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# The Knowledge Base of Subject-Matter Experts in Teaching: A Case Study of a Professional Scientist as a Beginning Teacher

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**Abstract:**

One method of addressing the shortage of science and mathematics teachers is to train scientists and other science-related professionals to become teachers. Advocates argue that as discipline experts these career changers can relate the subject matter knowledge to various contexts and applications in teaching. In this paper, through interviews and classroom observations with a former scientist and her students, we examine how one career changer used her expertise in microbiology to teach microscopy. These data provided the basis for a description of the teacher's instruction which was then analysed for components of domain knowledge for teaching. Consistent with the literature, the findings revealed that this career changer needed to develop her pedagogical knowledge. However, an interesting finding was that the teacher's subject matter as a science teacher differed substantively from her knowledge as a scientist. This finding challenges the assumption that subject matter is readily transferable across professions and provides insight into how to better prepare and support career changers to transition from scientist to science teacher.

**Keywords:** STEM; science teaching; scientist; subject matter knowledge; contextual knowledge; career change; pedagogical content knowledge, beginning teachers

In 2000, the American National Research Council undertook an extensive study of the option of attracting highly qualified professionals, namely PhDs in science and mathematics, to secondary school teaching. The committee's report concluded that: "Ph.D.s, who are trained to be inquisitive, to be creative, and to challenge established wisdom, will provide new leadership and be catalysts for change in science and mathematics education throughout their careers" (Morris, 2000, p. ix). The report presented a persuasive argument for encouraging highly qualified scientists and science-related professionals to change careers and become teachers of Science, Technology, Engineering or Mathematics (STEM) because they bring to the classroom (a) advanced subject matter knowledge and (b) knowledge of STEM in the real world. Encouraging highly qualified people into teaching is an important strategy in many countries and numerous initiatives have been implemented to persuade professional scientists and high performing graduates to school teaching (e.g., Teach for America, Teach for Australia, Teach First (UK), Teach First Deutschland[1]). Although much research exists on early teaching experiences of beginning teachers (Ingersoll & Strong, 2011) including science teachers (Luft et al., 2011), there has been limited research on highly qualified professional scientists pursuing a teaching career and how they apply their advanced subject-matter knowledge.

Thus our interest was in the experiences of highly qualified professional scientists who were confident and competent in their subject-matter knowledge but were now embarking on a new career in secondary science teaching. Scientific and mathematical conceptual knowledge and knowledge of the culture and context in which STEM is practiced while important are not sufficient for effective teaching (e.g., Shulman, 1986). Advanced content and contextual knowledge may position an individual teacher to have insights into the domain and understand the norms of practice in STEM-related careers, but without pedagogical content knowledge, professional knowledge of the curriculum, knowledge of teaching practices and an understanding of student learning, the advanced content is likely to be of limited value (e.g., Baumert et al., 2010; Bransford, Darling-Hammond & LePage, 2005; Van Driel, Beijaard, & Verloop, 2001).

Many challenges confront mid career professionals with PhDs or other advanced qualifications engaging in these communities (Watters & Diezmann, 2012, 2013). The immediate concern of all beginning teachers is how to cope with a new situation, new experience and new identity (Feiman-Nemser, 2003). In this paper, we investigate the teaching of Abi who possesses a doctorate in biological science and graduate qualifications in teaching to understand what knowledge and

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[1] http://www.teachforamerica.org/; http://www.teachforaustralia.org; http://www.teachfirst.org.uk/; http://www.teachfirst.de /

experiences she, as a subject-matter expert, draws on to develop student understanding. Furthermore, the episode we analyse involves Abi teaching a topic where she has substantial domain knowledge and interest but as a beginning teacher has limited “strategic knowledge” and little experience in integrating these different forms of knowledge. The research question addressed in this paper is, “In what ways does a beginning teacher with subject matter expertise exploit her knowledge base to engage students in learning?”

## Theoretical Background

Research on beginning teachers in general showed long ago that beginning teachers tend to rely more heavily on one domain of knowledge while experienced teachers tend to integrate all domains of knowledge in their teaching (Grossman, 1990). However, for many beginning teachers their level of knowledge in any domain is limited. Most beginning teachers progress from school to university and back to school with few opportunities to apply their subject matter knowledge in any real world situation. Teachers need a corpus of knowledge that enables them to transform the subject matter or content they are teaching in ways that facilitate the learning of a diverse group of students with differences in prior knowledge, and abilities.

Mounting research has confirmed the importance of quality teaching in maximising student achievement (e.g., Hattie, 2009; Rivkin, Hanushek & Kain, 2005; Rockoff, 2004). However, defining the attributes of quality teachers is somewhat problematic. The relative importance of a teacher’s own subject matter knowledge of what they teach, their teacher preparation program, their personality and their dispositions toward teaching are all hotly debated (Berry, Daughtrey, & Wiede, 2009; Bransford, et al., 2005). We draw on Alexander’s (2003) work on domain expertise, Shulman’s (1986) thoughts on pedagogical knowledge and that of Hill, Ball and Schilling (2008) with regard to the interaction between content knowledge and pedagogical knowledge.

Alexander (2003) argues that expertise involves the integration of *domain knowledge, strategic knowledge* and the *interest* of an individual. Drawing on decades of study of expert problem solvers, others (Bransford, Brown, & Cocking 2004) identify experts as those who (1) notice features and meaningful patterns of information that are not noticed by novices; (2) have acquired a great deal of content knowledge that is organized in ways that reflect a deep understanding of their subject matter; (3) have knowledge that cannot be reduced to sets of isolated factors or proposition but, instead, reflects contexts of applicability: that is, the knowledge is "conditionalized" on a set of circumstances; (4) are able to flexibly retrieve from memory relevant knowledge quickly and with little attentional effort; (5) know their disciplines thoroughly and; (6) have varying levels of flexibility in their approach to new situations. Sternberg and Horvath (1995) emphasise the capacity of expert teachers to solve problems of everyday teaching drawing on experience. Following Alexander's conceptualisation of expertise, for an individual to be a proficient teacher s/he would have a comprehensive knowledge of all dimensions of Education (domain knowledge), be knowledgeable about the purpose or relevance of what is being taught (strategic knowledge), and have a high intrinsic interest in the topic to be taught. Teaching expertise is achieved as a culmination of a process of acclimatisation and integration of personal knowledge bases to generate professional teaching knowledge. Substantial evidence points to the significance of professional community interactions, through which teachers collaborate, engage in discourse about teaching and have opportunities to observe each other teaching, which enables them to utilise these forms of professional knowledge (e.g., Darling-Hammond & Richardson, 2009). Alexander's work provides one perspective of expertise in teaching although the challenge remains to define what constitutes domain and strategic knowledge in the field of education. Subject matter knowledge does constitute a significant component. Teachers who have deep knowledge of their subject tend to focus on systems and underlying concepts and are effective in implementing inquiry approaches to learning. In contrast, teachers with a superficial subject matter knowledge focus more on isolated concepts and adopt more transmissive approaches in teaching and have less effective capabilities to implement engaging inquiry-oriented lessons (e.g., Roehrig & Luft, 2004; Trigwell, 2011). Hence, substantial content knowledge can impact positively on pedagogy.

Shulman (1986) proposed that another form of knowledge essential for teaching was pedagogical content knowledge (PCK). This was defined by Shulman as "[knowledge] which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching. … in a word, the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). Shulman's proposition stimulated a large number of studies that have attempted to refine the concept of PCK in science education (e.g., Gess-Newsome & Lederman, 1999; Hashweh, 2005; Loughran, Berry, & Mulhall 2006; Park, Jang, Chen, & Jung, 2010).

The study of pedagogical content knowledge is not confined to science education. Working in mathematics education, Hill, Ball and Schilling (2008) have attempted to refine the roles of subject matter knowledge and pedagogical content knowledge and their interaction. According to Hill et al., knowledge for teaching in a particular domain requires (a) subject matter knowledge and (b) pedagogical content knowledge. They expand on subject matter knowledge to acknowledge specialised content knowledge (SCK) and common content knowledge (CCK). SCK includes knowledge of how to represent conceptual ideas or provide explanations for common problem solving methods. CCK is Shulman's (1986) subject matter knowledge that is knowledge of the concepts germane to the domain. The third dimension of subject matter knowledge – knowledge at the horizon – is not clearly defined by Hill et al. but could be considered highly specialised knowledge that would be possessed by experts in a field who are at the forefront of knowledge in their discipline and would incorporate Alexander's (2003) notion of strategic knowledge and high interest described previously. Thus, a new teacher with advanced subject matter knowledge, such as

Abi, should have a wealth of content knowledge including expertise in some aspect of their field but be a pedagogical novice. Hill et al.'s refinement of PCK in the context of mathematics learning introduces the concept of knowledge of content and students (KCS) and knowledge of content and teaching (KCT). KCT focuses on knowledge of the content to be taught and effective ways of teaching it. KCS specifically relates to teachers' knowledge of their students' capabilities in relation to learning this content.

In our adaptation of Hill et al's (2008) model shown in Figure 1, we conceptualise that teachers within a particular domain of knowledge (e.g., biology) need to have a generalised or common understanding of the field (CCK). With further specialisation they acquire specialized content knowledge (e.g., microbiology SCK) and given sufficient engagement with the field will acquire expertise "knowledge at the horizon" (KH). That is, experts are able to make contributions to the field as one might expect of an active research scientist. Hill et al.'s (2008) domain map of knowledge for teaching developed in mathematics provides the means to test this assumption. In considering PCK, we argue that teachers need a sound understanding of the curriculum both in terms of what should taught and the emphasis adopted in the curriculum (KC). Knowledge of content (KCT) and how it is taught is acquired initially in preservice teacher education through exploration of different teaching strategies but further develops with experience. Acquisition of KCS involves awareness of student learning and the misconceptions or the alternative frameworks students bring to a lesson. Such knowledge is acquired through two sources, first there is empirical evidence from teacher education research possibly acquired in preservice programs. Second, there is the knowledge of the group of students for whom the teacher is responsible, which is acquired through experience or strategies, such as pretesting.

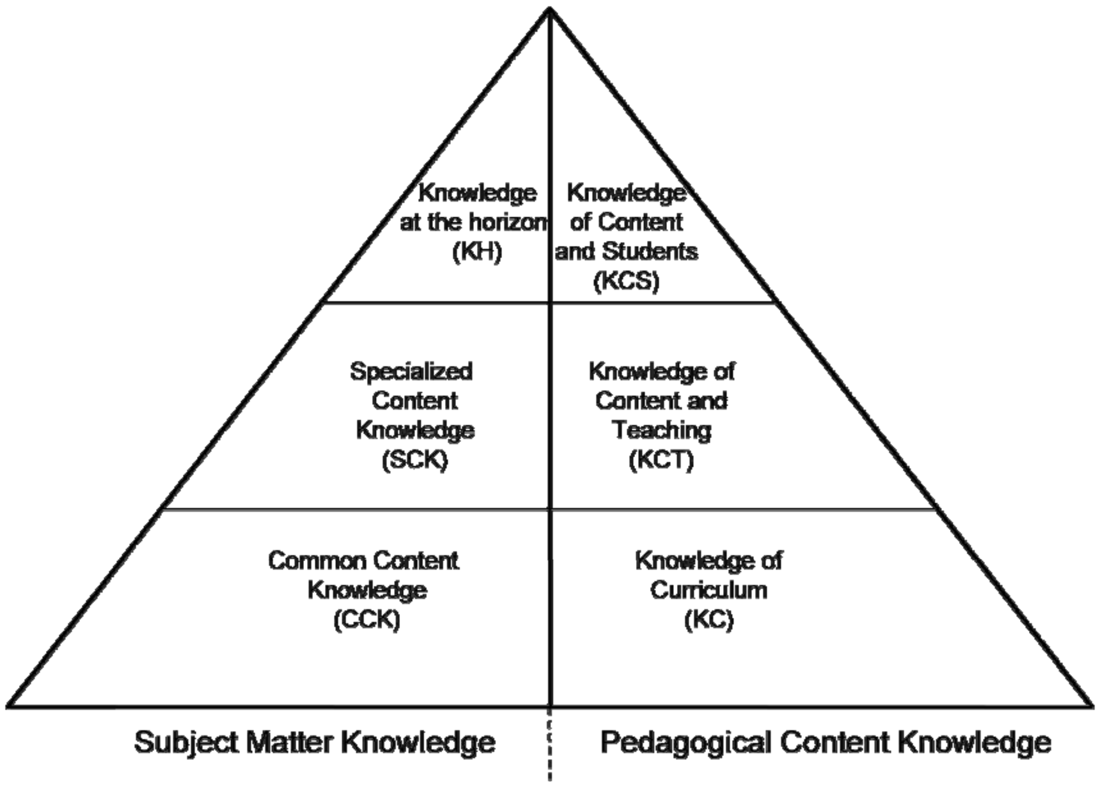


*Figure 1*. Domain map of knowledge for STEM teaching adapted from Hill et al, 2008, p. 377.

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Notwithstanding the validity of a beginning teacher's views of his or her science teaching students' viewpoints are also valid. According to van den Heuvel-Panhuizen (2008), students can provide insight into the effectiveness of instruction from their vantage point as experienced learners. She uses the term "didactikids" to refer to students when they are undertaking the role of reflective commentators on their education.

## Methods

This study was part of a larger 3-year longitudinal study of beginning STEM teachers who possessed advanced qualifications or industry experience prior to becoming teachers. All completed a one-year post graduate Diploma of Education course at different teacher education faculties across the state. In this paper we focus on a case study of one teacher, Abi, to explore how she exploits her expert subject matter knowledge base to engage students in learning. Abi's professional expertise is in microbiology where she held a PhD and had practised as a research scientist for over 10 years.

In her first year of teaching, Abi was assigned to a class of highly capable Year 8 students. At Year 8 level, students are introduced to a range of topics drawn from biology, physics, chemistry and earth science. Over the three years of the longitudinal study, Abi was observed teaching across a number of grade levels and topics. Because Alexander (2003) had suggested that optimisation of expertise occurs when there is alignment among the dimensions of domain knowledge, strategic processing and intrinsic interest, we analysed a set of lessons that were of particular interest to Abi namely microbiology. Abi, in her reflections on her teaching with the researchers, described this particular set of lessons as being successful and enjoyable to teach.

Abi's eight lessons were conducted late in third of four teaching terms. The set of lessons involved an introductory theory lesson on microbiology and cell biology, six practical lessons, introducing students to the handling and use of microscopes, the preparation of slides for optimum viewing and the exploration of different types of cells. The students were given the opportunity to work in small groups of 3 or 4 on their tasks. The final lesson was a quiz and closure on the topic. All lessons, except the final were 40 minutes in length. The final lesson was 70 minutes.

Data were derived from several sources, namely interviews, video recordings of the lessons, and focus group discussions with students.

Interviews were conducted before and after the implementation of the eight-lesson teaching sequence. Interviews (approx 1 hour) conducted before the teaching sequence followed a protocol adapted from the literature (Luft & Roehrig, 2007; Richardson & Simmons, 1994). Luft and Roehrig developed a semi-structured Teacher Beliefs Interview (TBI) comprising seven questions. TBIs allowed them to access the thinking of a teacher and in an investigation of beginning teachers. Our adaptation followed their principles but included follow-up questions that probed participants' beliefs in more detail and sought information from the teachers about the planned teaching episode. All lessons were videotaped by the teacher without the researchers being present to minimise disruptions to the natural progression of the lessons. The post teaching interview involved a 5-6 hour debriefing and review of the teacher during which time the video tapes were reviewed and salient or interesting events discussed. Thus the post interviews capitalised on the video providing a rich source of reflections through stimulated recall (Calderhead, 1981).

A focus group interview (approximately 40 mins) was conducted with six randomly chosen students after the completion of each teaching sequence. The focus was on students' experiences during the set of lessons, their assessment of their learning and the nature of the learning environment. Field notes also recorded the school environment and resources (Lawrence & Green, 1995).

The Reformed Teaching Observation Protocol (RTOP) protocol (Piburn & Sawada, 2000) was adopted to capture those characteristics that define "reformed teaching" and contains twenty-five items, with each rated on a scale from 0 (not observed) to 4 (very descriptive). Piburn and Sawoda grouped items with similar patterns of factor loadings that revealed five dimensions of reformed teaching, namely, (1) a pedagogy of inquiry teaching, (2) content or subject-matter knowledge, (3) pedagogical content knowledge, (4) community of learners and (5) reformed teaching which represented how teachers encouraged divergence of thinking and capitalised on students' input. RTOP thus allowed documentation of the balance of content knowledge evident in the lessons with aspects of pedagogical knowledge.

Field noteswere also recorded of the school environment and resources (Lawrence & Green, 1995).

Thus as is appropriate in a case study design a range of different sources of data were utilised and collected over an extended period of time and analysed by at least one of the researchers and a trained research assistant. The participant, Abi, during debriefing sessions also contributed to data analysis enhancing credibility of our interpretations. Multiple sources of data ensured consistency in our interpretations. These elements align with Patton's (2002) criteria for trustworthiness in post-positivist research.

The following approach to data analysis was adopted. Audio recordings from the extended interviews were transcribed verbatim. Data analysis proceeded through two cycles (Saldana, 2009). The first cycle comprised descriptive coding in which the interesting events that occurred over the three years were identified. From these events we selected a set of lessons on microscopy for further analysis and a second cycle of coding. This set of lessons, taught in 2009, was of particular interest as stated above as it provided an opportunity for Abi to exploit her substantial knowledge of the content. We assumed that her specialised content knowledge (CCK), strategic knowledge in microbiology (SCK) and interests would be aligned and hence optimise conditions for teaching. The second cycle involved a priori coding where categories were established from the theoretical framework of Hill et al., (2008) described previously. For example, we sought evidence of practices or utterances the exhibited levels of microbiological knowledge (CCK, SCK, KH). One of the researchers and a research assistant analysed these data reaching consensus on coding. Further analysis of classroom observations were analysed using RTOP by two research assistants and one of the authors. Abi also contributed to coding her own teaching using the RTOP instrument. Discrepancies in coding were reconciled through discussions. Analysis of focus group interviews was conducted more inductively whereby we sought to identify common themes raised by students during the sessions.

## Results

We commence by presenting a brief context of Abi's class, her perspective of the set of lessons and that of her students. We then analyse Abi's teaching knowledge through our adaptation of Hill et al.'s (2008) domain map of knowledge for teaching (Figure 1).

In the jurisdiction where this study was undertaken, Year 8 is the first year of high school. Students (ages ~ 13 yrs) are drawn from a number of primary schools, and hence, have varying experiences in science. The school was located in a relatively affluent metropolitan district with a diverse student body comprising mostly students of Caucasian heritage but with a minority being of East Asian background. Although there is no standardised testing of students, ability levels are assessed using school-based instruments and these results used to stream students in Year 8. Abi, in her first year of teaching, was assigned to an upper ability class. Observations of the class and reviews of the video tapes of approximately eight hours of teaching confirmed that generally students were engaged and apparently enjoyed the learning opportunities. For most students, the topic of microscopy was novel. As primary schools lack the sophisticated scientific equipment and students are taught by teachers with limited expertise in science, few of the students would have been exposed to the level of content presented by Abi.

The goal of these lessons was for students to become familiar with the use of microscopes and to examine a range of tissues and microbiological life in a pond in the school grounds. The first lesson was directive in that Abi provided background concepts concerning animal and plant cells adopting a lecture approach. In following lessons, after a brief formal introduction to set the stage for that lesson, students were allowed to proceed with their tasks using the microscopes to examine a range of sample tissues. Abi moved from group to group discussing what they were observing and providing guidance. She was quite competent in her knowledge of microscopes and cellular structure and encouraged students to explore variations in their own samples. Students were given flexibility in that they were able to choose their own tissues to examine. They were also encouraged to explore other aspects of the specimen. Those who finished early could attempt to reference their drawings with material in the textbook. There was a lot of student discussion, opportunity for problem solving in regard to the use of microscopes and preparation of slides, and interpretation of images viewed. Students were encouraged to observe differentiation between the various plant and animal cells to strengthen their conceptual understandings. Abi would draw attention particular interesting events such as the drawings of one student who had chosen some material from the pond. The lessons were well paced, students were generally on task and they had plenty of time to achieve the aims of the lesson. What was often missing was any closure in which students had opportunities to reflect on what they learnt, to explain their experience or for the teacher to draw some conclusions out of what was done.

Analysis of the videos of this and the subsequent lessons using the RTOP provides some perspective of the alignment of the lesson with principles purported to indicate a reformed inquiry oriented approach to science teaching. On a five-point scale the median occurrence on each of the dimensions described above was either 1 or 2 indicating limited implementation of reform-oriented pedagogical strategies. The exception was subject matter knowledge where the median occurrence was 3 which implied there was frequent evidence of practices that involved fundamental concepts of the subject, the promotion of strongly coherent conceptual understanding and related content to real world experiences. It was clearly evident in the lesson that Abi was explicit in presenting important procedural information relating to microscopy, and gave some choice to the students in the selection of material to examine. There were long periods of questioning and interaction between her and students. There was evidence that learning was being directed more by student investigations and questions emerging from observations than teacher delivery. However, she was directive in clarifying procedures and suggesting students vary their procedures rather than providing explanations in response to questions. RTOP analyses of lessons in subsequent years indicated marginal increase in the adoption of reform-oriented practices. For example, she adopted the use of group prepared concept maps that students shared through presentations which indicated that students were encouraged to represent phenomena in a variety of ways and communicate ideas to peers. Although she regularly used group work the primary purpose was managerial enabling students to access limited equipment.

In summary, analysis of the classroom video data indicated high Specialised Content Knowledge (SCK) but fewer instances of knowledge of content and students (KCS). That is, Abi focussed on information delivery rather than engaging in dialogical processes that encouraged students to explain or discuss their ideas. At times the explanations appeared to confuse students who struggled with the abstractness of the ideas. There was limited evidence that she sought to establish what knowledge students had of some topics.

We now turn our attention to Abi's reflections on the lesson. Abi perceived herself to have substantial capability in both *content* and *contextual* knowledge of science compared to her teacher colleagues. When discussing her teaching, she reflected:

> Content knowledge is no issue …Just comparing myself to some of the teachers that haven't got that background [scientist] ... I think I have a broader view [context], like I think sometimes I'm able to see things from much further back so they're [other teachers] right up at the front of the particular detail maybe of the subject that they're covering … but I think I have a perception of context … I can see that there's so much I can use to provide context for my kids. (Interview

2009)

This perspective reinforces the contention that Abi brings conceptual knowledge and knowledge of the culture and context in which STEM is practiced to her teaching. That is, she has common content knowledge (CCK) of science and specialized content knowledge (SCK). In addition, we would recognise elements of strategic knowledge in that she understood the implications and purpose of learning microbiology as is evident in her comments in the following section.

***How does a teacher with advanced subject knowledge apply this knowledge in instruction?***

Abi spoke explicitly about how she was able to apply her content knowledge to various contexts. For instance, in an interview, she gave the example of how her knowledge of microscopy supported learning through the narratives she was able to use with particular science topics.

> We've just started doing microscopes with the Grade 8s in the unit so we're doing sort of life under the microscope and I'd collected a bunch of images for them … Whereas I sort of talked to my kids more about the significance of microscopy and different things that it can be used for which I think maybe the other teachers, you know they had that narrow perspective that microscopes allow us to look at things at that small detail. (Abi, 2009)

However, Abi acknowledged that her ability to use stories in teaching science varied with the topic. Whereas she had stories for microscopy, she lacked stories for earth science. Hence, her specialized content knowledge (SCK) was restricted to her specific area of expertise.

> I find some topic[s] easier to do that, like the microscope one that we were doing today … I simply have those stories, they're just more accessible. …I have all the connections as well [for microbiology] but with something like — I know Earth science is something I'm shocking at ... it wasn't as obvious what I should tell them beyond just the flat definitions for them. (Abi, 2009)

Stories were clearly an important tool in Abi's repertoire and she compared her ability to identify suitable stories as "light bulb" moments similar to when students grasp a concept. "The kids are having their light bulb moment when they actually grab hold of the concept, but I'm having my own little light bulb moment and so I'm going 'that story really worked with the kids'" (Abi, 2009). Whereas students' light bulb moment related to content knowledge, Abi's related to pedagogy.

Abi also spoke about how she was able to supplement the core curriculum from her own experience. For microscopy, she added additional slides and photographs (SCK).

> Whereas I actually ended up talking to my kids about you know we looked at some cancer cells that were done using fluorescent microscopy. We looked at lots of different images like biological, like ecological field studies, where they were looking at animal structures and just did that breadth. (Abi, 2009)

> Today I was explaining to them we did an exercise with the microscope, like I actually put up all these different pictures of different things and ... I asked them which one of these is a micrograph of an artery... asking them what...which one they thought was an artery so I had 6 photos up and I had deliberately selected things that you might mistake for an artery so I had a cross section of a grape you know of a thick edge and then it had its cells in the middle so it would look a bit (like a vein). (Abi, 2009)

However, despite these initiatives, her approaches were not always successful. Abi commented that one of the students misinterpreted the slide of the grape as the slide of a vein. Her pedagogical purpose appeared to relate to encouraging students to reason about the slides but the task itself was overly challenging because they could not reason successfully due to a lack of content knowledge and Abi ultimately gave them the answer.

> And one of the kids did exactly what I thought they would do and it was stained sort of blue around the outside and pink in the middle so they'd obviously …, I was like "Joe (pseudonym) why do you think that's it?" And he said, "It's red and white Miss you know because there's red cells in the middle and blue around the outside so that's a bit like vein" … Even though I knew I was about to tell him he was wrong, I compliment them on their reasoning so I said to Joe, "Excellent you're using what you know about blood and you're trying to work this out". And then when I came back to it and I gave them the answer. (Abi, 2009)

Although it is accepted pedagogical practice to problematise tasks to elevate the level of challenge, the tasks should be achievable by the students with the teacher's support. Resorting to supplying the answer suggests that there was no logical way for these particular students to be successful. Abi's questionable pedagogical approach using the grape could be explained by her novice teacher status. However, it is less easy to explain, why, with her professional scientific knowledge, she engaged her students in what was essentially a futile task because they lacked the knowledge to distinguish between the slides of a vein and a grape. This episode illustrates that although Abi exhibited a high level of specialized content knowledge (SCK), her knowledge of content and students (KCS) needs developing.

Abi drew on her expertise in another microscope lesson when students had the task of finding organisms in pond water. Reflecting on this lesson, Abi acknowledged it was problematic.

A[2]: (One task) was to look at the sample under the microscope and see if they could find an organism … The pond water that we have has several different organisms in it from small fish to worms, nematodes, all sorts of stuff.

R: Now there was a problem wasn't there, that there was no organisms in the water — because of the rain?

A: This was a bit of a disaster when I got them to do the research.

Abi's lack of forethought in asking the students to examine pond water diluted with fresh rainwater to identify organisms appears a basic oversight for a professional microbiologist. Hence, like the grape task, the pond task lacked opportunity for applying knowledge of microscopy. The task also illustrates that she focussed on her highly specialised knowledge grounded in a history of microbiological research (SCK) and was less conscious of other contextual issues such as the impact of rainwater on the environment (CCK).

Although Abi spoke at length about microscopy in her interview, and the associated content and context, only a few students commented about their learning in microscope lessons. Those who did revealed that their learning had two aspects. The practical use of the microscope as a tool was referred to by two students at quite basic levels: "I learnt that if you put your eye to a microscope it hurts" and "Just really looking in the microscopes, looking at the different levels (magnifications)." There was also the knowledge of cells and the practical element of staining cells with student interest piqued due to the practical tasks.

> My favourite thing was when we got to look at all the different cells and see what's inside them and that, and my group we saw two cells splitting apart. (SCK)

> The best part was dyeing (staining) the cells and looking at what cells through the microscope

[2] A represents Abi; R represents the Researcher.

> and looking how detailed they were. (SCK)
>
> (We learnt about) the structure of cells and what happens in the cells. (SCK)
>
> The prac we did was pretty cool because we were using microscopes to look at cells and it taught us not only how to use microscopes but seeing all the cells was pretty cool and yeah, they all looked amazing. (SCK)

Thus, there was clear evidence that the students were interested in microscopy and engaged in learning about specialized content knowledge.

Taking on the role of ‘didactikids’, Abi’s students had suggestions to improve her teaching about microscopy referring to explanations, use of technology and specialty microscopes. The students recognised her limitations in PCK.

> She could have maybe explained how to use the microscopes a little better. (KCS)
>
> Use different types of microscopes, like electron microscopes and that to help see it differently and see further. (KCT)
>
> She could have used a microscope that she could put up onto the big screen so that we could all see it better (KCS), and then we could all know what she's looking at and she could describe it to us and stuff. (KCT)

As Abi had advanced knowledge of microscopy, the students’ suggestions have merit. Two students also mentioned another content issue at a more general level relating to how she taught students who were already competent at the year level work.

> The only problem is that she doesn’t let anyone do the work before (independently), instead she just explains everything to everyone even when people know what to do. (KCS)
>
> I think she should teach other stuff to people who already know the stuff. Say, if we all already know the stuff in Year 8 science she should try to teach us some Year 9 stuff, or Year 10, and to

improve our knowledge. (KCS, KC)

The ability to advance students is often restricted by a teacher's knowledge base — a situation not relevant to Abi who had substantial content knowledge of microscopy (SCK). Again an issue of Abi's need to have a better understanding of student learning needs (KCS).

## Discussion

Abi commenced her teaching career with an assumed advantage of expert science content knowledge together with knowledge of applications of her knowledge. In our adaptation of Hill et al.'s (2008) framework, Abi was an expert particularly in her specialised content knowledge (SCK) and with a doctorate, at the forefront or horizon of her field (KH). Abi was confident in her own abilities and had the support of her administrators who shared that confidence. She was immediately interested in the intellectual work of the class and sharing her passion for microbiology. However, her expert subject-matter knowledge does not seem to have advantaged her students to a great extent, perhaps to the contrary. Her focus in teaching drew heavily on specialized knowledge while overlooking other general knowledge of science (CCK), for example the oversight evident in the impact of rain on the pond life. She also demonstrated limited flexibility in her approach to new situations. Her expertise was contextualised to a professional science laboratory and not the realities of a school environment and the need to confirm the existence of microbiological samples in the local pond. Abi's difficulties can further be explained by gaps or shortcomings in the domain map of her knowledge content for teaching (KCT) and her knowledge of students (KCS) (Hill et al., 2008).

Abi's pedagogical knowledge, like that of many novice teachers, still needs to develop. However, her limited understanding of professional knowledge (KCS) for teaching to some extent thwarted the achievement of intellectual outcomes. Presumably, her *knowledge of the curriculum* (KC) will develop over time. However, in addition to knowledge of the curriculum, she needs to develop *knowledge of content and students* (KCS) and *knowledge of content and teaching* (KCT). Lightbulb moments such as recognising that students were interested in narratives of which she had many illustrates the emergence of understanding of ways to deliver content (KCT). At present, Abi's KCS appears to be limited at this stage, with her students commenting that she provided too much information about how to do a task, when some students did not require this information. She also failed to recognise students' proficiency in the tasks she set, such as the grape slide she used. Thus, although Abi understood the importance of practical activity for learning in science, she needs to build her knowledge of what students can typically do at this year level (KCS). Abi also needs to develop her knowledge of content and teaching (KCT). Engaging students in a task in which they searched for nonexistent organisms in pond water showed a lack of KCT. However, Abi could have capitalised on her specialized subject knowledge (SCK) here to discuss some likely reasons why no organisms were present, thereby, introducing the relationship between rain and pond life. Each of these gaps in pedagogical knowledge (KCS, KCT, KC) is expected at least to some extent in a teacher who has changed careers from scientist to science teacher.

Individuals entering teaching training programs with science degrees, particularly doctorates, are assumed to have advanced subject matter knowledge and even knowledge at the horizon. However, Hill et al. posit that subject matter knowledge has two strands:

> *Common content knowledge* (CCK), roughly described as knowledge that is used in the work of teaching in common with how it is used in many other professions or occupations that also use mathematics, and *specialized content knowledge* (SCK), or the mathematical knowledge that allows teachers to engage in particular teaching tasks, including how to accurately represent mathematical ideas, provide mathematical explanations for common rules and problems, and examine unusual solutions methods to problems. (pp. 377-378)

Applied to science teaching, Abi has CCK. However, she needs to further develop SCK because the specialised knowledge of a science teacher differs from that of a scientist. In parallel, Ball et al. (2008) argue that there is a distinct difference between the work of mathematicians and that of mathematics teachers. They give the example of error analysis, which is part of the work of both mathematicians and mathematics teachers and argue that this work is done quite differently by each of these professionals:

> Although mathematicians engage in analyses of error, often of failed proofs, the analysis used to uncover a student error appears to be related to, but not the same as, other error analyses in the discipline. Furthermore, whereas teachers must process such analyses fluently, no demand exists for mathematicians to conduct their work quickly. (p. 397)

Applying this distinction to the work of a scientist and that of a science teacher, a plausible explanation for Abi's choice of a cross section of a grape on a microscope slide could be that for a scientist the grape slide illustrates a particular point, however this point was lost on the students whose knowledge of science was far less sophisticated than that of scientists and hence, their reasoning was misdirected. This distinction between the specialised knowledge of scientists and science teachers creates a conundrum because in order to be successful in teaching, to some extent, career-change scientists will have to modify their identity to think like teachers (For further discussion of the identity development of Abi and other career-change teachers see Watters and Diezmann (2012). From the perspective of preservice training, a career-change teacher seems to be pedagogically vulnerable, for example, by engaging students in activities where there is limited chance of success, such as identifying a grape slide and failing to capture organisms in the pond excursion. A further concern was to overlook the level of capability of students despite her personal capability in microscopy. These "pedagogical faux paxes" would be part of the learning of a traditional beginning teacher, however there are high expectations that career-change teacher will apply their subject matter knowledge, which needs to be accommodated in preservice training.

## Conclusion

This study has extended the literature on beginning science teachers by foregrounding the complex interactions between expertise in content knowledge (CK) and being a novice in teaching. Most beginning teachers focus on survival, classroom management, themselves and knowing what to teach. As Abi was confident in her knowledge of microbiology and passionate about the topic her focus was on sharing that knowledge. Her intention of establishing highly intellectual discussions and learning was constrained by her limitations in pedagogical content knowledge. She was held in high regard by her students but they recognised her limitations which created some tensions. Nevertheless, Abi perceived that the lessons were successful and hence felt confident in her pedagogical practices. Indeed, as indicated by further analysis of teaching in subsequent years her development of pedagogical knowledge was limited.

Abi's experiences were not unique among the participants in this longitudinal study. Although observations of experienced engineers revealed that they struggled with teaching year8 students basic algebra, and competent professional chemists struggled with fundamental ideas in chemistry, their self perceptions were always positive. A common theme was the level of confidence that the teachers had in their subject matter knowledge particularly if teaching within their field of expertise but limited understandings of students as learners and strategies to make content relevant to students. These findings are suggestive that their subject matter expertise and self-perceptions of successful teaching established levels of teacher efficacy that contested the need for further development of pedagogical knowledge. As Abi stated in a final interview about further professional development was a “waste of time”.

The arguments for training scientists to become STEM teachers are well intentioned. However, for career changers to be successful in the classroom, they need differential training that equips them to move fluidly between their familiar world of science with knowledgeable colleagues and the classroom world with less knowledgeable learners of science. For career-change teachers, the classroom world is paradoxical because they have years of classroom experience as learners. However, in the transition from student to teacher, career changers need to appreciate that this familiar world (classroom where they were a student) is now unfamiliar territory (contemporary classroom). Our adaptation of Hill et al’s (2008) domain map (Figure 1) highlights some of the unfamiliarities they will encounter and need to address for a successful transition. Holistically, career-change teachers, like Abi, need to transition from their roles as scientist to that of bricoleurs, a term coined by Lévi-Strauss (1962) to explain differences in types of knowledge. Reilly (2009) explains

> Instruction might well be understood as bricolage in that he (teacher) constructs opportunities that open spaces of possibility, not destined certainties. He understands the school year, not as a collection of units of study ready to be enacted, but rather as learning that is collaged and juxtaposed and made with students along the way. As such, he reuses strategies and texts, changing intention to match perceived need, pulling in materials he finds at hand as needed. (p. 383)

One application of bricolage, for Abi, would have been to draw on her orientation towards storytelling to relay another instance when no organisms were found in a sample and to have the students propose plausible explanations for why they failed to see specimens in the pond water. This process would have communicated to students that even professional scientists are sometimes unsuccessful but there is an underlying reason for their lack of success.

How this might be achieved for career changes like Abi will require addressing on multiple fronts. For example, most, but not all, these career changers are passionate about teaching and about their subject but this passion needs support within the schools. The relationships and support provided to career change teachers is problematic and elaborating on the experiences of the teachers in this cohort are beyond the scope of this paper. Suffice to say, that most were provided with limited support in their early teaching and their expertise and particular limitations were overlooked by administrators, and in some instances, these teachers were marginalised because of their perceived content expertise. The nature of this support and particularly the emphases that may be necessary in preservice education relates to building pedagogical knowledge. Over confidence in a teacher's belief that they are engaging students because they are experts in the content may need challenging. Career change teachers such as Abi were successful learners and struggled to understand why students did not understand the content that to them was obvious. Deeper understanding of KCT and KCS, that is knowledge of students as learners and how to engage them meaningfully with the content should be a core focus of their professional development and preservice courses.

The goal for Abi and other career changers is to develop the mindset of the bricoleur for use in tandem with their subject matter knowledge. However, the identity development of career-change teachers is not straightforward and requires that teachers are able to develop a sense of autonomy and confidence as teachers within a supportive work environment (Watters & Diezmann, 2012).

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