaching journal entry

The need for molecules.

Read this POE. It's designed to help students understand the structure of water and seems perfect for differentiating between particles generally, and atoms and molecules.

The teacher asks the class of year 9 students if they know what the chemical shorthand for water is. A number call out, they have all heard it before, and the class quickly settles on H_2O. What does that mean? Easily the class agrees that it means water is made of H and O and that there is twice as much H as O.

The teacher then asks them to draw a "super-magnified" picture of how a beaker of water might look if we could see how the H and O are arranged in it. Students think and quietly draw their own pictures.

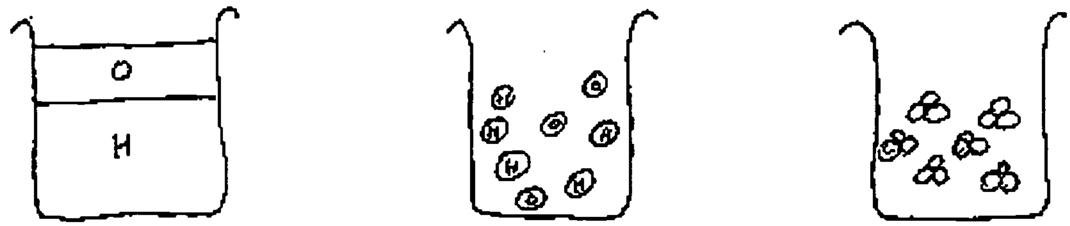
The teacher asks them to look at a beaker of water boiling at the front of the class, and to imagine the steam above the beaker. Students each draw a "super-magnifier" representation of what this would look like. The teacher walks around and asks several students if they would like to put their diagrams on the board so that there are a range of ideas shown for both liquid and gas.

PM - teaching journal entry

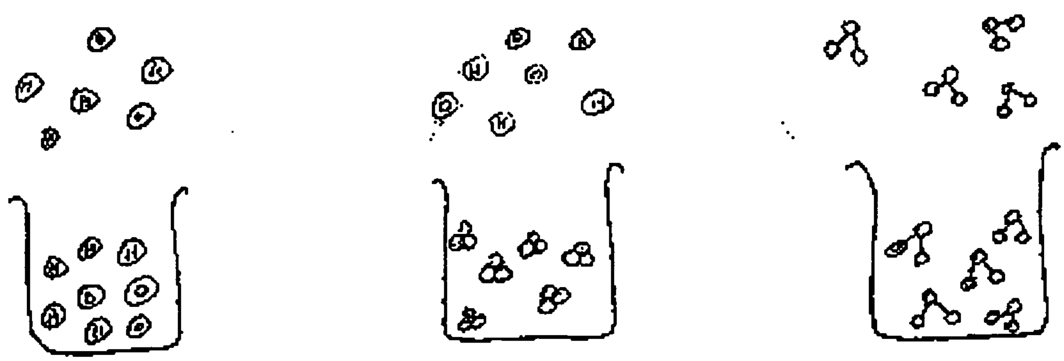
9G:It seems this idea of 'the smallest bit' is really the important idea to come to, and it would have been confusing talking about atoms to start with (especially as everyone knows that water is H_2O and has constructed some vague idea of what that means, even if just that it's made of hydrogen and oxygen).

It's amazing the constructions of what water being H_2O and so made of two parts hydrogen to one part oxygen means to them - this is the best lesson I've ever had about the variety of interpretations that can fit one piece of information!

I'm always a little bit nervous asking them to bare their ideas on the board, but lots of people were very willing. Lots of thanks and praise of course!



Picture 1: (examples of individual student's pictures of water in a beaker drawn on the board)



Picture 2: (examples of individual student's pictures of boiling water in a beaker drawn on the board)

People were pretty strong on the idea of ratio - it was important to them that it was two parts hydrogen to one part oxygen (is this just the power of the annotation - because the formula says so??). I'm still amazed at the first one - after all the work we (they!) have done with particles..... Several students commented on this: "it can't be that - it has to be made of particles". Picture 1(and to some extent picture 2) was challenged by asking what would happen if we tipped some of the water out of the beaker. There was some debate as to whether it could "even itself up" but it generally offended their notion of the 2:1 ratio. So we were left with hydrogen and oxygen either separate or together.
Of course all the "separates" in liquid were separate in gas (what would we do if they weren't!). Of the others only Carolyn and Polly kept the molecules together in the gas, the rest had them separating into hydrogen and oxygen.
In the end most of the class were happy with picture 3 as the best representation of water, so we moved on to work out how we could decide which was the best picture of the steam.

The teacher asks the class how they could find out whether boiling water really does separate into hydrogen and oxygen as it boils. When students suggest somehow testing to see if those gases are there, the teacher is ready to produce, and then demonstrate the presence of, hydrogen in a test-tube. She asks the class what it will mean (in terms of choosing the best picture) if they do find hydrogen above boiling water, and what it will mean if they don't.

MB - teaching journal entry

9R:Demo'd hydrogen test - they loved it (have to be careful that the 'bang' isn't the only thing they remember). Sarah T tested the water vapour for hydrogen (she was pretty nervous). Nothing happened (of course).

Next point they said that the H stays behind and oxygen is given off.(!)

Kylie G: maybe it separates into the H and O gases then recombines again and that's why you feel the water droplets on your hand if you put your hand over it.

Steph: but when we see the pics in the book it says solids 'break up' into liquids, so then the liquid also 'breaks up' into a gas, therefore H_2O *breaks up into H + O.*

Bron: yeah, and we did the role-play about ice melting and water boiling we all had to break apart and run around the room then (she looked pretty smug). [A problem I'd never thought of before but which seems pretty obvious now it's pointed out.]

There wasn't time to work through all of this but what I LOVE is that they are fighting for those models, and coming up with ideas to defend them as hard as they can. LOTS of thinking....

You've got 9R next - you need to: 1.demo O_2 *test and test boiling water >>> which is most likely model?*

2. acknowledge Kylie G's observation and deal with it (no H or O found by testing)

3. introduce term molecule as the smallest bit of water and link that back to the role-play (ie acknowledge Bron's point and help them understand that the people were molecules / smallest bits of water)

MB demonstrates a similar test for oxygen and a student applies it to the boiling water. Via a great deal of class discussion consensus is reached that picture 3 is the most suitable one to represent water as liquid and as steam.

Students draw diagrams again in their books, and write down how they know that the hydrogen and oxygen stay together as water boils. Their next writing task asks them to apply the new terms atom and molecule in describing water (and some other substances).

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The classroom is set up in the following way for the next lesson.

Beaker of water boiling out the front. Students, with a partner, are to: Draw big pictures that show what happens as water boils. Be ready to demonstrate their understanding to the teacher using some pieces of duplo.

PM - teaching journal entry

9G: The girls worked in pairs with textas on butcher's paper. They started off working on their explanations on the butcher's paper but eventually everyone had their duplo going to help them work out what the pictures actually should be. I'm sure it helps their thinking to be able to manipulate a model while they are trying to put snapshots of it down on paper. I'm sure that's a big problem with lots of the diagrams they get to see - it's hard to think about what's happened for one diagram to move on to the next.

The best bit was that working through the boiling water scenario with particular pairs of stds. (Tammie and Nat were struggling) led to me asking them to use the duplo to show the smallest bit of water they could possibly get. Then asking which of the terms (atom, molecule, compound, element) we could use to describe it. It was REALLY POWERFUL for several stds.. "Is this still water?" or "What have I got now?" when breaking up the molecule. "Show me an atom of water" "... a molecule of an element" "...an atom of a compound" "... the smallest bit of an element" etc. It was easy to see which bits particular stds. were having trouble with, and to work through it with them then and there.

Overview

We do not envisage that PaP-eRs should have a particular format or style. A PaP-eR should be an engaging portrayal of the elements of PCK that are being illustrated for the reader. Therefore, PaP-eRs should have a variety of formats (eg. an interview, observer's voice, journals, window into a lesson, students' voice and actions, and so on) so that their portrayal allows the reader to identify with the situation and, as a result of the particular framing of the pedagogy, content and context, to draw meaning from ir.

In concert with the PaP-eRs, the central representation (see Table 1) must be conceptualised (with a particular group of students' in mind) as a necessary construction to codify and categorise the knowledge and content under consideration so that it might be manageable and useful for others. Well-constructed PaP-eRs ***should*** then bring this central representation to life and shed new light on the complex nature of PCK both for teachers and educational researchers. This we see as one way of helping to create opportunities to better understand, and hence value, the specialist knowledge and skills of teachers and to make the tacit explicit for all audiences.

We realise that the use of PaP-eRs as insights into elements of PCK has moved a considerable distance from case methodology as it is generally used. However, our proposed approach through the use of PaP-eRs still contains many of the qualities that first inspired this investigation so that portrayal of PCK might indeed be possible. We contend that PaP-eRs then need to:

- capture the rich detail of classrooms so that they 'ring true' with teachers and engage them in thinking through a 'real situation'

- illustrate some of the central content representation, and/or may be the 'way in' ie reading a PaP-eR and grappling with the questions it raises may be the way a reader comes to consider certain aspects of the content in the first place; or comes to reconceptualise and extend their understanding of the content
- illuminate dimensions of teacher thought in concert with classroom action. Particularly so in relation to the thoughts and actions that combine in teaching ***particular*** content to particular students so that students' learning is enhanced.
- act as stimuli for reader thought and discussion and explicitly link to the central representation of the content.

Conclusion

In coming to better value teachers' knowledge and practice, there is a need to be able to articulate and document what it is that teachers know and are able to do and this is central in coming to understand science teachers' pedagogical content knowledge. Malcolm (1999) noted that in deconstructing one's teaching it begins to make the tacit explicit for others. In teaching, this is not a common approach to understanding practice - yet it must surely be an important element of a profession. Although Roth (1998) argues that the subtleties of quality teaching may defy analysis, we believe that there is a need to work to illuminate practice so that it can be viewed, analysed and understood by others.

Through this project our research team has examined Pedagogical Content Knowledge in such a way as to come to understand that it is ***not*** a single entity that is available and easily accessible in science teachers' practice. Our view of PCK is that much of what PCK may be is tacit in a science teachers' practice and that the ability to recognise and document it is influenced by the researchers' understanding of what they believe they are looking for.

The literature has demonstrated that PCK has certainly been well accepted by the academic community as a useful construct but convincing concrete examples of PCK are difficult to find. Our development of the PaP-eR as a way of documenting elements of PCK is one way of attempting to begin to portray PCK to others. As our project continues, we hope to develop a substantial collection of papers focussing on particular content areas (eg. electricity, circulatory system, forces, the planets etc.) that combined will better illustrate the nature of PCK and begin to offer ways of sharing this within the profession.

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