How Does That Work? Developing Pedagogical Content Knowledge From Subject Knowledge

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ABSTRACT: The development of subject knowledge and pedagogical content knowledge has been the focus of much educational research and debate in recent years. Of particular interest is the process by which preservice science teachers develop pedagogical content knowledge from their subject knowledge. In the study presented here, a process of writing narrative explanations of scientific phenomena was developed as part of a preservice teacher education course at a U.K. university. This process revealed the importance of teachers having *coherent internal accounts* to explain phenomena, which they can then share with students through meaningful discourse and joint action. Developing these coherent internal accounts would appear to be part of the process by which subject knowledge is transformed into pedagogical content knowledge.

Ask typical high school students what makes a good teacher, and their answer will usually include the response that good teachers are able to explain ideas and concepts in a way that students can understand (Wilson & Mant, 2011). However, there would appear to be a lack of science education research into teacher explanations, perhaps because of the recent focus on student learning (e.g., inquiry learning and argumentation) and the association of teacher explanations with a lecturing approach (Geelan, 2012). In this study, an "explanation" is used to denote the story that explains a particular event or phenomenon (Ogborn, Kress, Martins, & McGillicuddy, 1996) and that the teacher wishes to become the common knowledge shared by teacher and student alike and developed "through discourse and joint action" in the classroom (Edwards & Mercer, 1987, p. 161). Explanatory stories are valued, as they help learners to see science as a set of "interrelated ideas," to see the overarching ideas and not just the detail, and to develop the depth of understanding desired (Millar & Osborne, 1998, p. 2012). It is suggested that understanding the importance of such stories and learning how to develop them is a crucial part of becoming an effective science teacher and that the process of doing so should be explicit within preservice teacher education to prepare science teachers to introduce and develop the scientific story in a persuasive way that helps students to internalize it (Mortimer & Scott, 2003). One approach to this process is presented here from research carried out with two cohorts of preservice science teachers at a U.K. university. Furthermore, the findings contained herein indicate the existence of an important step to be taken when moving from the development of teachers' subject knowledge to the development of their pedagogical content knowledge (PCK)—namely, that of developing teachers' *coherent internal accounts*.

Developing Preservice Science Teachers' Subject Knowledge

Increasingly, the quality of science teachers' subject knowledge is coming under scrutiny, as it is held to be one of the key indicators of the quality of science teaching (Royal Society, 2007). One way of improving teachers' subject knowledge is to encourage those with higher qualifications to enter the progression. From September 2012, the bursaries available to those undergoing postgraduate preservice teacher education in the United Kingdom will vary according to the classification of their prior degrees (http://www.education.gov.uk/get-into-teaching/funding/postgraduate-funding). Another approach is to develop preservice science teachers' subject knowledge during their training, although it is thought to be unrealistic to expect all science teachers to know *all* the concepts and ideas contained in the National Curriculum for Science in England and Wales at the end of a 1-year preservice teacher education course (Lock, Salt, & Soares, 2011). That recent study showed that across a number of institutions in England and Wales, preservice teacher education courses sought to develop both subject knowledge and PCK in their preservice science teachers through interactive workshops. Use is also made of not only self-assessment, where preservice teachers audit their subject knowledge, but also diagnostic questions, such as those developed through the Evidence-Based Practice in Science Education Project at the University of York (Millar & Hames, 2003). Lock, Salt, and Soares (2011) found that preservice science teachers question the effectiveness of subject knowledge audits, and although they value workshops and teachers as resources for developing their PCK, they rely heavily on material resources (e.g., books) for developing their subject knowledge. While the development of subject knowledge before, during, and after preservice teacher education is vital, what is of interest here is the process undergone by preservice science teachers as they learn to translate their "science" into "school science" and how to teach it (Kind, 2009; Kind & Taber, 2005). This is of interest to teacher educators not only in the United Kingdom but also internationally, given the widespread concern about the recruitment and retention of science teachers (e.g., Rhoton & Bowers, 2003).

PCK in Science Education

PCK has been of great interest to education researchers since Shulman's (1986a, 1986b, 1987) paradigm-shifting proposal of it as a domain of teacher knowledge. Shulman defined PCK as a

> special amalgam of content and pedagogy that is uniquely the province of teachers, their own form of professional understanding. . . . It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented and adapted to the diverse interests and abilities of learners, and presented for instruction. (1987, p. 8)

Its development is closely related to the development of subject knowledge as "pedagogical reasoning begins with comprehension of the content and goes onto transformation of that content for teaching purposes" (Cooper & McIntyre, 1996, p. 14). This is not a simple two-step process where first one learns the content and then learns how to teach it, as teachers continue to learn as they use knowledge, and, as is often said, "we never really learn something until we have to teach it" (Eraut, 1994, p. 46).

However, PCK can be seen as something of an academic construct, full of jargon and hard for teachers to relate to (Loughran, Berry, & Mulhall, 2006). Although the difference between knowing a subject and knowing about the teaching and learning of it has been embedded in the English and Welsh national standards for teaching for over a decade (Scott, 2001), there are various definitions and conceptualizations of PCK (Gess-Newsome, 1999; Nilsson, 2008), and teachers need support in identifying and articulating its components (Loughran, Mulhall, & Berry, 2004; Mulhall, Berry, & Loughran, 2003).

The ability to develop effective explanations of key scientific concepts in the classroom can be considered part of the PCK that science teachers need to acquire—however, little is understood of the explanatory frameworks that science teachers draw on to help their students develop a more scientific understanding (Geelan, 2012). With colleagues from my institution, I am engaged in a research project that examines the characteristics of effective scientific explanations and how they are co-constructed in the classroom, drawing on the perspectives of both teachers and students. This work is yielding usable professional knowledge, which will be shared with preservice and in-service science teachers and science teacher educators through a teacher education instructional resource. As part of this, I decided that it would be useful to investigate the explanations given by preservice science teachers, using written narrative explanations of scientific phenomena, with the outcomes providing a baseline to inform the design of the instructional resource. Despite this initial focus on outcomes, it soon became apparent during the course of the investigation that the process of writing narrative explanations was significant.

Value of Writing Narrative Explanations

Writing narrative explanations of scientific phenomena has been reported to be of interest in science education. Edgington and Barufaldi (1995) asked three research physicists and five high school physics teachers to write explanations of the Newton's cradle demonstration and then interviewed them. All eight participants described it as a series of collisions and used the concepts of energy and momentum to explain it, but their explanations varied in level of detail and complexity. The focus was on comparing the explanations offered by researchers and teachers (rather than helping preservice teachers prepare explanations for use in school), such that teachers tended to approach it as if there was a single correct answer, whereas the researchers considered different possibilities. Johnston and Ahtee (2006), in their study of preservice primary school teachers' attitudes toward teaching science in the United Kingdom and Finland, asked participants to write explanations of what happens when two balloons are tied at either end of a stick and one is inflated and to consider what difficulties school students would have with this activity. They found that poor subject knowledge hampered student ability to develop PCK, identifying a need for preservice teachers to understand the scientific content to be taught and its context in the curriculum before considering how to teach it. Similarly, Touger and colleagues (Touger, Dufresne, Gerace, Hardiman, & Mestre, 1995) asked physics undergraduate students to write explanations of various mechanics situations. Crucially, they found that to write expertlike hierarchical explanations, the students not only needed a well-developed knowledge store but also needed to be well organized. Interestingly, de Carvalho and Paulo (2004) found that asking primary school pupils to write explanations of scientific phenomena developed their understanding—rather than the process being hampered by a lack of it—and did so more than classroom dialogue.

These studies show that writing narrative explanations is a useful way of exploring subject knowledge in science, not only for teachers, but also for students at a variety of levels and can form part of the process of developing that subject knowledge; hence, it was a valid strategy to employ in this study.

Method

The aim of the study was to examine the explanations held by preservice science teachers, which they then drew on to explain scientific phenomena in the classroom. The research was carried out at a U.K. university with preservice teachers on a 1-year Postgraduate Certificate in Education (PGCE) course. The cohort comprised 49 preservice teachers, of whom 18 had a first degree in physics or engineering, 17 in chemistry, and 14 in biology. Twenty-three of them had not studied physics past the age of 16, and so their levels of background knowledge varied a great deal. The gender breakdown was 29 women and 20 men, and their ages ranged from 22 to 51 years.

Setting and Marking the Written Tasks

During the first term of their course, the preservice teachers attended a series of workshops, each on a key area of the English and Welsh National Curriculum (e.g., reactivity, particles, photosynthesis). These were aimed at developing their subject knowledge, helping them to identify common misconceptions, and introducing them to a variety of approaches to teaching each particular area. I taught four of the workshops: particles, forces, electricity, and energy. Common to each workshop was a key demonstration, which I would typically introduce to the preservice teachers and discuss with them how it worked and how it could be used in school. However, these explanations—co-constructed through dialogue but still essentially "owned" by myself—did not enable all the preservice teachers to fully understand the demonstrations, nor did they feel able to give a detailed explanation when using them in school. Neither did the verbal explanations allow investigation of the preservice teachers' explanations nor exploration of the difference between describing something (i.e., giving information about it) and explaining something, where the links between different pieces of information are made (Horwood, 1988). The principles of the PGCE science course at my institution should be emphasized at this point:

> Rather than attempt to train all students to teach in a particular way, we aim to build on your existing strengths—as good scientists and as mature, autonomous, motivated personalities—to help you teach in the way most suited to you and your school students. (http://www.education.ox.ac.uk/courses/pgce/subjects/science/)

As such, it was important to me that I did not simply tell the preservice teachers the explanation they should use. It was decided to set a task for the preservice teachers where they wrote their own explanation for each demonstration, using diagrams if they wished, on blank pieces of A4 paper and to research the process and outcomes of doing so. The four demonstrations are described in Table 1. The explanations were written by the preservice teachers during the workshops while they sat at tables in groups of four or five, with each group containing a mixture of subject specialisms (physics, chemistry, biology). The explanations were then handed in, and, if incomplete, the preservice teachers were told that they could complete and submit them later. It was made clear that these explanations did not contribute to any assessment about whether participants passed the course but were wholly formative in purpose. I marked the explanations as follows: Correct or well-phrased points were ticked, with comments being written occasionally, and questions were written next to incorrect, incomplete, or obscurely worded phrases. The explanations were returned to the preservice teachers at subsequent workshops where I would

Table 1. Four Demonstrations and the Key Points That Should be Included in Any Explanation of Them

Demonstration: Description	*Key Points for Explanation*
Egg and conical flask	
Boiling water from a kettle was poured into a conical flask. A peeled hard-boiled egg was placed in the neck of the flask, and it proceeded to move downward, apparently being "sucked" into the flask.	Pressure of gas mixture inside flask is reduced (via condensation and density arguments) compared to the external air pressure. Hence, the egg is pushed into the flask by the air particles outside exerting a force on it (so including ideas about how gas pressure arises).
Rocket balloons	
Rocket balloons (as typically found in toy shops) were inflated and released to "fly" around the room.	The gas pressure inside the balloon is greater than the air pressure outside the balloon (again including ideas about what gas pressure is). When the balloon is released, the gas exits the balloon, resulting in an unbalanced force pushing the balloon forwards.
Burning pencil	
A graphite pencil (typically HB) was sharpened at both ends and 24 V applied across it (taking appropriate safety precautions). The pencil smoked; the graphite glowed red; and the wood caught fire.	Graphite is a semiconductor, so when a voltage is applied across the pencil, charge can flow around the completed circuit. Due to the high resistance, a great deal of energy is transferred to the pencil, resulting in fire (as heat, oxygen, and fuel are all present). Should include ideas about what voltage, current, and resistance are in terms of movement and properties of charged particles.
Melting ice	
One ice cube was placed on a metal frying pan and one ice cube on a plastic chopping board. The one on the metal pan melted first, despite the board feeling warmer to the touch.	Metal is a better thermal conductor and thus transfers thermal energy more quickly than the plastic board away from your hand in one situation and toward the ice cube in the other. Should include ideas about how thermal energy is transferred in different types of solids.

summarize the key points that should be included in an explanation, highlight any strengths found to be common across the explanations, and any commonly occurring errors. Questions were taken from the group at this point, and individual discussions were offered but taken up by only one or two. An offer was also made for the preservice teachers to revise their written explanations and resubmit them, but none availed themselves of this opportunity. Three examples of these written explanations can be found in Appendix A.

Evaluating the Written Tasks

To investigate the extent to which the preservice teachers thought that writing these tasks and receiving written feedback had aided the development of their subject knowledge and PCK, two evaluations were carried out: written evaluations and focus group interviews. Each year, at the end of the first term, the preservice science teachers on this PGCE course complete an evaluation form that asks them to comment on their experiences thus far. This year, three questions were added to the form—these can be found in Table 2, with the overall responses. This questionnaire technique was employed as it enabled responses to be obtained from the whole cohort through a preexisting mechanism. The questions were structured in such a way as to yield affirmative or negative responses, which could then be justified further, and the majority did offer justification for their initial responses.

The submitted responses were collated and inspected for commonly occurring and unusual answers and were then used to devise a semistructured interview schedule for four focus groups, to explore the previously given responses in more detail and to provide opportunity for them to express further views. The interview schedule can be found in Appendix B. These groups comprised two to four preservice teachers each, with a mixture of genders and ages to be reasonably typical of the cohort. One group had participants whose first degree was in biology, another with chemistry degrees, and two mixed groups: One had a mixture of physics and biology degrees; the other had degrees in biology or chemistry. Participants were selected on the aforementioned basis from those who had already agreed to take part in research interviews, with care being taken to omit any preservice teachers whose high-stakes assessment on the course I was directly involved with, to avoid undue pressure on participants (Youens & McCarthy, 2007). Invitations were sent by e-mail, and the group interviews took place at mutually convenient locations and times.

Findings and Discussion

Did Completing the Written Tasks Aid Subject Knowledge Development?

Table 2 shows that 38 of the 49 preservice teachers thought that writing explanations of these four phenomena did aid their subject knowledge development. Questionnaire responses said that this process highlighted areas that they needed to revise (n = 9), helped them clarify concepts and deal with

Table 2. Responses to the Evaluation Questionnaire

The Four Explanations Tasks	*Yes*	*No*	*Missing*	*Total*
Did these tasks help you to develop your subject knowledge? Please explain your answer.	38	7	4	49
Did these tasks help you to think about how to explain concepts to students? Please explain your answer.	41	3	5	49
Did you find the written feedback useful? Please explain your answer.	41	4	4	49

their misconceptions (n = 5), and taught them new concepts (n = 4). These were corroborated by the interviews, with interviewees saying, "It was really useful for building your curriculum knowledge across the board," "I just knew as a fact that metal conducts better than wood, but I realized that I'd either forgotten or never really knew why," and "I've been away from science for a while, and actually just sort of trying to work things out from first principles again was really helpful for me."

The interviewees also valued it as an opportunity to learn from their peers through discussion and to think about phenomena in a new and more in-depth way:

> We've all seen a rocket balloon go before and I think quite a few of us had seen the egg, but never really sat down and gone "How does that do that?" . . . I found myself having to ask the physicists about things and checking things with the chemists.

And this process helped them to realize the degree to which they assumed knowledge in others: "I think the problem with physicists is sometimes that you sort of know a lot of stuff that you think everybody else knows, but actually they don't really know that," which posed difficulties at times, as "it becomes sort of internalized knowledge that you don't need to think about, but then it's really difficult to explain to someone else."

These findings demonstrate that the process of writing narrative explanations of four simple phenomena enabled the preservice science teachers to develop their own subject knowledge, where needed, and to translate their "academic science" into "school science" (Kind, 2009).

Did the Written Tasks Help the Preservice Teachers to Develop Their PCK?

The responses from the evaluations and the interviews showed that the preservice teachers had been able to develop their PCK in a number of ways.

Learning to explain demonstrations. The four demonstrations described in Table 1 are not new or novel ones (videos of all four can be found on YouTube), but they could be considered a standard part of a science teacher's repertoire. Introducing preservice science teachers to these typical demonstrations is part of the role of preservice teacher education; however, it is more important to learn how to plan and prepare the discussion about the demonstration that will enable the students to make meaning from it (Mortimer & Scott, 2003) and leave with a coherent understanding of the phenomenon. From Table 2, it can be seen that an overwhelming 41 out of 49 participants said yes, the tasks had helped them think about how to explain to students' in their evaluations, with 9 already stating this in their response to the previous question. The main reason given was that this process highlighted the need for them to think about clarity in their explanations and to develop arguments from basic principles in a logical way (n = 13). Others stated that the tasks had helped them to think about explanations in a new way (n = 5), to consider the need to use language carefully (n = 4), and to think more about students' perspectives of learning (n = 4). Again, this was supported by the interviewees, who found that the tasks had encouraged them to use diagrams and a step-by-step approach. They had questioned themselves as to "what do I need to explain first before I can explain what happened there?" The process had highlighted to them that "you've got to make sure that you know what you're explaining and keep using the same terms" and

> when I came to doing teacher demos it helped me think about how am I going to set this up, how am I going to make them think about what I want them to think about but not necessarily say exactly what's going on.

The responses clearly show that the process of writing these four narrative explanations had created opportunities for the preservice science teachers to think about the demonstrations in detail and to ensure that they fully understood what was occurring and why, appreciating the complexity of these apparently simple phenomena and the importance of using scientific language carefully (Evagorou & Osborne, 2010; Wellington & Ireson, 2008; Wellington & Osborne, 2001). It seems that they had learned to generalize these principles and apply them to other demonstrations, valuing the confidence that they gained from feeling well prepared.

Giving feedback to students. As already discussed, preservice science teachers are expected to know a great deal of subject knowledge as well as develop their pedagogical skills, and some develop their subject knowledge in university science departments rather than education departments. However, Lock, Salt and Soares (2011) found that the approach taken by the latter departments tended to be valued more by preservice science teachers, as it developed their pedagogical skills as well as their subject knowledge. The process described in this study was seen as modeling good pedagogic practice by the participating preservice teachers: Rather than being told information and correct answers, they were questioned and expected to develop their own thoughts, fostered by opportunities to discuss with peers, which can be compared with practice described by Mortimer and Scott (2003).

The marking process, although time-consuming, gave a greater level of purpose to the tasks, as each received specific guidance about how to improve, and it was perhaps a more effective way of learning about the importance of written feedback rather than hearing about it in a session on formative assessment (Black, Harrison, Lee, Marshall, & Wiliam, 2002). This can be evidenced by the response to the evaluation question about the usefulness of the written feedback, which was overwhelmingly positive (41 of the 49 participants). The preservice science teachers felt that receiving individual written feedback had helped to improve their explanations (n = 11) and had also improved their subject knowledge (n = 5), with a number simply stating it was useful (n = 8). The interviewees strongly agreed with this because "it was very focused on which bits you'd done well, which bits you need to think about more," saying that it was "very important" and made the whole exercise "meaningful." They also felt that the questioning approach of the written feedback had modeled a useful way of marking their own students' work, finding that students

> come back to read it and they think "Oh, you know I haven't really included that in my explanation" . . . because at the end of the day it's about training them to write explanations of their own thoughts. It's what teaching's all about, getting the thoughts onto the paper.

It can be seen from these findings that the individual written feedback was greatly valued by the preservice science teachers and was an important part of the process.

Learning Science From Students' Perspectives

The findings also revealed that participating in this process had enabled the preservice science teachers to experience learners' perspective: "It made me appreciate how students can struggle with concepts in the classroom because I was struggling with it." This became particularly apparent when discussing the negative responses to the evaluation questions in the focus group interviews. Seven participants had found that the process had not helped their subject knowledge, saying that they had had insufficient time to complete the task (n = 4), had found it hard and confusing (n = 3), or already knew it (n = 2) (multiple responses were possible). Three had said that it had not helped them with explaining, with similar comments being given: The tasks were hard (n = 3); there was insufficient time (n = 2); and the task was unclear (n = 1) (multiple responses). And despite the majority of preservice teachers' valuing the feedback, 4 responded negatively: Some wanted to be given a model answer (n = 4); others felt demoralized (n = 2) and thought that the feedback was too fussy (n = 2) and requested a mark (n = 1) (multiple answers). The interviewees were unsympathetic to these viewpoints—"that's what we do to the kids all the time, and that's the challenge for them and you learn things from the challenge. You can't just leave us here all afternoon to write, it just would be ridiculous"—also stating that more time would have allowed them to "go off on a tangent and start thinking about it, getting more and more flustered and more and more confused." As one interviewee pointed out, the time allowed was longer than the few seconds of thinking time that one would have if asked a question by a student in a lesson!

The interviewees suggested that the negative comments reflected the "comfort levels" of some of their peers, recognizing that the workshops and written tasks happened in the context of a fairly challenging course: "It's not any more demoralising than any other session that we've had this year', and that some people "are just generally demoralized." One admitted, "I'm one of those people that doesn't want to write something down until I think I've got it right." These insights into learners' perspectives were useful to them when working with students in school.

Regarding the structure of the task, the interviewees felt that a more structured task "wouldn't have highlighted to me exactly where my misconceptions lay or where my lack of communication was." They were also aware that they all had different background knowledge and were developing different teaching styles in the classroom, and so they approached the tasks in different ways, thus appreciating that more structure would have restricted the way that they developed their subject and pedagogic knowledge through the tasks. This reflects the principles behind the design of the task, which were grounded in the ideals of the course, as discussed earlier.

Finally, the negative responses about the written feedback were generally not shared by the interviewees, who found the feedback "encouraging" and "you were stretching us rather than being picky; it felt like being stretched" and that this was what good teaching was about—"you could always improve on something." However, the issue of model answers provoked some debate: Some interviewees pointed out that they could "Google" an answer immediately after the workshops without waiting for the written feedback and that "a model explanation is really only in your words. And actually what we need to do is to develop the skills to put in our words. So actually [a model answer] wouldn't really have helped really probably." Others would have valued a model answer, perhaps as an option for those who felt their own explanations to be inadequate. None of the interviewees would have valued being given a mark, seeing this as superfluous, feeding unhealthy competitiveness, and thought that it would have been difficult to devise a fair mark scheme for the tasks and would not necessarily "help you be a teacher."

Although the negative responses to the evaluation questionnaires were not echoed by the interviewees, they did feel able to make some suggestions to adapt the process of setting and marking these written tasks to enable preservice teachers on future courses to feel more supported and less threatened by it. These are discussed later.

Had This Process Affected Their Practice?

The interviews were carried out 6 weeks after the last task was completed, and it was evident from the discussions that this process had directly influenced their practice, applying what they had learned from it while planning and teaching in school. At a pedagogical level, they had translated it into their own classrooms: "I actually tried. . . . I set them as homework to write an explanation." Several had taken the questioning approach used in the written feedback and applied it in their own marking, while others had used the demonstrations in their own teaching and had fed back on this to the rest of the peer group—for example, "they could tell me what was going to happen, but when it happened they couldn't believe it and they were really excited," and each demonstration is "quite exciting to watch but also because you haven't necessarily been taught it, they can come up with a range of explanations and then it's something to focus a lesson on."

Similarly, the process had encouraged them to consider explicitly the PCK in their explanations: "really thinking about exactly how you're doing your explanation and keeping it as simple but as clear as possible." The importance of language and the value of diagrams were also evident: "I definitely taught a lesson whereby I was thinking . . . because I'd gone through that exercise . . . specific terms and careful use of language," and "because some things you really can't convey as well with words as you can with pictures."

The study reported here confirms the findings of previous studies discussed earlier (de Carvalho & Paulo, 2004; Touger et al., 1995)—namely, that the process of writing an explanation of a particular phenomenon for assessment helps one to identify any misconceptions still held, to develop one's subject knowledge. More important, the process of writing an explanation helps to organize one's knowledge in a way that simply answering questions does not, and this leads to the final point.

Coherent Internal Accounts

Thus far, the discussion has identified ways in which the process reported here is able to help develop the subject knowledge and PCK of preservice science teachers. However, what is of greater interest is the theoretical contribution made by the study—specifically, the identification of an explicit step for science teachers to take when transforming their subject knowledge into PCK. This step is the development of a coherent internal account (CIA), the "story" that explains the phenomenon in question that the science teachers have in their heads and that is the understanding they wish to share with their students for them to take away in their heads.

This can be seen from the findings, which clearly showed that this process had emphasized to the preservice teachers the importance of "organizing your thoughts and thinking what do you need to discuss first in order for them [the pupils] to get to the point where they have that understanding"; "I would definitely try and think through the steps and the order" and "to check you can explain it beforehand." Crucially, the interviews revealed that the preservice teachers had realized that

> if you write it down yourself you might realize that you can't explain it . . . unless you try and put it into words either on paper or spoken then you might not realize that what's in your head is not necessarily that ordered.

As well, "there is a difference between being able to quote a definition and being able to understand what the definition means." This was echoed in all four focus groups, clearly showing that the preservice teachers had recognized their own need to have an explanation ready in their heads before teaching a lesson:

> It made me just think about how I explained something in the way that you might want to hear how the explanation works rather than just a load of rambling nonsense, which doesn't really get to the point or just kind of works its way around it, and then eventually within 5 minutes, whereas it could have only taken 2 minutes, you get to a place where they *might* understand.

As teachers, they needed CIAs.

Within the various models proposed to encompass the different forms of teachers' professional knowledge (for a discussion, see Kind, 2009), the suggestion of CIAs would provide a way of making the transformation between subject knowledge and PCK explicit to science teachers. This is different to teachers showing that they know and understand a concept (e.g., by answering a set of diagnostic questions): Having a CIA is being able to use this knowledge to explain a particular phenomenon, with the next step being using one's PCK to teach it to others. Once teachers have the CIA, they can devise the questions to pose to students, and they can outline the discussions that they want to have with them, as well as the active hands-on learning experiences that will all enable the students to develop their own CIAs, explaining a particular phenomenon or concept. It is suggested that experienced science teachers have these CIAs, but, clearly, preservice science teachers need to develop them—but with the question being how?

The approach described here would seem to be one valid way of explicitly teaching preservice science teachers to develop their own CIAs: Those who have been through the process were able to articulate how it had enabled them to organize their own thoughts and understandings in preparation for doing demonstrations with students in school and how they recognized the importance of doing this at an individual level. In addition, much of the process is inherently valuable for pedagogical development—providing useful examples of reliable demonstrations of key phenomena in school science and modeling good pedagogic practice through discussion and written feedback. However, the marking load for myself was substantial, and there were some criticisms of the process. These led to some adaptations in the following academic year.

Subsequent Adaptations to the Process

Thus far, the findings presented have been from the first cohort of preservice science teachers who had completed this series of written explanations tasks. Because of the ethical requirements for the evaluation process, they were all aware that they were participating in educational research, and this had slightly colored their experiences: They did not want to "destroy the exercise" or "muddy the evidence." Initially, it had been the outcomes—the written products of the tasks—that had been of interest to me, but it quickly became apparent that the process itself was important and greatly valued by the participants. Hence, it was decided to keep these as an established part of the interactive workshops taught by me on the PGCE course and, given the richness of the evaluation data yielded by the first cycle, that this "research project" aspect could be omitted. Two adjustments were made to the process: When the written tasks were introduced, I held a longer discussion with the preservice teachers about why the phenomenon occurs, and I gave more detail about the concepts to be included in the explanations. Similarly, when the written explanations were returned, I spent more time discussing them, orally giving a "model answer," with the aid of diagrams on the board. Further findings about the content and form of the written explanations and the extent to which they reflect pupils' misconceptions about these concepts will be published in due course. The issue of the marking load was not solved by these adaptations, except that increased experience enabled me to word my questions more effectively when writing feedback.

Conclusion

Little is understood about how subject knowledge is transformed into PCK (Kind, 2009), and though explanations are deemed of vital importance in science education, there is a shortage of research into how experienced science teachers explain (Geelan, 2012). The findings from the study presented here have revealed the existence of a step that preservice students have found to be crucial in the process of developing PCK from subject knowledge—namely, that of having a CIA.

Hence, an important part of preservice teacher education is enabling preservice teachers to develop their own CIAs for the phenomena they demonstrate in their classrooms. This needs to start with the realization that they must have a CIA, not just a set of facts. CIAs must be carefully thought through for their use of language, models, and analogies, with the aim being to build up and improve scientific understanding, not perpetuate misconceptions. Good CIAs explain phenomena, drawing on key scientific concepts and relating them to others. Writing down the CIAs may be important in the early stages of preservice education, as it makes the process explicit to the preservice teachers and enables formative feedback to be given by teacher educators. One way to help preservice teachers develop their own CIAs has been presented here, arising out of the design of the PGCE course at my institution—that is, in the context of a course that privileges development of autonomy. Other ways must exist, and I intend to carry out cross-curricular collaborations within my institution and other institutions to develop other ways.

Appendix A: Sample Narrative Explanations About the Burning Pencil Demonstration

Sample 1

Two power packs connected in series give the circuit a high potential difference. The circuit is completed, causing current to flow. The graphite core in the pencil is a semi-conductor and has a high resistance. This means that the electrons collide with the carbon atoms of the graphite more frequently. This results in a large number of the electrons passing their energy onto the graphite via vibrations. The large energetic vibrations transfer energy as heat to the wood. The combination of heat (vibration energy of the particles), fuel (wood) and oxygen cause the wood of the pencil to catch alight and burn.

Sample 2

The pencil is sharpened at both ends and crocodile clips used to connect the graphite into the series circuit with two power packs. Graphite is a semi-conductor, so it conducts electric current, but not very well: the rate of flow of electrons is the electric current. When the switch is turned on, the electrons (current) start to flow. The power packs in series give a large amount of energy to each unit of charge flowing through (24V=24 joules per coulomb).

Since graphite is a poor conductor, it presents resistance to electron flow through it. The electrons collide with the atoms of carbon as they flow through. These collisions transfer energy from the electrons to the carbon atoms, which start to vibrate more, which results in an increase in temperature. More and more electron collisions produce more and more heat in the carbon/graphite. Eventually, the temperature gets high enough for the wooden pencil casing to spontaneously combust.

Sample 3

The pencil is acting as a resistor with the graphite of the pencil completing the circuit. Electrons are given energy by the battery. They flow round the circuit in a stream, forming a current driven by the "push' from the battery—its potential difference. The electrons have to give up their energy to get through the pencil since the graphite has a high resistance in comparison to the wires. This is why we need 24V, we need enough to get enough electrons going through. This energy transforms into heat. Eventually the graphite gets hot enough to make the wood burn.

Appendix B: Interview Schedule for Focus Group Interviews

Explain purpose of interview—to explore their views about the process of developing their explanatory skills—not about their own skill level!

Ask permission to record. Remind preservice teachers of 4 demonstrations—egg and conical flask, rocket balloon, burning pencil, ice melting in metal pan and on plastic board.

1. Were these interesting demonstrations?
2. Do you think they would be useful in developing students' understanding?

3. In terms of watching, discussing and then writing the explanations—helping develop your own subject knowledge—83% interns said yes, with most common reasons being "it highlighted areas to revise" and "made me think about how to explain". To what extent do you agree with those statements? Please explain.
4. 15% interns said it didn't help with subject knowledge—they needed more time to think about/discuss it, they found it confusing and/or hard and they felt uncertain about it until they received the marked feedback. To what extent do you agree with those statements? Please explain.
5. A number also said that they were already comfortable with the subject knowledge being covered. To what extent do you agree with those statements? Please explain.
6. 89% of interns said that the process helped them to think about explanations—with the most common answer being the need for clarity and logical steps which build on basic ideas. To what extent do you agree with this statement? Please explain.
7. Other positive comments included a focus on the careful use of language, thinking about explanations from the learners' perspectives and that it was useful to focus on explanations like this. To what extent do you agree with those statements? Please explain.
8. 7% expressed negative comments—writing explanations was hard, there was not enough time, expectations for the task were not clear and the process was hampered by lack of subject knowledge. To what extent do you agree with those statements? Please explain.
9. 89% also said that the written feedback was helpful—it was detailed and helped improve both subject knowledge and the quality of the explanation. To what extent do you agree with those statements? Please explain.
10. 9% expressed negative comments—some felt the feedback was too fussy and others wanted a model answer to be given. To what extent do you agree with those statements? Please explain.
11. Others felt demoralised by the feedback, one felt confused and another one wanted the tasks to be given marks. To what extent do you agree with those statements? Please explain.
12. Do you think it is important for us to emphasis explaining?
13. Do you think this is a helpful way of doing it?
14. What suggestions do you have to improve it?

Thank you very much for your time. TEP

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