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Paper 3: Science Learning Progressions, Discourse, and Teacher Pedagogical Content Knowledge

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Background

The work reported here is part of national project across middle and high schools in the U.S. to develop learning progression frameworks (descriptors and assessments) for three core strands of environmental science: *biodiversity*, the *carbon cycle*, and the *water cycle*. As indicated in the *Next Generation Science Standards* (2013), learning progressions are descriptions of increasingly complex understandings of a subject (e.g., the water cycle) and associated measures for the development of learner knowledge. A progression is anchored at the lower end by what we know from interviews and observations about how younger students reason. The learning progressions in our work are anchored at the upper end by what disciplinary education experts identify as the knowledge needed for college, career, and citizenship readiness. The development of the learning progression framework is grounded in teacher practice and student learning experiences.

The larger *Pathways* project, from which the work reported here has emerged, included development and implementation of sets of activities called *teaching experiments* (one set of materials for each of the three main topics of biodiversity, water cycling, and carbon cycling). Each teaching experiment is a series of orchestrated lessons, concrete strategies, and instructional resources to be used in concert to support learner development of the normative standard scientific discourse for the topic. Each exemplifies socio-scientific norms for making, testing, and conveying the results of hypotheses related to the sub-area and for the broader scientific community (e.g., the complexity of making an argument in science; Driver, Newton, & Osborne, 2000). The materials are based on the project's foundational perspective of a four-level learning progression (see Table 1). Given space constraints, what is offered in Table 1 is necessarily generic. The detailed descriptors for each topic (biodiversity, water, carbon) are many pages long. They are based on analysis of hundreds of student responses, in writing and in cognitive interviews, to content-specific questions.

The project also created and implemented teacher professional development around the use of the teaching experiments. Professional development included teachers experiencing a teaching experiment as a learner before attempting to use it in their own classroom and field site activities.

Table 1. Learning Progression Developmental Levels – General Descriptors

LP Level	Title	Description
4	Scientific Model-Based Accounts	Students apply fundamental principles, such as conservation of matter and energy and genetic continuity, to phenomena at multiple scales in space and time (generally consistent with current national standards).
3	Incomplete School Science Accounts	Students show awareness of important scientific principles and of models at smaller and larger scales, but they have difficulty connecting accounts at different scales and applying principles consistently.
2	Elaborated Force-Dynamic Accounts with Hidden Mechanisms	Students continue to focus on actors, enablers, and natural tendencies of inanimate materials. However, they add detail and complexity, especially at larger and smaller scales.
1	Simple Force-Dynamic Accounts	Students focus on actors, enablers, and natural tendencies of inanimate materials, using relatively short time frames and macroscopic scale phenomena.

Problem and Research Question

For curriculum developers and teacher educators, learning progressions hold promise as a means to enrich teachers' understandings about (and orientations to) science, build knowledge of curriculum, deepen attention and response to student thinking, harness the power of formative assessments in service of student learning, and provide a tool for teachers in planning, instructing, and reflecting on their work. However, what we do not yet know are the specifics of how this promise may be realized in professional development (PD) or classroom instruction.

The specific research question addressed here is: *What is the nature of teacher discourse knowledge development in learning about learning progressions, as evidenced by professional discourse on (a) important science ideas and (b) how to make those important ideas relevant to students?*

Theoretical Framework

The theoretical foundation for this study combines existing frameworks for the development of pedagogical content knowledge (PCK) with emerging work on professional and classroom discourses and how they come together during instruction (e.g., Gunckel, 2013; Hauk, Toney, Jackson, Nair, & Tsay, 2014; Shulman, 1986). Current models of PCK in science assert several core constructs (knowledge of content and students, knowledge of content and teaching, knowledge of curriculum, and knowledge of assessment), as discussed in Paper 2, as well as a broader category – orientation towards science and its teaching and learning (Park & Chen, 2012). *Orientation* includes valued beliefs about the nature of science, about the purposes of its teaching and learning, and preferred methods for inter-generational transfer (teaching) of science values and of science tools and artifact use. A teacher's preferred orientation (e.g., discovery, inquiry, guided inquiry) is an instantiation of a culture in a broad sense. Each privileges certain ways of gaining understanding of the physical environment, policies, connections, and situated meanings. Moreover, each orientation presumes a particular way of noticing and handling intercultural differences, such as those among the science sub-disciplines that intersect in a classroom, as well as institutional culture of science encoded by the teacher's orientation, that in the curriculum, and of home culture(s) of science known to students (individually or collectively).

Only recently have models of PCK and teacher development begun to consider teacher *orientation to the difference* and how that orientation shapes instruction. This is more than orientation towards science and its teaching and learning, it is orientation towards the differences between teacher and student orientations about science teaching and learning. Orientation to the discipline and orientation to the difference are evidenced in the classroom in myriad ways. Researchers have investigated vocabulary and discourse practices (e.g., Windschitl, Thompson, & Braaten, 2008), gestures (Alibali et al., 2012), and norm-setting (e.g., socio-scientific norms, Driver, Newton, & Osborne, 2000). If PCK is the reshaping and melding of knowledge and beliefs about the discipline and about pedagogy into instructional realizations in the classroom, then certainly the aspects of communication just listed are part of PCK. In work reported elsewhere (Hauk et al., 2014a), we have offered an expanded model of PCK that makes explicit the idea of *knowledge of discourse*. The category *knowledge of discourse* addresses two parts of the Park and Chen (2012) model of PCK: teacher orientation and knowledge of assessment. While teacher orientation is a kind of *relational* understanding guiding classroom discourse, knowledge of assessments is a kind of teacher *instrumental* understanding that influences the mechanisms for communication – together the two shape accepted constructions of meaning in the classroom. Such a model might be pictured as shown in Figure 1. It is in the connections between Knowledge of Discourse and the other aspects of PCK that orientations are manifested. The learning progression approach of noticing, assessing, and adjusting instruction to respond to student development, touches on every aspect of PCK pictured in Figure 1.

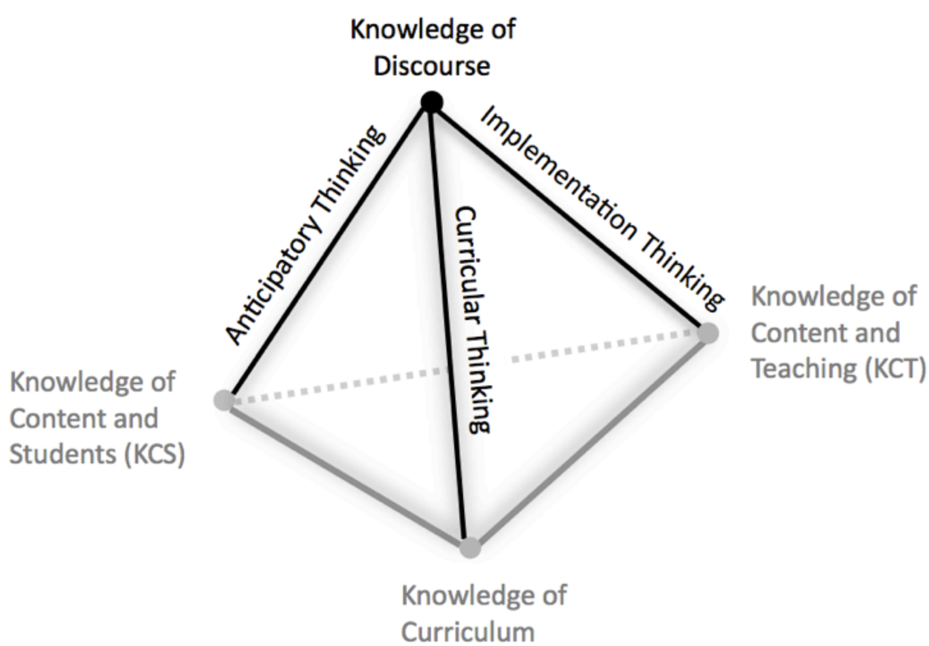

Figure 1. Extended model of PCK (Hauk et al., 2014a).

Methods

We report here on a small study that examined teacher responses to open-ended questions about two particular discourse-rich aspects of PCK: what constitutes an important understanding in a science topic and what teachers make of the idea of convincing a student that the understanding is important. The Important Understanding item calls on Knowledge of Curriculum *and*, because it asks for what is "important" and to consider class "context," it also engages Knowledge of Discourse. Consequently, we say that the answer is an articulation of Curricular Thinking – the pathway that connects Knowledge of Curriculum with Knowledge of Discourse. The item calls on teachers to use Knowledge of Content and Students and, because it asks the teacher to articulate values, what is "important" to students, it also engages Knowledge of Discourse. Thus, we suggest that response to the prompt is an articulation of Anticipatory Thinking (see Figure 3).

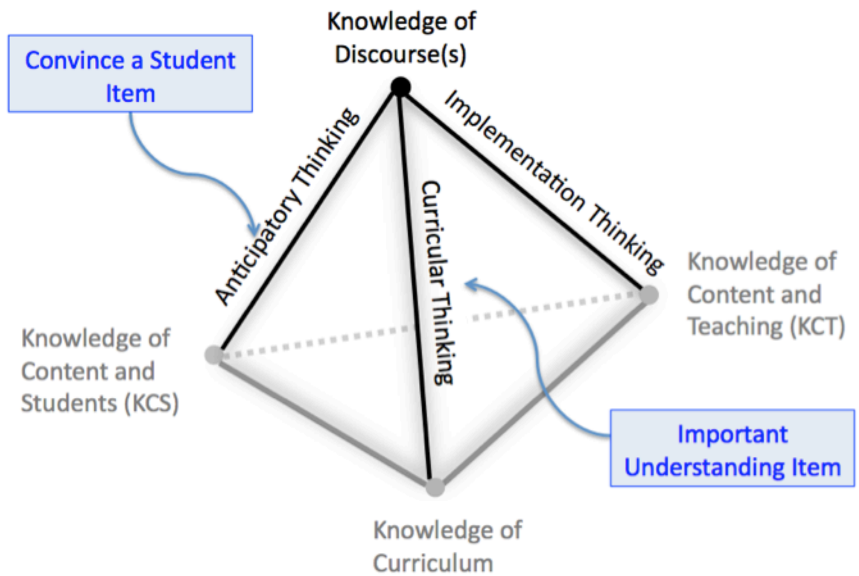

Figure 3. Hypothesized relationship between prompts and PCK model.

We gathered written responses from 181 teachers before, during, and after their use of project-designed learning progression-based lessons (pre/post pairs for teachers in four U.S. states who had participated in professional development that focused on one or more of the three topic strands - water cycling, carbon cycling, and/or biodiversity). Constant comparative coding and refinement through inductive analysis of teacher statements resulted in two rubrics for identifying teacher position along developmental continua. One continuum for the *Important Understanding* item and one for the *Convince a Student* item. For each prompt, we provide the codes. For the *Convince a Student* item we also include some examples for each code.

> *Important Understanding* Prompt:
> Choose the topic you most often teach (Carbon, Water, Biodiversity) [then] List the most important understanding for this topic that students in this particular course should master by the end of your instruction. Be as specific as possible, considering the grade, course and context of your class.

Important Understanding Codes:

Use of science language (discourse) in describing an important understanding.

1+ = May or may not use science terminology OR may describe context but does not link content to context; superficial description (e.g., force-dynamic language), no evidence-based or principle-based description – Consistent with the language associated with Learning Progression Level 1 and transitioning into Level 2.

2+ = May use science terminology about content and there is some linkage between content and context; some descriptive specificity but may be incomplete or error-based – Consistent with the language associated with Learning Progression Level 2 through the transition to Level 3 school science narrative usage.

3+ = May use multiple science terms with content linkage to contextual purpose; specific description(s) that are either evidence-based or principle-based or both – Consistent with the language associated with Learning Progression Level 3 proficiency and moving into Level 4.

4+ = Context is clearly articulated and use of science terms links to contextual purpose; specific description(s) that are evidence-based and principle-based – Consistent with language and context-shifting use of ideas associated with Learning Progression Level 4.

Convince a Student Prompt:

If you had to convince a student in the course that the understanding #1 you listed above [in previous item] was important for their everyday life, what would your argument be?

Convince a Student Codes:
Category 1: Asserting. Statements of fact or questions without explicit connection to student's lived experience
In ecosystem energy flow, many different organisms fulfill each role. It is important to have a large variety of organisms available for each role in case of events that effect any single one. *[8648-Cont]*
Without carbon life on earth as we know it would not exist. *[8231-New]*
All living things are made up of cell. Cell is the basic unit of structure and function of living things. Living things are classified according to the types of cells - eukaryotes or prokaryotes. All cells with the same function are grouped together calls tissue, the organ to organ system. *[8618-New]*
Category 2: Comparing. There are distinct systems, including human systems. Implicitly or explicitly includes "you are part of the human system." Some connection to student lived experience, possibly through "should" messages or analogies, usually compare/contrast or c/c questions about "real life"
Not all animals can live in the same habitats, so as humans we need to understand our effects on the environment so that we know the impact we may have on a given ecosystem. By affecting an ecosystem we could harm or kill an animal species. *[1367-Continuing]*
The natural cycling of water has been a determining factor in the success or failure of individuals, populations, civilizations, and species, since long before humans ever appeared on Earth. It is still that way today. A deep understanding and appreciation of this truth will help keep you, and every group you are a part of, from making disastrous choices. *[8632-Continuing]*
I would compare what plants need to grow and be healthy to what we as humans need to grow and be healthy. Students would work on the similarities and differences between plant and human needs. *[7831-New]*
Category 3:Collecting. We are all in this together messages; humans and (other) animals share biological needs and resources. Connection to student experience possibly through "you should care because we all do" and "harm to one being is harm to us all" messages.
CODED as 2.5 (on it's way to 3 for attention to relevance): I would relate it to them and their personal experiences. For example, in Ventura excess blooms of plankton result in a red tide of that plankton that produce a toxin that then gets magnified through the food chain and causes marine mammals to get sick and beached. The public sees the marine mammals and the city workers will tape an area around the mammal so the general public leave the animal alone. Also, people are not suppose to eat

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The concept that life changes over time is important to a student's daily life because as changes take place to the environment, organisms must in turn change or die. So, as humans impact the environment, it is important to know that this impact will also impact living organisms. Another example I would use to help reinforce the topic of evolution is the tolerance bacteria have gained toward antibiotics. Each year, students have to get another flu shot...why?, because of the mutations or changes that occur that change the resistance of bacteria to our vaccinations and antibiotics. *[1527-New]*
What did you have for lunch? Did you know that nothing in your lunch would exist without photosynthesis? Even if you had a steak, that steak came from a cow that got it's energy from it's food, grass. The grass got it's energy from the sun and stored it in a process called photosynthesis. The cow got it's energy by 'stealing' stored energy from the grass. We got our energy, by 'stealing' and using stored energy from the cow. *[8533-New]*
We would take a look at the Earth. The majority of the water on Earth is in the ocean, too salty to use for most purposes. So we depend on the water cycle to produce fresh water. Some fresh water falls from the sky, where it goes after it evaporates from the ocean, as snow and ice. It might melt, but an awful lot stays frozen, in glaciers and snow-caps. Of all the water on Earth, only about 1% is fresh, liquid and available for human, animal and plant use. Many places in the World, like Somalia right now, face tremendous hardships because they don't have enough water. We must take care of the water we have so we can continue to help folks around the World who don't have it, and take care of ourselves too. *[592-Continuing]*
Category 4: Synthesizing. There are multiple systems, including human(s), and human interaction with other systems involves cause/effect/consequence that may come back to affect humans. Implicit or explicit full cycle with student-relevant details at multiple reference points in the cycle; language of argument is readily accessible to students at multiple LP levels.
CODED as 3.5 (diversity of student relevance/LP not explicit): I would have the students think about their life in terms of all the different species they encounter each day, whether as part of the environment, their food, and their friends and pets. Then I would have them think about all the other species that they may not see but that essential to life, like decomposers and scavengers. By emphasizing the interconnectedness of life, hopefully the students will not only see their role in it but also the grand role of biodiversity.
CODED as 3.5 (language fairly elevated for the 9th grade students mentioned by teacher as target audience in response to earlier part of the item; diversity of student experience/LP not explicit). Evidence of human impacts are seen in real time phenomena such as global climate change. There are many aspects of this that can affect you personally. For instance, changes in precipitation and temperature patterns can alter the weather where you live, bringing more floods, droughts or other extreme events. Species losses not only mean that your children might never get to see a polar bear or manatee, but also that fruit that you enjoy will no longer be able to be grown because its pollinator has become extinct or that an exotic plant with a compound which could have been the cure for cancer was never discovered. Economically, the greenhouse gasses that cause many of our pollution problems will also become more scarce and more expensive, most likely sparking conflict in the world as they do so. Future jobs may center on finding alternatives and engineering solutions to the many impacts we have had on our global environment.
Category 5: Inventizing. There are many overlapping systems and complex interactions among them that can be exemplified in student-relevant/student-elicited experience; personal and communal experience can be transferably informative for understanding and modeling systems. *More detail:* Multiple interacting systems linked to stated anticipations about student thinking and

Findings

The approach to the research question required attention to three aspects. There are the methodological results related to validity and reliability, statistical results from examining the coded data, and theoretical implications for PCK model building based on these.

Methodological

A sample of 5 teachers, 5 teacher educators, and 5 science education researchers agreed on the face validity of the items. Methodologically, we examined the reliability of coding using a multi-coder consensus and comparison method. Two coders generated the coding rubric from an examination of 40 randomly selected responses, then independently classified a randomly selected set of and additional 40 teacher responses and subsequently met and reconciled coding to consensus. The independent coding and consensus check-in process was repeated until all responses had been coded and reconciled. A third coder, with the coding rubric and at least three examples for each code in hand, independently classified 50 randomly selected teacher responses. Inter-rater agreement was 95%. The methodological result is that the survey items and coding process show promise as valid and reliable means for capturing information about teachers' knowledge of discourse for science teaching.

Empirical

The quantitative results are from explorations of categorical data (codes). We examined the data for change across time in the nature of teachers' responses to the two items mentioned above.

Important Understanding

As noted above, in coding, the "**1+**" indicates a response with little or no science terminology and superficial description (e.g., force-dynamic language) and no evidence-based or principle-based description, consistent with learning progression Level 1 transitioning into Level 2. A "**2+**" indicates a response with some formal science terminology and some link between content and context, though it may be incomplete or error-based (i.e., consistent with learning progression Level 2 transitioning to Level 3, school science narrative).

Note that there are three rows, A, B, and C, in Table 2. Analysis first considered whether a teacher was New to the project in the first year of the survey or was Continuing (had participated in project PD in the previous year). Quantitative exploration of the coded data indicated that a strong covariate in gain among the group of continuing teachers was whether or not they left the project after exactly two years, at the end of Year 2. Thus, Group B describes teachers who participated in Year 1, continued in Year 2, and also participated (or planned to at the time of the survey) in Year 3. Group C, "Ended" are those who participated in both Year 1 and Year 2 but left at the end of Year 2.

Table 2: Comparison of Important Understanding Results at Two Time Points (Year 2, Year 3).

	Change Paired *t*-test	N, Pop (Pairs)	Time 1 Mean (SD)	Time 2 Mean (SD)
A. New	Gain, significant, $p<0.000$	49 (32)	1.06 (0.3), Level 1+	1.50 (0.6), Level 2+
B. Continuing	Gain, not significant, $p=0.3$	44 (24)	1.48 (0.6), Level 1+	1.58 (0.7), Level 2+
C. Ended	Gain, near significant $p=0.08$	27 (20)	1.25 (0.6), Level 1+	1.38 (0.5), Level 1+

Results reported in Table 2, across years, are on paired values (hence the smaller *n* values in parentheses), for those participants who responded to the prompt in both years. Parallel to results reported in Paper 2, but here across all three science topic areas, we see an increase in the code values. This indicates an increase in the complexity of responses and in the nature of appeal to higher learning progression discourse in teacher responses. This gain was statistically significant except for those in Group B, who were already in year 2 (or more) of involvement with the project's PD. We conjecture that the gains for Group A, the New teachers, may be more pronounced because they had less progressions-related PD than continuing teachers. Also, notice that the group who were Continuing had a higher mean coding of level of discourse than either of the other two groups.

Convince A Student

Unlike the *Important Understandings* results, Continuing teachers had significant gain over time in framing science for students, that is, in talking about how to make the science relevant to students. So, too, did the few participants who had similar experiences but who were in the Ended group (see Table 3). Also worth noting is that a similar proportion of teachers in New and Continuing groups completed both survey items, but a smaller proportion of teachers in the Ended group actually completed the Convince a Student item in both years. In the Ended group, though 20 of 24 (83%) responded to the Important Understanding prompt, only 7 of 24 (29%) responded to the Convince a Student item (the next item on the survey).

Table 3: Comparison of Convince-A-Student Results at Two Time Points (Year 2, Year 3).

	Change Paired *t*-test	N, Pop (Pairs)	Time 1 Mean (SD)	Time 2 Mean (SD)
A. New	Gain, not significant, p=0.35	50 (28)	1.78 (0.6)	1.83 (0.6)
B. Continuing	Gain, significant, p=0.04	43 (24)	1.77 (0.6)	1.98 (0.6)
C. Ended	Gain, significant, p=0.02	24 (7)	1.56 (0.5)	2.00 (0.7)

Theoretical

Taken together, the two sets of empirical results may be an indicator. It may be that learning to articulate instructional goals (important understandings) *must precede* learning how to make those goals relevant to students (convince-a-student).

The theoretical results provide insights for model-building. In particular, they have implications for describing and identifying aspects of PCK and how understanding in each of these grows (see "Implications for Research and Development" below). The project has developed resources for three of the four edges in Figure 1. The learning progression descriptors (the specific versions of Table 1) articulate the connection between Knowledge of Content and Students and Knowledge of Curriculum. The teaching experiments call on teachers to link Knowledge of Curriculum

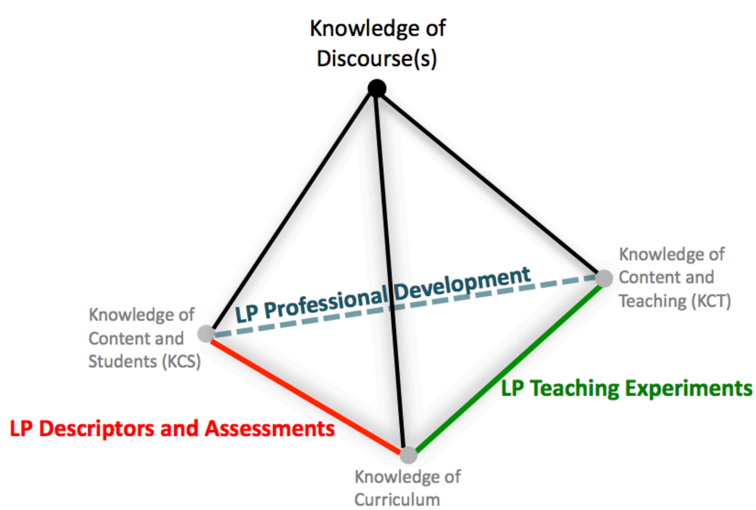

Figure 4. Hypothesized relationship between Pathways resources and PCK model.

with Knowledge of Content and Teaching. The professional development activities join Knowledge of Content and Students with Knowledge of Content and Teaching. While each of these project resources has had implicit messages about Knowledge of Discourse, none has tackled it directly (Figure 4).

Discussion

This work contributes to knowledge of how PCK and ways of thinking that make up PCK are combined and may need to be sequenced in a learning progression-based context. Learning progression descriptions of valued ways of knowing at each level provide language and context as teachers prepare for, enact, and reflect on classroom implementation (of teaching experiments as well as their usual curriculum). Inherent in the learning progression approach to instruction is a growth in knowledge about various socio-scientific norms and ways to promote them during instruction, including a move from teacher-centered to student-centered activity. In other work we have described a variety of teaching strategies that support such student-centered learning progression-based instruction and the challenges of providing professional learning opportunities accessible to traditionally prepared teachers (Hauk, Yestness, Roach, Berkowitz, & Alvarado, 2014b). Without the language necessary for discussing instruction, teachers may describe many practices as "just good teaching." An affordance of attention to discourse in pedagogical content knowledge development is that it can provide researchers and teacher educators a framework and language for unpacking "just good teaching." This is a necessary predecessor to supporting teachers in unpacking scientific, socio-scientific, and instructional ideas. The coding developed for the project may turn out to be helpful here – offering more description, examples, and language for making sense of discourse(s). An area for further work is how the coding scheme can help us build an explanation for the development of PCK up, out of the foundational plane (e.g., the particular items we coded gave us information related to a *face* of the tetrahedron – see Figure 5).

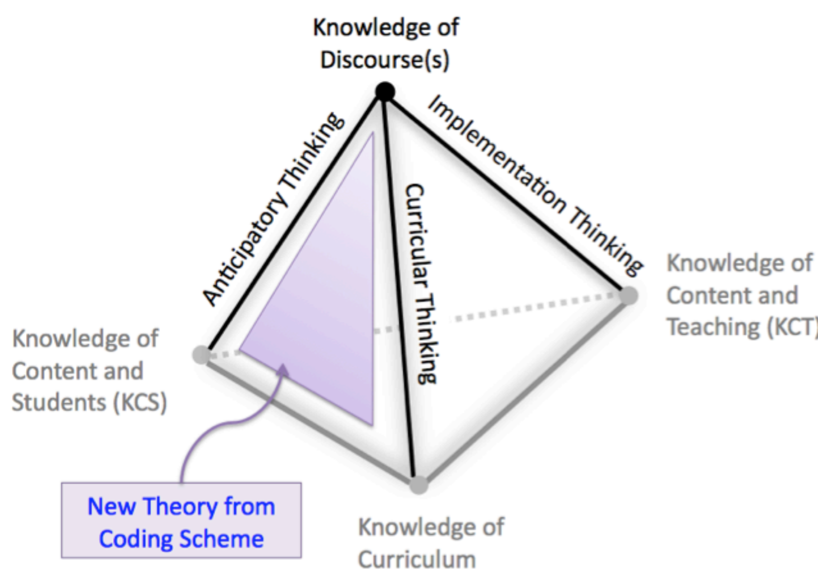

Figure 5. Potential area for further development – describing professional thinking and knowledge development along a face of the PCK model.

What is needed to build on the results of the small study reported here, and the other studies in the project, is a framework for the growth of a teacher's understanding of Discourse (in the big D sense of Gee, 1996: communication situated in the socio-scientific and socio-cultural value systems present for the people in the room). That is, what is happening as understanding is generated and (re)shaped using the various knowledge and thinking components in Figure 1?

One way to build on these general and learning progression-based results is to examine the use of a framework for PCK (e.g., something like Figure 1) during professional development. The diagram can be reflective and discursive tool. The use of such compact visual models as a shared referent provides an opportunity to teacher educators, teachers, researchers, and developers to increase the precision with which they think about and describe learning. With the visual model and the associated documents of learning progression descriptors and types and processes in understanding, people can point and say, "I'm trying to be explicit about…" Or "What does it look/sound like when I (the teacher) am noticing the properties that lead from Level 2 to Level 3 understanding? What does it feel like when I am ready to structure my observations about Level 3 ideas and begin to abstract to principle-based reasoning? What would it look like for my biology students?" Or "What I see in this video of science teaching seems to be evidence of a student building from Level 2 to Level 3 understanding because…" and "To help students build a socio-scientific norm of referring to principles, my next instructional move would be…" Next steps include use of the framework to scaffold productive conversations about pedagogical content knowledge, to identify the kinds of thinking needed for student-centered science teaching, and to be specific in responding to the ways that both professional and student understandings grow.

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