2016

Not a stale metaphor: The continued relevance of pedagogical content knowledge for science research and education

H. Emily Hayden
Iowa State University, ehayden@iastate.edu

Michelle Eades Baird
University at Buffalo

Not a stale metaphor: The continued relevance of pedagogical content knowledge for science research and education

Abstract

Pedagogical content knowledge (PCK) is a foundation for teacher standards such as the Interstate Teacher Assessment and Support Consortium (InTASC) (Council of Chief State School Officers, 2011) and a critical element of teacher preparation and professional development for multiple fields, including science teaching (Purzer, Moore, Baker, & Berland, 2014). But several years ago Settlage (2013) presented a powerful critique of PCK, rejecting the way it positions knowledge in the abstract, "solely ... what teachers store in their heads" (p. 10) and calling for more evidence connecting PCK conceptualisations to actual teaching activity. In truth, theoretical descriptions of PCK abound (Darling -Hammond & Bransford, 2005; Hashweh, 2005; Lee & Luft, 2008) and most utilise the lens of the researcher (Lee & Luft, 2008). While this helps us conceptualise teaching and imagine what could be, what is needed are more illustrations of what is.

Keywords

Pedagogical content knowledge, science, adaptive expertise, critical reflective inquiry, science instruction

Disciplines

Educational Assessment, Evaluation, and Research | Higher Education | Science and Mathematics Education

Comments

This manuscripts is published as Hayden , H. E. & Eades Baird, M. (2016). Not a stale metaphor: The continued relevance of pedagogical content knowledge for science research and education. Under review: Pedagogies: An International Journal. Posted with permission.

Not a Stale Metaphor: The Continued Relevance of Pedagogical Content Knowledge for Science Research and Education

Pedagogies: An International Journal

Corresponding author: H. Emily Hayden, PhD
Iowa State University
1550 Lagomarcino Hall
Ames, Iowa 50010
ehayden@iastate.edu

Michelle Eades Baird
University at Buffalo
Buffalo, NY

Pedagogical content knowledge (PCK) is a foundation for teacher standards such as the Interstate Teacher Assessment and Support Consortium (InTASC) (Council of Chief State School Officers, 2011) and a critical element of teacher preparation and professional development for multiple fields, including science teaching (Purzer, Moore, Baker, & Berland, 2014). But several years ago Settlage (2013) presented a powerful critique of PCK, rejecting the way it positions knowledge in the abstract, “solely … what teachers store in their heads” (p. 10) and calling for more evidence connecting PCK conceptualisations to actual teaching activity. In truth, theoretical descriptions of PCK abound (Darling-Hammond & Bransford, 2005; Hashweh, 2005; Lee & Luft, 2008) and most utilise the lens of the researcher (Lee & Luft, 2008). While this helps us conceptualise teaching and imagine what could be, what is needed are more illustrations of what *is.*

Abell (2008) asked if PCK is still a viable framework for teaching and educational research, and our conversations with colleagues raised similar concerns, especially when attempting to bridge the theory-to-practice gap and describe how PCK could be utilised as a framework for improving classroom teaching practice. A robust body of research positions reflective inquiry as the foundation for adaptive teaching practices (Author, 2013; Korthagen & Vasalos, 2005; Loughran, 2010; Rodgers & Raider-Roth, 2006) and during reflection pedagogical knowledge and content knowledge elements of PCK can be combined with observations of students’ responses, resulting in renewed and revised instructional actions. Such reflective, adaptive inquiry utilises the integrative knowledge that is PCK (Gess-Newsome, 1999) and the resulting instructional actions enact PCK: they put into action the amalgamation of content and pedagogical knowledge (Shulman, 1987) with “particular inner knowledge” (Borowski, et al., 2012, p. 25) unique to the teacher, the context, and the students at hand. Our purpose is to describe empirically the connection between reflective, adaptive inquiry and instructional actions that turn PCK into action, as viewed through the lens of a practicing teacher.

The Problem with Pedagogical Content Knowledge

The link between conceptualizations of PCK and enactment of PCK in teaching practice is complicated by several challenges to clarity. For example, Borowski and colleagues (2012) categorised four divergences in the literature about PCK. First, the nature of PCK is contested: is it unalterable, or does it change with experience and certain types of preparation and professional development? Second, how should we model PCK? Is it a knowledge base, a product of practice, or both? Third, should PCK be studied at the micro (topic) or macro (domain) level? And finally, where should the emphasis of research on PCK occur: in the translation of teacher knowledge to practice, or in the relationship between teachers' PCK and student results? Even more vital concerns are raised by Settlage (2013): that PCK 1) is silent on issues of diversity, multiculturalism, and equity in education; 2) promotes passive versus active views of knowledge; and 3) offers nothing of substance for dealing with the much-studied topic of student misconceptions. If these concerns are valid, then PCK holds very little value for current classroom research and teaching, and contains nothing to help improve understandings of diversity, multiculturalism, and equity, and promote engaged learning and responsive, adaptive teaching.

PCK: A Framework for Action

We believe differently. We believe PCK is grounded in a focus on student learning and thus responsive to diversity, multiculturalism, and equity at this fundamental level. When defined this way, PCK becomes a framework for action because it induces teachers to notice and address student misconceptions, and teach in ways that honor both the curriculum and the students at hand. We base our beliefs on studies of master teachers in action in both classroom (Author, 2013; Author 2016) and clinical settings (Author, 2012a, b). Here, we present findings from our analysis of one master teacher's reflection and specific decision making for instructional action in a 7th grade science classroom in order to describe her enacted PCK practice, and we use these descriptions to consider each of Settlage's (2013) critiques.

Literature

PCK is a complex construct, "difficult to articulate" (Lee & Luft, 2008, p. 1360) but in need of a shift from abstract to concrete (Berry, Loughran, & van Driel, 2008; Lederman & Gess-Newsome, 1992) if it is to be useful to teaching practice (Settlage, 2013). There is wide acknowledgement that expert teachers enact a particular body of knowledge consisting of methods for combining content and adapting pedagogy to present their discipline in ways that honor their students' learning needs as well as the content (Borowski et al., 2012; Corno, 2008; Duffy, 2005; Loewenberg Ball, Thames, & Phelps, 2008; Vaughn & Parsons, 2013). Shulman (1986; 1987) first drew attention to this overlap between pedagogical knowledge and content knowledge, and Abell (2008) further described PCK as the dynamic transformation of many types of knowledge, with content as the central factor. This transformation involves more than subject area expertise and more than pedagogy: it is applied knowledge unique to teaching (Borowski, et al., 2012; Shulman, 1986;1987) and "constituted by what a teacher knows, what a teacher does, and the reasons for the teacher's actions" (Baxter & Lederman 1999, p. 158).

We agree with Shulman's (1987) definition of PCK as a kind of knowledge unique to teaching, separate from other knowledge bases that teachers utilize: knowledge of students, of teaching, of curriculum, and so on (p. 8). But we also agree with the many researchers who have lamented a lack of demonstration studies that could illustrate this unique and specialised knowledge (Borowski et al., 2012: Berry, et al., 2008; Hill, Ball, & Schilling, 2008; van Driel & Berry, 2012). Shulman himself (1987) made the case for working with practicing teachers to "develop codified representations of the practical pedagogical wisdom of able teachers" (p. 11). He argued that the lack of such detailed descriptions has contributed to methods of teacher training and evaluation that emphasise basic skills tests and behavioural checklists, thus trivializing teaching by ignoring its complexities and diminishing its demands (p. 6). Shulman cautioned against this reduction of teaching to checklists and observations free of content knowledge understanding, and van Driel and Berry (2012) expanded on his theme, asserting that demonstrations of enacted PCK would need to be more than "a set of specific guidelines to teach certain subject matter" (p. 27).

Such attempts would not capture the nuanced nature of PCK, and therein lies the problem: PCK is nuanced precisely because of its unique application. It is specific to aspects of content, context, and instruction, with methods not necessarily transferrable in whole or part to other content or contexts. Borowski et al., (2012) asserted that "neither content knowledge nor generic teaching skills alone are sufficient to be an effective teacher" (p. 29) but the situated nature of PCK becomes a problem when attempting to describe it in broader action.

Observing and Studying Situated Knowledge

The acknowledgement that teaching requires situated and special kinds of content knowledge (PCK) is worth exploring, and Loewenberg Ball and colleagues (2008) prompted researchers to "specify the nature" (p. 394) of this knowledge and how it is enacted with students. Examining teachers' unique ways of reflecting on their practice could reveal the instructional transformations teachers make to insure student learning (Loughran, Mulhall, & Berry, 2004) and examining teachers' unique ways of turning such reflection into action has been a focus of our work (Author, 2012; 2013). Here, we continue our efforts to do what Settlage (2013) advocated by "conscientiously pushing at the weak spots in PCK" (p. 5) to develop stronger, more resilient understandings of the ways teachers teach. Caution is required, because creating yet another list of "best practices" will not be useful. Such approaches tend to be overgeneralised in alarming ways that often lead to scripted instruction and a strictly technical view of teaching (Evans, 2007). What is needed are more descriptions of how teachers utilise, blend, and co-opt the multiple types of knowledge they possess to craft and deliver effective instruction in situated practice.

Studies have observed and explored PCK in various educational contexts (Baumert et al., 2010; Borowski et al., 2012; Lee & Luft, 2008; Loewenberg Ball, et al., 2008). Loewenberg Ball and colleagues (2008) distilled four unique knowledges of PCK for mathematics teaching: common content knowledge, specialised content knowledge, knowledge of content and teaching, and knowledge of content and students. More specifically, and within the field of science teaching, Lee and Luft (2008) asserted that PCK is "a class of knowledge … central to science teachers' work" and includes knowledge of content, goals, and students, with additional knowledges of resources, teaching, curriculum organization, and assessment identified at varied times during a teacher's career. Lee and Luft (2008) further clarified the situated nature of PCK, adding that this type of knowledge "would not typically be held by scientists or by teachers who know little science subject matter" (p. 1345).

Such frameworks are useful for clarifying the topics teachers consider as they make decisions and craft instructional actions. But it is our belief that enacted PCK in classroom teaching draws from all the knowledges Lee and Luft (2008) described, often integrating and considering several at a time during decision making. This integration of knowledges results in enactment steps a teacher takes in order to deliver instruction that honors both the content and the students at hand. The enactment is actual PCK: taking instructional action that integrates multiple knowledge bases in overlapping, blended, co-occurring, and clarified ways.

Purpose of This Study

To bring clarity and pragmatic purpose to understandings of PCK we need explorations of classroom enactment through the specific lens of teacher practice. With that in mind, the purpose of this research is to move beyond theoretical descriptions that produce propositions but no actions, and explore teacher reasoning that produces "judgment and action … in a context of uncertainty" (Shulman, 2007, p. 561). Results of this exploration could set the stage for more examinations of enacted PCK by describing knowledges and practices viewed through a teacher's interpretive lens, adding to the research base of descriptions of enacted PCK, and supporting a view of PCK as a construct that informs, inhabits, and transforms teaching practice instead of residing in what Settlage (2013) called a "stale metaphor" (p. 6).

Our focus was to explore PCK as the translation of teacher knowledge to practice (Borowski et al., 2012) and to push at the weak spots (Settlage, 2013) by providing more promising frameworks of teaching actions and teaching moves, instead of merely describing what teachers store in their heads. Through our analysis we found support for defining PCK as Loewenberg Ball et al. (2008) did, positioning it as "knowledge at the intersection of content and teaching" (p. 402) that coordinates the content at stake with instructional options, or pedagogy, and the characteristics of the moment. With these elements in mind we sought to describe both how a 7^{th} grade science teacher connected reflective inquiry with instructional adaptations, and what this enactment of PCK at the intersection of content and teaching can say with regard to Settlage's (2013) three critiques. How did one 7^{th} grade science teacher use reflective inquiry to formulate and enact instructional adaptations, and what do her actions, as enactment of PCK, have to offer to consideration of Settlage's (2013) critiques?

Method

Data Sources

Lee and Luft (2008) argued that educational researchers should credit the richness of expert teaching practice, and should provide representations of PCK that accurately reflect teachers' perspectives in addition to theoretical perspectives if we hope to influence learning processes of teachers. Thus, we analyzed one teacher's reflective inquiry process and subsequent instructional actions in a series of interviews over three academic years, using her descriptions as the lens through which we captured her teaching practice. Ann is a 7th grade science teacher who holds endorsements in middle level and elementary education, and is certified in English Language Arts (ELA). At the time of this study she had taught for 22 years: five years in 7th grade science and 17 prior years in English Language Arts for 4th through 6th grades. She had provided professional development and teacher leadership in her school and district for many years, and had participated in select national on-site science training and research experiences. These markers of expertise and leadership, combined with her extensive classroom practice rendered her practice and methods worthy of study.

Twelve open-ended interviews (60-90 minutes each) were conducted over three years, beginning in Ann's third year of teaching science. With grounded theory as our analytical method, initial analysis of the interview transcripts used critical incidents as the unit of analysis. We defined a critical incident as any time Ann used extended dialogue to describe decision making and teaching actions around an event. Transcripts from all years were coded independently by both authors, utilizing dual coding (Barry, Britten, Barber, Bradley, &

Stevenson, 1999) to insure validity. Transcripts were reviewed additional times by the first author to develop descriptive names for themes that emerged from the critical incidents identified over the three years of the study.

Analysis and Framework

Using theoretical coding we sought to weave data back into a coherent whole (Charmaz, 2006), conceptualizing how critical incidents identified Ann's enactment of PCK, and how her enactment might inform Settlage's (2013) critiques. Tables 1 and 2 provide a view of how and when enactment codes emerged during data analysis, the frequency of each, and which body of knowledge each code enacted. As we identified enactment codes, we returned to the literature to search for other researchers who might corroborate what we were seeing; others who might have documented PCK enacted in classroom practice. Loewenberg Ball et al. (2008) initially triangulated what we were seeing, and their definition of PCK as "knowledge at the intersection of content and teaching" (p. 402) was supported early in our analysis as we discovered the different ways Ann responded to her students by analysing and adapting her actions to make content accessible (see Table 1).

Most enactment codes were present in the first year of analysis, and there were many co-occurrences of enactment codes that are not depicted in the tables due to space considerations. But, as seen in Table 2, some enactment codes increased in prevalence and intensity in years two and three. Ann's growing familiarity with the interview process may have led to increased detail in her descriptions, allowing us a more complete picture of enacted PCK in her daily instructional life, and our continuing study of the literature across all the years of data collection and analysis helped us to notice and note these more prevalent, pressing occurrences and to make continuing connections to the knowledges of PCK.

In our review of the literature we discovered Lee and Luft (2008) who also delved deeply into the PCK processes of secondary science teaching. The Knowledges of PCK for science teaching they identified connected most directly with the enactment codes we discovered, and these Knowledges became the organizing conceptual framework for the data.

Many examples of Ann's enacted PCK emerged: incidents when she developed teaching actions that drew explicitly from multiple Knowledges to honor both the content and the students at hand. In order to visualise how she did this, and thus "develop codified representations of the practical pedagogical wisdom" of this able teacher (Shulman, 1987, p. 11) we had to deconstruct her instructional responses, discovering how her actions related to multiple, overlapping, co-occurring Knowledges. Thus, while Lee and Luft explored teachers' conceptualizations of PCK, divided into seven supporting Knowledges that science teachers store in their heads, our analysis focused on Ann's actions and how she combined and drew from those Knowledges to enact PCK. Table 3 details how Ann enacted PCK in all aspects of her teaching, showing which enactment codes supported each Knowledge (Lee & Luft, 2008) and providing examples from the transcripts that illuminate each enactment code.

As analysis proceeded we began to envision enacted PCK as a pathway that good teaching rests upon: separate steps a teacher might choose to take, each supported by a conceptual Knowledge base of PCK and each supporting effective teaching and learning. But because we did not discover any kind of hierarchy or order of development, nor do we mean to imply such, we instead envisioned enacted PCK as a pathway through a constantly changing landscape, such as in a forest or wetland. The steps on the pathway represent teaching actions that can give access to effective teaching and learning regardless of how the landscape, or teaching context, might shift.

The Knowledges of science teaching provided support for each of the steps: the teaching actions Ann used to enact PCK. Figure 1 presents our model of enacted PCK. Each teaching action Ann used to enact PCK is represented on a steppingstone that is undergirded by one of Lee and Luft's (2008) conceptual Knowledges of science teachers' PCK.

Results

Enactment of PCK

We present three vignettes here that situate Ann's enacted PCK during instructional decision making, teaching interactions, and mentoring of a student teacher. Within each vignette we discuss both the Knowledges of PCK, which we depicted in Figure 1 as the supports, as well as the *steppingstones*: how the Knowledge was enacted. The conceptual supports are denoted by capitalization (e.g. Knowledge of Teaching) while the enactment codes are denoted with italics (e.g. *problem identification*).

Teaching vocabulary. Our initial interviews with Ann revolved around discussion of an extant text: the 37 vocabulary terms that were part of the first nine-week unit of study, "Inside Earth", in her school district's science curriculum (Table 2). This extant text was not created by the researchers nor was it a product of the research experience, but it existed as part of the case and reflected shared definitions within our research topic (Charmaz, 2006). It was a framing element of our conversations because Ann had to make decisions about the use of this list. Successfully developing full knowledge of 37 vocabulary terms within nine weeks of study challenged notions of cognitive load for vocabulary learning (Fisher, 2007), so she needed some way to sort terms for differing instructional emphasis.

We introduced the three tier system (Beck, McKeown, & Kucan, 2002) as a way to address this extant text. Within any list of vocabulary terms some words are well known and need very little instruction. Beck et al., referred to these as Tier-1 words. Conversely, some words are very specific to certain contexts, and need to be known and used only within those contexts. These are Tier-3 words. In between are Tier-2 words: high frequency words for the mature language user. For teachers, these are the words that need to be heavily emphasised with students, and that are crucial for students to develop full meaning knowledge of, because these are words students will encounter repeatedly as they progress through school and move into later careers.

Ann's decision making process around the vocabulary list utilised the conceptual supports of Knowledge of Teaching and Knowledge of Students. She enacted these conceptual supports through *problem identification*: including her consideration of what students are likely to think and what will be confusing, the most interesting, motivating examples for students, what students will likely do with a task, and whether they will find it easy or hard (Loewenberg Ball et al., 2008; Shulman, 1986). Teaching these vocabulary terms required Ann to enact *evidence of student knowledge* to hear and interpret students' emerging and incomplete thinking, and to consider misconceptions students were likely to hold (Sadler et al., 2013).

Utilizing this and subsequent unit lists Ann selected ten words per semester for special emphasis. She did this by combining tier guidelines with her conceptual Knowledge of Science: utilizing the *science concepts* students needed to master. Her initial analysis revealed Tier-1, well known words: (earthquake, volcano); Tier-2 words with multiple meanings across contexts (crust, mantle), or likely to recur in science curricula (granite, inner/outer core) and Tier-3 specialised words (asthenosphere, lithosphere).

Tier-2 words warrant the most instructional time (Beck et al., 2002) because they are high frequency words for mature language users, and most useful for current and future learning. Tier-3 words warrant "point-of-contact" teaching because they are highly specialised and infrequently appearing. Ann's sorting and decision making process for these 37 words balanced these considerations with required science learning. Separate analysis of the list by the researchers revealed different considerations brought to the task by those outside of content area teaching. Author One looked at the list (Table 2) and quickly judged several words as Tier-3 and worth mere point-of-contact teaching. But Ann spent extended time considering how each word supported and built necessary conceptual categories.

> [Students] need to know crust, mantle, outer core, inner core. And with mantle there's the lithosphere and asthenosphere. [Honestly] I'm not certain they need to know those two parts of the mantle. I think they have to be aware of them, and know they exist … And they're going to have to know the rock cycle. And the rock cycle has to do with the lithosphere. The only two I really need to think about then are do I really want [students] to know lithosphere and asthenosphere as part of [Tier-2 high emphasis list] or if knowing them within the context … I'm thinking that is enough. So lithosphere and asthenosphere may not be on my [Tier-2 list].

Teachers hold specialised knowledge for teaching and "they bring … knowledge of students, craft, and school structure that others cannot" (American Association for the Advancement of Science, 1989, p. 212). Ann's process illustrated this unique knowledge that is required "at the intersection of content and teaching" (Loewenberg Ball et al., 2008, p. 402): and her analysis revealed how she enacted this specialised knowledge to plan for instruction to support student learning.

Although lithosphere and asthenosphere occur infrequently and in very specific contexts (Tier-3) it was impossible for Ann to treat the terms lightly. She had to consider what students would be expected to know in upcoming content and assessments and how to provide access to that knowledge for her students. Clearly, simply talking about the academic values of Tier-2 versus Tier-3 words was of little use to Ann without her additional consideration of science content, student needs, and how students would react to the word-learning task. This represents enactment of PCK because she had to go beyond her Knowledge of Teaching and beyond her Knowledge of Curriculum Organisation and Knowledge of Assessment. She had to enact these knowledges of science PCK (Lee & Luft, 2008) by using the Tier framework as a *pedagogical tool*, engaging in extensive *curricular analysis* including the list of 37 words from her unit as well as state and local standards, and considering standardised *asssessments* as well. She enacted *problem identification*, and *generating solutions* in order to make instructional decisions that incorporated her Knowledge of Students and were considerate of her students' needs and how her students would engage with the word-learning task.

Ann utilised this integrative knowledge (Gess-Newsome, 1999) of content and pedagogy to select words for special focus that would push her students' thinking and concept development forward. She further integrated these with understanding of the moment: her students, their development, the likely manner of how conceptual development happens for 7^{th} grade science learners. This amalgamation of content and pedagogical knowledge with "particular inner knowledge" (Borowski, et al., 2012, p. 25) reflected Ann's ability to draw from multiple conceptual knowledges of PCK and make decisions that enacted the most pertinent features of each in her instructional choices.

Later, when Ann introduced the 37-word list to students she used the *pedagogical tool* of the Tier terminology in her explanations, leveraging Knowledge of Students with Knowledge of Teaching to make her thinking transparent by *describing* this as an effective technique for learning: differentiating importance of topics.

> I've used that language with the [students] too; "These are Tier-2 words, words that you will come in contact with later in science, and Tier-3: these words go with the other words in some way. You won't hear those spoken as often as you will crust, mantle, inner core and outer core."

Within vocabulary research, teachers are often encouraged to continue to share with their students the underlying system for our language: that words are built from meaning chunks (prefixes, suffixes, Greek roots, Latin stems). While students will not immediately grasp this underlying language system, over time and with repeated exposures it will become more naturally understood. The same could be true of organizational systems such as the Tier framework. Over time, as students are repeatedly exposed to such ways of thinking about complex information, these habits of mind will become more natural and available for the students' own appropriation. This sharing act reflects Ann's deep conceptual Knowledge of Students: a result of her consideration of what students will need for successful *engagement* with the task, now and in the future. Ann continued to revisit these required word lists throughout the study, and to revise her decisions in light of deeper *curricular analysis* and consideration of *science concepts*.

Active learner stance. In addition to leveraging different conceptual understandings of PCK, Ann described an intriguing capacity to view science content and instructional activities from a learner's stance. By taking this stance Ann could be especially attuned and present to areas of possible confusion within topics (Sadler et al., 2013). By enacting her Knowledge of Teaching in the form of *task analysis* she was able to use this learner stance when analysing curriculum.

> I break everything down into pieces. I need to think about how is this going to be understood. If I'm having trouble understanding it, how am I going to break it down for myself so I can understand it? That way I can turn it into something that the kids will understand as well. I can model it for them, and then I can teach it and they can apply it.

Ann's dual stance of learner/teacher helped her be "alive to [students'] thinking, affect, and learning" (Rodgers & Raider-Roth, 2006, p. 211), and to enact PCK by adapting content and pedagogy to the diverse interests and abilities of learners in her classroom (Shulman, 1987). She shared this *task analysis* with her student teachers, while also describing how she identified and utilised *student knowledge* and *student engagement*: enactments of her Knowledge of Students.

> I tell [student teachers], "You have to break down all the parts of that lesson so you understand what [you're] wanting students to learn. If you don't break it down enough, something in your lesson is going to fail or you're going to see this look on someone's face: 'I don't get it! I don't understand!' And that's the point where you didn't break it down enough for that student. [Ask yourself] "How else can I make it work so that they understand it better?"

Being present to the responses of her students supported Ann's critiques and deconstruction of the science curriculum and her "understanding of what makes … learning … specific topics easy or difficult [and] … the strategies most likely to be fruitful in reorganizing the understanding of learners" (Shulman, 1986, p. 9-10). Sadler et al. (2013) referred to this as "knowledge of student misconceptions" (p. 1024): an area of teacher knowledge that is understudied in science teaching but crucial to student learning and effective teaching (Nilsson, 2014) especially in areas that are likely to be misunderstood.

Another vignette more fully illustrates Ann's responses to students' confusions and her ability to "hear and interpret students' emerging and incomplete thinking" (Loewenberg Ball et al., 2008, p. 401) in an activity involving planting and plant life cycles.

> [My students said] "What am I supposed to do with this? Do you need to have the root?" [I said] "I think we do." "What if it breaks off?" I said, "Well, what do you think will happen?" I mean, they have *no idea*. And they're so excited now because we're going to grow radishes and lettuce and I said to myself, "I can't let this go! We've got to grow this stuff" and they say, "Will we be able to eat it?" [I said] "Well, I've never done this before: maybe we will and maybe we won't, let's see!"

Ann seized her students' emerging, incomplete thinking about plants as an example that would be useful and meaningful in a number of ways. This became a springboard to lessons on the scientific method:

> The next thing we did was a CD plant. We had a CD case. We put a line through the middle and [lined it with] a coffee filter. I got this idea at a conference last fall [and] modified it to use it for the scientific method. We talked about what a controlled variable was: one change, so … we put five radish seeds on one side, five lettuce seeds on the other side and let them grow. [Students] had to work together to write their question, they had to work together to write their hypothesis, create a data table, and then write their interpretation and conclusion.

Utilizing emerging, incomplete thinking to identify an interesting, motivating topic for students, then combining this with her Knowledge of Resources and recalling an idea from a conference to enact an *activity* specific to students' needs demonstrates Ann's response to the requirement for "knowledge at the intersection of content and teaching" (Loewenberg Ball et al., 2008, p. 402).

She combined the content: plant life cycles and the scientific method (Knowledge of Science, *science concepts*), with a resource from professional development: the CD plant activity. She enacted PCK at this intersection by adjusting the CD *activity* to provide an *engaging* (Knowledge of Students) and systematic application of the scientific method.

PCK for teacher development. The previous vignettes demonstrate the usefulness of PCK as a conceptual framework that can be enacted for instructional practice. The following demonstrates its usefulness in thinking about teacher development. Ann described how she made her enacted PCK habits of mind explicit while working with a student teacher to co-plan a unit on force and motion.

> [The student teacher] tends to jump into things quickly without thinking through, so I'm the piece of the puzzle that helps her reframe and connect. We were drawing things out on the board, trying to understand, trying to come to a conclusion so we could reframe this activity [from] the book to make sense where we want to go with our students versus doing it the way [the book] suggests. She sketched some ideas down and I said, "Take this home, come back tomorrow with a lesson, reframing the data table, and we can add anything we need". [Student teacher] says, "You've got to think about it this way or that way", and then I say, "We need to break this down more for these kids because I can see we need more with this and this, so I know the kids are going to need this and that". I guarantee we have several [students] that have some needs, they don't get math to begin with. So when we do both these activities, we're going to do them as partners and it's really going to test their brains on thinking. I want [student teachers] to really examine how well do you think when you do this? What are you using, what kinds of thinking is going on?

In this vignette Ann surfaces the likely confusions and needs of students, making them apparent for her student teacher and providing a planning scaffold that includes thinking about the enacted PCK that will need to happen when content and teaching intersect with student needs. While her student teacher brings Knowledge of Curriculum Organisation and *curricular analysis* to the lesson-planning task, Ann pushes her to also enact Knowledge of Students by thinking about *student engagement* and *evidence of student knowledge*, and Knowledge of Teaching in the forms of *task analysis*, *problem identification*, *generating solutions*, and *scaffolding*.

This is an important piece of learning that Ann, as an expert, can share with her novice student teacher since it contextualises the conceptual framework of PCK and transforms it to action. Beyond Knowledge of Curriculum Organisation and *curricular analysis*, successful teachers must also bring Knowledge of Students and Knowledge of Teaching to instructional tasks. Instruction will not be successful without translating theory into practice, and concept into action. In this vignette Ann showed her student teacher how to combine the Knowledge of Curriculum Organisation she had gained from her teacher preparation programme with other Knowledges she will use as a practicing teacher. Ann described her own habits of mind to her student teacher, and showed how to embody her teaching by being present to the experiences and ways of thinking students bring to learning tasks.

Responding to Settlage

The concerns Settlage (2013) raised with PCK as it is currently conceptualised served as alerts to those in the research community who wish to validate and promote the complex and highly specialised work of teachers. Settlage charged that PCK is silent on issues of diversity and equity, promotes views of knowledge as passive versus active, and ignores the research on teachers' responses to student misconceptions. In our analysis of Ann's enacted PCK we found responses to these concerns, and evidence that enacted PCK has much to offset these critiques.

Concern #1: issues of equity. When a teacher engages in instructional planning that foregrounds students' needs she enacts equity at a most basic level. Ann promoted action for equity through her own planning as well as through her mentoring of student teachers, by modeling and enacting PCK and turning conceptual processes into teaching actions. When Ann enacted *task analysis, problem identification*, and knowledge of *science concepts* she transformed her conceptual Knowledges of Teaching and Science using a student-focused lens, foregrounding her students' likely responses to the content and what they would need to gain from the unit of instruction. She used the *pedagogical tool* of the Tier framework to sort the 37 vocabulary words based on their usefulness for building concept knowledge, and leveraged her Knowledge of Students to include consideration of how they would *engage* with the curriculum and what they would be likely to think (*student knowledge*). Ann not only kept student needs at the forefront of her own planning, she brought awareness of this way of thinking to her student teacher's attention as well when she directed her to consider the different needs of students and explicitly guided her to a *scaffolding* strategy to accommodate math challenges and make content accessible to all students.

Concern #2: Knowledge as an activity. Ann's ability to slip into learner stance to view curriculum and generate possible questions and misunderstandings was metacognition transformed to action, and enactment of knowledge at the intersection of content and teaching. Ann described a dual role, thinking about curriculum from the stance of a teacher as well as the stance of a student. She used action verbs in her descriptions, talking about breaking everything down into pieces, breaking it down for herself so she could then "turn it into something that the kids will understand as well”. Her analytical process aimed to move students from concrete actions to developing broader conceptual application: “[I] model it for them, then I can teach it, and they can apply it.” This action-to-application work Ann constructed for herself and her students is in direct contrast to Settlage’s (2013) concern that PCK is an abstraction that describes merely what teachers store in their heads. It is also an authentic description of the enactment of the gradual release of responsibility (Pearson & Gallagher, 1983).

Ann’s stances and actions during planning help her to be “alive to [students’] thinking … and learning” (Rodgers & Raider-Roth, 2006, p. 211). Because of this, she was able to plan for possibilities that the student teachers she worked with could not yet imagine. Ann was generous in sharing this knowledge with her student teachers, and by doing so she provided concrete models for the teaching of knowledge in action that is the unique province of practicing teachers and that comes to fruition whenever teachers make thoughtful instructional decisions at the intersection of content and teaching.

Concern #3: Student Misconceptions. Another of Settlage’s (2013) critiques of PCK was that it offers little to address student misconceptions. But Ann was uniquely present to the responses of her students, and her presence was evident in her critiques and deconstruction of the *science concepts* and her “understanding of what makes … learning … specific topics easy or difficult [and] … the strategies most likely to be fruitful in reorganizing the understanding of learners” (Shulman, 1986, p. 9-10). This knowledge of student misconceptions is crucial to student learning and effective teaching (Nilsson, 2014; Sadler et al., 2013).

In describing the unit on plant life Ann clarified how she used her students’ incomplete knowledge and misconceptions as springboards for instructional planning: “I said to myself, ‘I can’t let this go!’” Her ability to “hear and interpret students’ emerging and incomplete thinking”

(Loewenberg Ball et al., 2008, p. 401) led her to enact conceptual Knowledge of Resources with *activity*: using a CD case planter to provide concrete experiences with the plant life cycle. She recognised this highly interesting and motivating example for her students and used it as an opportunity to apply the scientific method by turning students' questioning and exploration toward the disciplined process of scientific inquiry, connecting the *science concept* (scientific method) to concrete questions and application.

Loewenberg Ball and colleagues (2008) observed that some representations are especially powerful, and others, although technically correct, do not open ideas as effectively. Ann was attuned to her students' misconceptions, and used them as windows of opportunity. Her view through these windows led her to plan activities that capitalised on emergent and incomplete thinking, and extended learning. In this analysis, Ann used her Knowledges of Science and of Resources as the primary tools for planning based on her observations of misconceptions, but it was her Knowledge of Students and her ability to be present to their learning that really opened up the possibilities for rich instruction. Contrary to Settlage's (2013) critiques, Ann saw and capitalised on students' misconceptions, enacting PCK in ways that pushed student learning forward from there.

Conclusions

Is PCK a viable construct for analysing and advancing the real work of classroom teaching? We believe it is, and have specified how Ann enacted PCK to support student learning. This research bridges the theory to practice gap by revealing how she integrated multiple conceptual knowledge bases into her decision-making and teaching practice, and adding to the base of descriptions of the "practical pedagogical wisdom of able teachers" (Shulman, 1987, p. 11). Additionally, the enactments we have described could be useful in future work with novice teachers, since they identify key actions novices could rehearse as part of their teacher training, a practice Lampert et al. (2013) found to be valuable.

Referring again to our conceptualisation of enacted PCK as a raised walkway through a changing landscape (Figure 1) it is interesting to note that our analysis revealed a number of enactment themes for Ann's conceptual Knowledge of Teaching: *pedagogical tools, task analysis*, *problem identification*, *generating solutions*, and *scaffolding*. In the translation of any theory (vocabulary learning, PCK, scientific method) into practice it is easy to become mired down, and it seems logical a teacher would need many tools to enact this particular body of knowledge. Our analysis revealed Ann's abundance of tools for utilising her Knowledge of Teaching, and the particular ways she leveraged these with tools to enact Knowledge of Students, Knowledge of Curriculum Organisation, and more.

Further, we believe that PCK continues to hold distinctive value in the forum of public scholarship as a way to talk and think about the work of teachers. Ann's descriptions provide a foundation for understanding how teachers integrate the multiple knowledge bases of teaching and how they transform conceptualisations of PCK into action. Her descriptions also provide insight into how such patterns of transformative, analytical thinking can be shared with student teachers, helping them to develop awareness of the integrative knowledge (Gess-Newsome, 1999) that effective teaching requires, including reflecting, adapting, and planning; with content, pedagogy, and characteristics of the moment in mind. Our hope is that other researchers will take up this work with teachers in varied content areas to explore and describe the ways teachers turn reflection on all the conceptual knowledge bases of teaching their content into instructional actions that benefit the learning of their students.

Limitations

The results reported here reflect the teaching descriptions of one middle school science teacher. As a result, findings should be interpreted with care, and broad generalizations cannot be made. It is worth noting that PCK enactment codes emerged or reappeared with increased depth or prevalence throughout the second and third years of interviews with Ann (Table 2) indicating that this analysis was able to represent the complexity and nuance of this broad body of teacher knowledge. Ann's personal profile also lends weight to the findings reported here: she has extensive teaching experience in several middle level grades and content areas, in addition to leadership roles within her district and involvement in national select science research projects.

While the work begun by Shulman (1986;1987) did much to focus attention on the unique tasks of teaching and the distinct bodies of knowledge teachers navigate and converge in their daily work, it is profiles of teachers like Ann that will ultimately give meaning to the conceptual findings of Shulman (1986, 1987) Loewenberg Ball et al., (2008) and others. Meeting students at the intersection of content and teaching, and moving learning forward demands this kind of work.

References

Abell, S. K. (2008). Twenty years later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education, 30(10)*, 1405-1416.

American Association for the Advancement of Science (1989). *Science for all Americans: A Project 2061 report on literacy goals in science, mathematics, and technology.* Washington, DC: Author.

Barry, C.A., Britten, N., Barber, N., Bradley, C., & Stevenson, F. (1999). Using reflexivity to optimize teamwork in qualitative research. *Qualitative Health Research, 9(26)*, 26-44.

Baumert, J., Kinter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., Kulsmann, U., Krauss, S., Neubrand, M., Tsai, Y. (2010). Teachers' mathematical knowledge, cognitive action in the classroom, and student progress. American Educational Research Journal, 47(1)133–180. DOI: 10.3102/0002831209345157

Beck, I. L., McKeown, M. G., & Kucan, L. (2002). *Bring Words to Life: Robust Vocabulary Instruction*. New York: Guilford Press.

Berry, A., Loughran, J., & van Driel, J. H. (2008). Revisiting the roots of pedagogical content knowledge. *International Journal of Science Education*, 30(10), 1271-1279, DOI: 10.1080/09500690801998885

Borowski, A., Carlson, J., Fischer, H. E., Henze, I., Gess-Newsome, J., Kirschner, S., & van Driel, J. (2012). Different models and methods to measure teachers' pedagogical content knowledge. In C. Bruguiere, A. Tiberghien, & P. Clement (Eds.), E-Book Proceedings of the ESERA 2011 Conference: Science Learning and Citizenship. Part 13. Co-editors Jouni Viiri and Digna Couso, pp. 25-36. Lyon, France: European Science Education Research Association.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis.* Thousand Oaks, CA: Sage Publications Incorporated.

Corno, L. (2008). On teaching adaptively. *Educational Psychologist*, *43*(3), 161–173. doi:10.1080/00461520802178466

Council of Chief State School Officers, (2011, April). *Interstate Teacher Assessment and Support Consortium (InTASC) Model Core Teaching Standards: A Resource for State Dialogue*. Washington, DC.

Darling-Hammond, L., & Bransford, J. (Eds.). (2005). *Preparing teachers for a changing world: What teachers should learn and be able to do*. San Francisco, CA: Jossey-Bass.

Duffy, G. G. (2005). Developing metacognitive teachers: Visioning and the expert's changing role in teacher education and professional development. In S. Israel, C. Block, K. Bauserman, & K. Kinnucan-Welsch (Eds.), *Metacognition in literacy learning: Theory, assessment, instruction, and professional development* (pp. 299–314). Mahwah, NJ: Erlbaum.

Evans, R. (2007). Existing practice is not the template. *Educational Researcher*, 36(9), 553-559. doi:10.3102/0013189X07313149

Fisher, D. (2007). Creating a schoolwide vocabulary initiative in an urban high school. *Journal of Education for Students Placed at Risk*, *12*(3), 337-351.

Gess-Newsome, J. (1999). PCK: An introduction and orientation. In J. Gess-Newsome and N. Lederman (Eds.) *Examining PCK: The construct and its implications for science education* (pp. 3-20). The Netherlands: Kluwer Academic Publishers.

Hashweh, M. Z., (2005). Teacher pedagogical constructions: A reconfiguration of pedagogical content knowledge. *Teachers and Teaching*, 11(3), 273-292.

Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking pedagogical content knowledge: Conceptualizing and measuring teachers' topic-specific knowledge of students. *Journal for Research in Mathematics Education*, 39(4), 372-400.

Korthagen, F., & Vasalos, A. (2005). Levels in reflection: Core reflection as a means to enhance professional growth. Teachers and Teaching: Theory and Practice, 11(1), 47–71. doi: 10.1080/1354060042000337093.

Lampert, M., Franke, M. L., Kazemi, E., Ghousseini, H., Turrou, A. C., Beasley, H., Cunard, A., & Crowe, K. (2013). Keeping it complex: Using rehearsals to support novice teacher learning of ambitious teaching. *Journal of Teacher Education*, 64(3), 226-243.

Lederman, N. G., & Gess-Newsome. J. (1992). Do subject matter knowledge, and pedagogical content knowledge constitute the ideal gas law of science teaching? *Journal of Science Teacher Education*, 3(1), 16–20.

Lee, E, & Luft, J. A. (2008). Experienced Secondary Science Teachers' Representation of Pedagogical Content Knowledge. *International Journal of Science Education*, 30(10), 1343-1363. DOI: 10.1080/09500690802187058

Loewenberg Ball, D., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching. What makes it special? *Journal of Teacher Education*, *59(5)*, 389-407.

Loughran, J. (2010). What expert teachers do: Enhancing professional knowledge for classroom practice. New York, NY: Routledge.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370–391.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.

Nilsson, P. (2014). When teaching makes a difference: Developing science teachers' pedagogical content knowledge through learning study. International Journal of Science Education, 36(11), 1794-1814, DOI: 10.1080/09500693.2013.879621

Pearson, P. D., & Gallagher, M. (1983). The instruction of reading comprehension. *Contemporary Educational Psychology*, 8, 317-344.

Purzer, S., Moore, T., Baker, D., & Berland, L. (2014). *Supporting the implementation of the Next Generation Science Standards (NGSS) through research: Engineering.* Retrieved from https://narst.org/ngsspapers/engineering.cfm

Rodgers, C. R. & Raider-Roth, M. B. (2006). Presence in teaching. *Teachers and Teaching: Theory and Practice,* 12(3), 265-287.

Sadler, P. M., Sonnert, G., Coyle, H. P., Cook-Smith, N., & Miller, J. L. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. *American Educational Research Journal*, *50*(5), 1020-1049.

Settlage, J. (2013). On acknowledging PCK's shortcomings. *Journal of Science Teacher Education, 24,* 1-12.

Shulman, L. S. (2007). Practical wisdom in the service of professional practice. *Educational Researcher*, 36(9), 560-563. doi: 10.3102/0013189X97313150

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57,* 1-22.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher,* 15, 4–14. doi:10.2307/1175860 van Driel, J. H. & Berry, A. (2012). Teacher professional development focusing on pedagogical content knowledge. *Educational Researcher*, 41(1) 26-28. DOI: 10.3102/0013189X11431010

Vaughn, M., & Parsons, S. A. (2013). Adaptive teachers as innovators: Instructional adaptations opening spaces for enhanced literacy learning. *Language Arts*, 91(2), 81-93.

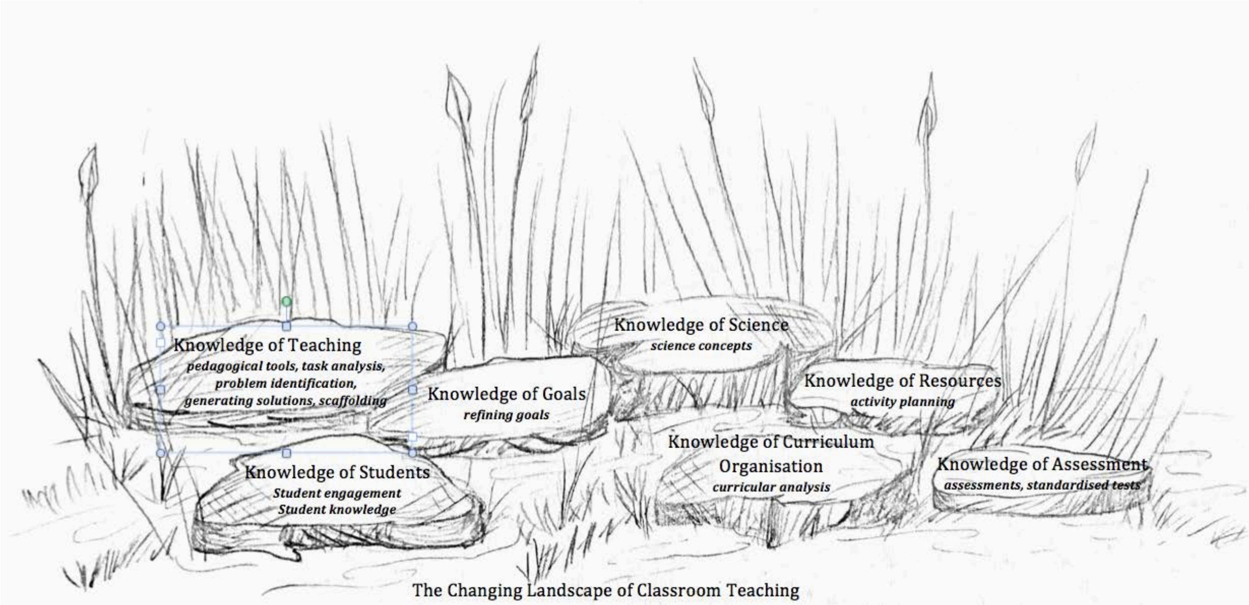

Figure 1. The changing landscape of classroom teaching.

Table 1. *Enactment code* emergence during analysis (frequency) and **Knowledges** supported in conceptual framework: Year One

Interview #1	#2	#3	#4	#5	#6
Problem Identification (6)	(1)	(3)	(2)		
Generating Solutions (15)	(4)				(1)
Activity talk (3)		(5)	(9)		(4)
Student Engagement (1)		(2)	(2)		
Student Knowledge (3)		(7)	(4)		(1)
Analysis of Data from personal website games students use (1)	Analysis: Tier (2)	Dale Chart analysis (2)			Analysis of vocabulary learning activities: real learning (2))
		Hunch and confirmation (6)			
		PCK: teachable moment, honoring content and students, management routine (8)	PCK: teachable moment, honoring (6) Activity+engagement Activity+generating solution	(10)	(6)
		Teacher as learner (1)	(1)		
		Refining goals (2)	(1)		*Refining goals* (2)

Knowledge of Teaching

Knowledge of Resources

Knowledge of Students

Pedagogical tools emerge: **Knowledge of Teaching**

<u>Definition emerges</u>: Knowledge at intersection of content and teaching: different kinds of actions teachers take, several at a time; blending knowledges to capitalize on teachable moments, meet students where they are

Knowledge of Goals

Table 2. *Enactment code* emergence, (frequency), and **Knowledges** supported in conceptual framework: Years Two, Three

Interview #7	#8	#9	#10	#11	#12
	Problem identification (1)				
Generating solutions (8)					
Activity talk (3)	(7)		(3)		(7)
	Knowledge of students (6)			(1)	(5)
	Student engagement (3)			(2)	
	Scaffolding learning (1)				
	Task Analysis: S4V8 (3)				
PCK: Activity+engagement Activity+generating solutions			(1) honoring students		(9) Tchr reflection(1) Teacher as learner(2)
Curricular Analysis: word choice (5) *Curricular Analysis: assessment tool* (4) Analysis: academic language, disciplinary vocabulary (3) *Analysis: tier Science concepts* (1)	Analysis: academic language, disciplinary vocabulary (5) *Analysis tier Science concepts*(1)	(1) *Analysis: tier Science concepts* (3)		*Curricular Analysis: word choice (1)* *Curricular Analysis: assessment tool* (1)	(2) (1) (6)
	Assessment (4)			(1)	

Knowledge of Teaching

Knowledge of Curriculum Organisation

Knowledge of Science

Knowledge of Assessment

Table 3. Conceptual framework **Knowledges**, corresponding ***enactment codes*** present in analysis, and examples from transcripts

PCK Conceptual Framework (Lee & Luft, 2008)	***Enactment code***	Example
Knowledge of Teaching	***Pedagogical tools:*** In this example Ann talks about her use of the Tier framework to sort vocabulary terms and how she shared that sorting system with her students.	Well actually, when we started this, the words I put together for all of unit one, each section of a chapter we were studying has its own set of words. You guided me to look at the words as Tier-1, Tier-2, and Tier-3 words so I put an asterisk beside the words I consider Tier-2 and the other words I consider Tier-3. I've used that language with the kids too: 'These are Tier-2 words, words that you will come in contact with later in science, and Tier-3: these words go with the other words in some way. You won't hear those in daily language. You won't hear those [Tier-3] spoken as often as you will crust, mantle, inner core and outer core' [words she identified as Tier-2].
	Task analysis: using both science curriculum expectations and academic language to think about learning demands on students.	So when they use a hypothesis that's a great example, because 'if we do this, then we think this will happen because...' I like asking them the 'because'. They don't have to do 'because' but I was asking them to because you had to have a reason why. And that gets to what we're going to be doing next semester because they really focus on how we go about testing and working with scientific methods. And using some inquiry to decide what we're going to do.
	Problem identification	But like today, when I was talking about compression of the snow, well, they had some reference point to that. So I could talk in conversation about [compression] and we could make that connection to what we just learned. So, that was kind of conversation but I really need some help in figuring out exactly where I want them to be in their writing and using their vocabulary. [Writing] is hard because

	   Generating solutions: working with a problem she identified earlier: [Students] don't take English and put it into science. They know it, they see it in English but they don't apply it. ***Scaffolding:*** See example in ***Activity Talk***, below.	we're not talking; we're not doing regular conversation. We're talking [and writing] informational text. When I was [teaching] climate change activities I did I-movies. [Students] did public service announcements in groups. Everybody had to write a report and pool their information together, everybody had to have a paragraph of information that they chose to put together, so it wasn't just them doing this little public service announcement, they had to know where they came from and what. Citations.
Knowledge of Students	***Evidence of student knowledge*** ***Evidence of student engagement***	Part of their vocabulary was 'convergent' and one of the [topics] was snow on Antarctica becomes compressed. I said, 'So the ice becomes compressed. What does that mean to you?' [Student] raised their hand and said, 'Well, that's like pushed together.' I said, 'Where else have we learned something about compression?' What boundary was that we were talking about?' 'Oh, that's a convergent boundary.' We actually germinate little seed packets. They get to choose carrots or broccoli. Last year [students] absolutely loved watching these these veggies grow, they were just so blown away by it. So I got a bunch of those [CD disc] cases. They'll get to plant some seeds and watch them germinate, take them home and plant them. I had a parent who emailed me this summer and said that their son had brought home broccoli and they planted it in the garden and had broccoli, broccoli and more broccoli.
Knowledge of Goals	***Refining goals***	I'm already thinking about how do I want to help students really use the language [of science]. How can I help them to get into the habit of "talking the talk"?
Knowledge of Science	***Science concepts***	I'm struggling with subduction because they do need to know the process of where the ocean crust sinks beneath the continental crust and back into the Earth. I was thinking should I introduce the word 'faults' to them or a break in the earth's crust, versus subduction?

		Well, faults is more of a Tier-2 word. And Tier-3 words go along with things like faults and so if we learn about different types of faults, those would be three-tier words. Subduction goes along with how the Earth has been formed and so I'm just not sure if subduction is a word that …we do use it a lot though. And faults' is a little more generic… **Interviewer:** Is it a high frequency word for the mature science language user? **Ann:** It could be. When I was doing my [geological survey trip], he used the word subduction often when talking about uplift of mountain ranges and how the Earth's crust had submerged or subducted underneath another one. It was interesting for that word to come up in conversation. I'm thinking [students] would understand faults more easily because they've heard that word more often.
Knowledge of Curriculum Organisation	***Curricular analysis:*** while reviewing her selections for Tier-2 words in preparation for year two, Ann talks through her decision to remove "scientific method" from her list of terms for special focus.	So I [would] still do some application of scientific method that I would do anyway first semester but I think by second semester they would understand it because then they are really using it on their own versus learning it as a group
Knowledge of Resources	***Activity talk:*** this example includes discussion of vocabulary learning in science plus partial description of the process Ann used to ***scaffold*** learning. She used a series of three lessons to gradually release responsibility to students for setting up an experiment using the scientific method and writing a scientific report of findings.	In January, February, March I focused on how to write and use the scientific method and so the terms controlled experiment, variable, hypothesis all came to be part of the lesson. I did it in three different lessons, the first thing was a lesson where we grew mold. I went through the scientific method process with them and I provided the procedure, the materials, all they had to do was come up with a question. We talked about how to write a good question and a hypothesis. Then I created a data table and they had to think about the interpretation and the conclusion, we talked about those two things so we talked about two things in the beginning and two things at the end.
Knowledge of Assessment	***Assessments***	They take [the state test] in the spring. I have the set of words. I was given the words [at a conference] from the state education website.