A Framework for Developing Pedagogical Content Knowledge: The Role of Transformative Professional Development and Educative Curriculum Materials

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Abstract
We hypothesized that using educative curriculum materials as the core of a long-term, transformative professional development experience would be an effective way to strengthen teachers’ PCK for teaching high school biology. In this paper we describe the characteristics of the materials, the nature of the professional development program, and the resulting changes in teachers’ PCK. We designed this multi-year, multi-faceted intervention to challenge, deepen, and strengthen the participating teachers’ knowledge, beliefs, and practice in service of improving student understanding of biology. Our quantitative results show statistically significant increases in Academic Content Knowledge, General Pedagogical Knowledge, the Content Knowledge component of PCK, the Pedagogical Knowledge component of PCK, and changes in teaching practice toward more inquiry-oriented practice. The qualitative data gathered from teacher interviews help to explain the role the intervention had in generating these increases.

Introduction
For more than 30 years the construct of PCK has had a place in both the educational research literature and teacher education. Despite this longevity in the literature, it remains a challenging construct to measure and study. Like many others, we agree that developing high-quality PCK may be one of the keys to effective instruction and therefore improved student learning.

Shulman’s description of PCK provided one path for defining the nature of PCK and what it means when exemplified through effective teachers. He said that teachers with PCK have “an understanding of what makes the learning of specific topics easy or difficult” and have developed “ways of representing and formulating the subject that make it comprehensible to others” (1986, p. 9). Loucks-Horsley further emphasized the complex, integrated nature of PCK when she described it as “more than knowing content or how to teach in a generic way. It’s understanding what aspects of the content students can learn at a particular developmental stage, how to represent it to them, and how to lead
them into different conceptual understandings. ... Knowing the content is not enough” (Loucks-Horsley as quoted in Sparks, 1997, p. 20).

In the study reported here we hypothesized that using educative curriculum materials as the core of a long-term, transformative professional development experience would be an effective way to strengthen teachers’ PCK for teaching high school biology. As a result we designed an intervention in which teachers chose one of two highly educative biology curricula and committed to implement the program with fidelity while participating in a two-year professional development program. In this paper we describe the characteristics of the materials, the nature of the professional development program, and the resulting changes in teachers’ PCK.

**Developing and Strengthening PCK**

We worked from three key assumptions about Pedagogical Content Knowledge to design the intervention for this study:

1. There are three key components of PCK – content knowledge, pedagogical knowledge, and context knowledge.

2. PCK exists on a continuum; therefore every teacher has some degree of PCK. As a result each teacher’s PCK can be strengthened.

3. PCK is necessary for student success. Therefore, if a teacher’s PCK is strengthened, we should see a positive change in student achievement.

As we worked to operationalize what the continuum of PCK would look like, we focused on actions associated with the purposeful and deliberate planning of instruction that could result in a coherent learning experience for students. To measure this, we focused on a set of instructional episodes designed to teach five key concepts¹ in biology that were aligned with the standards in the teachers’ home state. Within these episodes, we looked for evidence of how or if the teacher justified the

¹ The five concepts were natural selection, cell transport, photosynthesis, protein synthesis, and carrying capacity.
importance and structure of the content they were teaching, their selection of pedagogical techniques, and how this combination effectively attended to the teaching context as it related to meeting student-learning needs (background knowledge, preconceptions, and common areas of conceptual difficulty). Working backwards, we designed the professional development program to highlight these aspects of implementing the new curriculum. Using the PCK literature as a guide, we organized the professional development program to draw out key features of the comprehensive, high-quality science curriculum materials the teachers were about to begin using so that, with the support of the materials, the teachers would exhibit the following PCK indicators in their classrooms:

- Describe the big ideas in a given content area and the relationship among those ideas.
- Articulate what they intend students to learn about those ideas.
- Understand why it is important for students to understand these ideas.
- Recognize the prerequisite knowledge that they as teachers must have to teach a concept.
- Understand the difficulties associated with teaching a particular concept.
- Draw upon a repertoire of ways to ascertain students’ understanding or confusion.
- Use knowledge about students’ thinking and context to influence instructional decisions.
- Present multiple representations for the teaching of a concept.
- Provide a rationale for the selection of teaching strategies and procedures.

Description of the Intervention Components

The intervention for this project included two primary components: the implementation of educative curriculum materials for high school biology and a two-year transformative professional development program. The professional development program consisted of three parts; 1) a multi-day process called Analyzing Instructional Materials (AIM) in which teachers analyzed the curriculum materials as a means of selecting the program they would implement; 2) an intensive, multiple week
summer experience on a university campus each year; and 3) periodic collaborative lesson study (CLS) sessions during the two school years. See Table 1 for a summary of how the experiences were structured for each cohort of participants.

**Table 1. Summary of Participant Professional Development Experiences**

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<tbody>
<tr>
<td>AIM process</td>
<td>Cohort A</td>
<td>Cohort B</td>
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<tr>
<td>Professional development coursework</td>
<td>Cohort A</td>
<td>Cohort A</td>
<td>Cohort A</td>
<td>Cohort A</td>
<td>Cohort B</td>
<td>Cohort A</td>
<td>Cohort B</td>
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<tr>
<td>Implement selected curriculum</td>
<td></td>
<td>Cohort A</td>
<td></td>
<td>Cohort A</td>
<td>Cohort B</td>
<td>Cohort B</td>
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<tr>
<td>Collaborative Lesson Study</td>
<td>Cohort A (2X)</td>
<td>Cohort A</td>
<td>Cohort A (3X)</td>
<td>Cohort A</td>
<td>Cohort B (2X)</td>
<td>Cohort B</td>
<td>Cohort B (3X)</td>
</tr>
<tr>
<td>Data collection</td>
<td>Cohort A</td>
<td>Cohort A</td>
<td>Cohort A</td>
<td>Cohort A</td>
<td>Cohort B</td>
<td>Cohort B</td>
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</tbody>
</table>

_Educative Curriculum Materials_

High-quality curriculum materials integrate a coherent organization of the content with research-based pedagogy. For this study, we are calling curriculum materials that include the integration of PCK “educative curriculum materials,” borrowing the term from Schneider & Krajcik (2002). They define educative curriculum materials as those materials “designed to address teacher learning as well as student learning” (p. 221). In addition, they say that “curriculum materials can be educative for teachers by offering support for teachers in thinking about: (a) content beyond the level suggested for students, (b) underlying pedagogy, (c) developing content and community across time, (d) students, and (e) the broader community” (p. 223). We find these definitions of teacher learning outcomes to be parallel with both our definition of PCK and our goals of a professional development program designed to strengthen PCK. Research shows that teachers who use educative materials enhance their content learning and incorporate specific strategies and representations suggested in the materials (Schneider & Krajcik, 2002).

To identify the curriculum materials that would be appropriate to include in our intervention, we commissioned a group at the University of Michigan under the direction of Joe Krajcik and Betsy
Davis to review eight sets of high school biology curriculum materials\(^2\) with the goal of determining their potential for promoting teacher learning. The review team focused on characterizing the materials according to their framework for educative curriculum materials, or materials that promote teacher learning as well as student learning (Ball & Cohen, 1996; Davis & Krajcik, 2005). This framework presents design heuristics intended to guide the design of such materials (Davis & Krajcik, 2005). The design heuristics are organized around support for the development of teachers' subject matter knowledge (SMK), pedagogical content knowledge (PCK) for science topics, and PCK for scientific inquiry. The framework emphasizes the importance of providing both rationales for instructional decisions and implementation guidance for teachers.

Although the design heuristics were not developed with the intention of using them for curriculum evaluation, the project staff worked with the review team operationalized them into a coding key. They then determined what sections of text to code for each set of materials. They decided to code ~50 pages of text having to do with ecology and ~50 pages of text having to do with evolution for each set of curriculum materials. While coding, they regularly calculated inter-rater reliability and tracked their growing collective understanding of the general coding procedure as well as specific rules of thumb that we could employ in determining how to code specific instances. After coding all 100 pages from each text, they wrote narratives describing each set of materials. They also engaged in quantitative analyses of the data (Beyer et al, 2009; Beyer et al, 2006). Two programs scored higher than the rest: *Insights in Biology*, developed by EDC and *BSCS Biology: A Human Approach*, developed by BSCS. Kendall/Hunt publishes both programs. A higher numerical score indicated that were more instances of support for teacher knowledge development within the two 50 page samples for each of these

\(^2\) We contacted the publishers of every comprehensive biology curriculum/textbook and invited them to submit their materials for review. There were 11 options on the market at the time. Publishers knew in advance which units would be reviewed and what the review criteria were. No one on the review team was associated with a publishing company or any of the authoring teams that developed the programs.
programs compared to all other programs. As a result of this review, project participants were required to select one of these two programs to implement for two school years during the course of the research study.

**Analyzing Instructional Materials (AIM) for Selection**

The professional development program began in the spring with a guided curriculum selection process facilitated by the project staff on how to select high-quality science teaching materials that aligned with the state science standards, that met research-based instructional goals such as the integration of inquiry with content, and that enhanced pedagogy and content knowledge. AIM is an evidence-based process with accompanying rubrics for analyzing instructional materials. BSCS adapted the AIM process from the work of the K-12 Alliance, a division of WestEd (Bybee et al, 2003). Using an inquiry-based approach that is consistent with a constructivist view of learning, the AIM process focuses teachers on asking questions, gathering information, and making decisions about selecting materials based on evidence that the materials will support high-quality instruction and lead to improved student learning. The key steps in analyzing each criterion involve teams reading the instructional materials and gathering evidence, analyzing and rating the evidence using a rubric, and scoring each component on a rubric. As the evidence is gathered, the teachers use the rubrics to analyze the evidence and score the instructional materials on their science content, the work students do, the work teachers do, and how student learning is assessed. (See Table 2 for an elaboration of the criteria.)
Table 2: AIM Rubric Criteria and Components

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Components</th>
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<tbody>
<tr>
<td>Science Content</td>
<td>Standards Alignment</td>
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<tr>
<td></td>
<td>Accuracy</td>
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<td></td>
<td>Concept Development</td>
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<td></td>
<td>Sequencing</td>
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<td></td>
<td>Context</td>
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<td>Work Students Do</td>
<td>Engaging Prior Knowledge</td>
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<td></td>
<td>Metacognition</td>
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<td></td>
<td>Abilities to Do Inquiry</td>
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<td></td>
<td>Understandings about Inquiry</td>
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<td></td>
<td>Accessibility</td>
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<td>Assessment</td>
<td>Quality</td>
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<td></td>
<td>Multiple Measures</td>
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<td></td>
<td>Use of Assessments</td>
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<td></td>
<td>Accessibility</td>
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<tr>
<td>Work Teachers Do</td>
<td>Instructional Model</td>
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<td></td>
<td>Effective Teacher Strategies</td>
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<tr>
<td></td>
<td>Teaching Strategies for Inquiry</td>
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<tr>
<td></td>
<td>Support for Work Teachers Do</td>
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</tbody>
</table>

Using the AIM process and tools, the participant school teams selected one curriculum for their subsequent professional development coursework and curriculum implementation. Across the two cohorts 10 participants selected *Insights in Biology (Insights)*, developed by EDC and 27 participants selected *BSCS Biology: A Human Approach (AHA)*, developed by BSCS.

**Summer Professional Development Experience**

A number of research reports indicate that professional development focused on the implementation of a well-designed, standards-based curriculum can have a significant impact on teaching and learning (Briars & Resnick, 2001; Carpenter et al., 1989; Darling-Hammond, 1997; Heller et al., 2004; Krajcik et al., 1994; Ladewski, 1994; Powell & Anderson, 2002; Russell, 1998; Schneider & Krajcik, 2002; Taylor et al., 2003). For example, a large-scale study by Cohen and Hill (2001) found that mathematics teachers who participated in sustained professional development based on the curriculum they were learning to teach were much more likely to adopt effective teaching practices than those who engaged in other kinds of professional development. Both effective teaching practices as well as teacher participation in professional development were, in turn, associated with higher achievement for
students on state assessments (Darling-Hammond, 1997; Heller et al, 2004). These findings are consistent with the writings of Sparks, who suggested that “powerful professional development engages teachers in sustained, intellectually rigorous study of what they teach and how they teach it” (2002, p.10).

Most teachers are not familiar with educative curriculum materials and are not experienced using materials in a manner that allows them to take advantage of the features that would improve their PCK and lead to higher student achievement (Ball & Cohen, 1996). As such, we focused the design of the professional development program to support the implementation of educative materials by carefully challenging teachers’ current beliefs about learning and teaching science so that their use of the materials could focus on improving student learning. In other words, professional development to learn how to use these curricula needed to transform, or change the nature of, the teachers’ beliefs and practices. The following ideas summarize the key characteristics of transformative professional development (Thompson & Zeuli, 1999) that we applied in our work:

- Create a high level of cognitive dissonance to disturb the equilibrium between teachers’ existing beliefs and practices and their experience with subject matter, students’ learning, and teaching;
- Provide time, contexts, and support for teachers to think and revise their thinking;
- Connect professional development experiences to teachers’ students and contexts;
- Provide a way for teachers to develop practices that are consistent with their new understandings; and
- Provide continuing help in the cycle of issue identification, new understanding, changing practice, and recycling.

This multiyear project for secondary biology teachers focused on providing comprehensive, coherent professional development experiences to become familiar with the curriculum materials, deepen their content knowledge, and expand their understanding of effective pedagogy. In addition
participants had the opportunity to earn 24 graduate credit hours free of charge and prepare their students for a new statewide science assessment while participating in a multi-district professional learning community.

In Summer 1 participants attended a two-week professional development experience on the campus of a state university. During this time they experienced the first two units of the curriculum as a learner and a teacher. (The AHA group received professional development on the Cell and Evolution. The Insights group received professional development on the Cell and Matter, Energy, and Organization.) While work with the curriculum formed the backbone of the summer experience, the participants’ time during the 10 days include five other types of activities: exploring key pedagogical issues, developing conceptual flow graphics (CFGs), creating collaborative lesson study plans for use during the school year, attending content deepening lectures by university faculty, and participating in data collection for the larger research study. The curriculum work plus these activities are described in greater detail below.

1. The **curriculum work** focused on unpacking the lessons within chapters and within units so that teachers not only understood the content and the nature of the laboratory activities, but also understood the rationale for the sequence of the lessons. During Summer 1 the teachers experienced all of the lessons in the first unit or two (program dependent). Of these they taught each other 37% of the time. Project staff taught the rest of the lessons.

As the teachers prepared their lessons to teach to their peers they were asked to think about all aspects of the lesson as a way to familiarize them with the features of the curriculum. Every lesson included some type of activity, usually a laboratory experience so the teachers had to order their lab supplies and handouts in advance. They were asked to use PowerPoint slides to guide the flow of the lesson so that they personalized the lesson and had an artifact to share with the other teachers. As they prepared the lesson and their slides they identified the following features of the lesson:
• Learning outcomes and indicators of success
• Stage of the instructional model
• At least one SciLinks (relevant web-based content) that went with the lesson
• Literacy strategies
• Examples of what student work might look like
• Any adjustments they might make for their classroom

2. We designed a number of sessions to strengthen teachers’ pedagogical knowledge and skills during Summer 1. These included sessions on building a culture of inquiry in the classroom, understanding the nature of science, considering the classroom management issues in a lab-oriented classroom, examining teacher beliefs about science and teaching science, reviewing effective assessment strategies, and using science notebooks effectively.

3. The work to develop Conceptual Flow Graphics (CFGs) occurred at the end of each chapter. Teachers worked in small groups to identify the overarching concept of the chapter. Then they scanned the teacher’s edition to review how the unit and each chapter was organized and what its instructional goals were. With that in mind they reviewed all the lessons in the chapter and noted the key ideas for each lesson in a table. Using the information they recorded in the table they transferred the overarching concept for the chapter to a sticky note, which they placed in the center of a large piece of chart paper. Then they discussed how the concepts in the lessons built on each other and how concepts in the lessons are extended in subsequent activities and connected to the overarching concept of the chapter. As a result of this discussion, they wrote the key concept for each lesson on sticky notes and arranged them in sequence around the overarching concept. Finally they used markers to draw arrows that indicate the strength of the connections between the big idea in each activity and the overarching concept. See Figure 1 for an example of a CFG.
4. Teacher teams spent at least one half day per unit choosing and articulating the details of a lesson they agreed to teach as similarly as possible before they met during the school year. The goal was to collect student work to bring to the Collaborative Lesson Study (CLS) sessions, which are described in more detail below.

5. Teachers completed PCK reflections and content tests when they arrived on campus and at the end of each unit. During the two week period in Summer 1, there were three sessions for data collection that accounted for approximately 9 hours of the professional development time.
6. During Summer 1, there was one content-deepening session, which focused on evolution for AHA, and on the cell for Insights. Additional content deepening sessions were incorporated into the state science teachers’ conference in the fall.

During Summer 2, participants attended a three-week professional development experience on campus that focused on the remaining three units of the curriculum. (For AHA: Heredity, Interdependence, and Matter, Energy and Evolution; for Insights: Heredity, Interdependence, and Evolution.) The second summer followed much of the same pattern as Summer 1, though some of the emphases shifted. For example,

- The teachers taught slightly fewer lessons (29% compared to 37% in Summer 1) though the lessons they taught in these units were more complicated and required greater preparation than the lessons from Summer 1.
- Teacher teams prepared three CLS lessons instead of two.
- With an additional instructional unit to learn, they spent about 12 hours in data collection sessions.
- Teachers attended three content deepening sessions during the summer – either biochemistry (for the AHA group) or evolution (for the Insights group), and one each on protein synthesis and habitat restoration (for both groups). Two of these sessions emphasized active research programs that teachers could use to illustrate key concepts and add state-level examples to their teaching.
- Teachers attended fewer pedagogical knowledge and skills sessions. During the second summer there were only three sessions: nature of science, assessing for understanding, and strengthening assessment practices.
• Teachers completed written reflections related to the chapters and units they just experienced. Project staff used these reflections as formative assessments to refine the professional development experiences, not as data for the larger research project.

**Collaborative Lesson Study (CLS)**
During the first school year, participants meet twice for collaborative lesson study sessions in which they shared student work from each of the instructional units they received professional development on during the summer. During the second school year, the participants met for three collaborative lesson study sessions. To prepare for each CLS, teams of teachers worked together during the summer to develop a plan to teach a common lesson following the same lesson plan and collecting the same student work. They identified a focus question related to student learning that was of common interest and then developed a scoring rubric for use in identifying high, medium, and low quality work products. They brought representative samples of student work to the CLS session during the school year. (See the template for collaborative planning is in Appendix A.)

During the school year session, small groups followed a strict protocol for reviewing the lesson and the student work products. This protocol, adapted by BSCS from McDonald’s Tuning Protocol (1996), helped keep the focus of the session on evidence of student learning rather than on a critique of teacher practice. After the first session, teachers’ nervousness about these sessions began to subside as a result of their growing familiarity with the protocol. (See Table 3 for the details of the discussion protocol.)

<table>
<thead>
<tr>
<th>Table 3: Collaborative Lesson Small Group Discussion Protocol</th>
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<td><strong>Time</strong></td>
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<td>5 min</td>
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<td>10 min</td>
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<td>10 min</td>
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</table>
In summary, we designed this multi-faceted intervention with educative curriculum materials and a multi-year, transformative professional development program to challenge, deepen, and strengthen the participating teachers’ knowledge, beliefs, and practice in service of improving student understanding of biology. To do this we built the intervention by combining essential elements of multiple conceptual frameworks. We drew from the educative curriculum materials work by making the role of high-quality instructional materials central to the intervention and the teachers’ work for two years. We brought transformative professional development to the foreground as teachers created CFGs, as the project staff modeled high fidelity enactment of the curriculum, and as content experts challenged the teachers’ understanding of how key concepts fit together and were supported by active research. Extending the summer professional development experience into the school year through Collaborative Lesson Study sessions helped emphasize the role of the reflective practitioner in implementing classroom-based change. The implementation of a comprehensive curriculum served as a means for emphasizing key ideas from the professional development program because using the program with fidelity was designed to be a reinforcement of the summer experience.
Description of Participants
We began the program with 48 participants distributed across two cohorts; however only 37 (77\%) completed the entire program. Four of the original participants were asked to leave the program because of their poor fit with the goals of the program. The additional seven who left did so for personal reasons such as an out-of-state move, a severe health situation, or maternity leave. Of those who completed the program, 62\% were female and 38\% were male. Twenty-seven participants implemented the AHA program and 10 participants implemented Insights. The majority (91\%) of the teachers taught in an urban area. All teachers were from the same southwestern state and taught high school biology. Two teachers taught in self-contained special education classrooms, everyone else worked in a traditional classroom with a range of students. Only 44\% of the teachers had more than 15 college credits in biology. Twenty-two percent taught in schools with more than 50\% of the students receiving free or reduced price lunches (a proxy measure for low socio-economic status). Teaching experience ranged from one to 20 years with an average of 7.4 years of classroom experience. More than half of the participants began the program with their Master’s degree and another 10\% acquired their Master’s degree through the program.

Data Sources
We collected data in a range of ways including formal content tests, written reflections from the teachers, daily video recordings of classroom practice, and periodic oral interviews. Each type of data was used in multiple ways as described in Table 4.

Table 4: Variables and Data Source

<table>
<thead>
<tr>
<th>Variable</th>
<th>Data Source</th>
<th>Description</th>
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<tr>
<td>Academic Content Knowledge (ACK)</td>
<td>• Major Field Test in Biology (MFTB)</td>
<td>The MFTB is an academic content test developed by the Educational Testing Service to assess college biology majors as they complete their academic programs. It was not well aligned with the curricula the teachers were implementing.</td>
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<tr>
<td>General Pedagogical Knowledge (GenPK)</td>
<td>• Classroom practice videos</td>
<td>Reformed Teaching Observation Protocol [RTOP] (Piburn et al, 2000) is a protocol that can be used for live or recorded classroom observations. To assess GenPK, we applied the RTOP subscale of questions.</td>
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<tr>
<td>Variable</td>
<td>Data Source</td>
<td>Description</td>
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<tr>
<td>Pedagogical Content Knowledge (PCK)</td>
<td>• Written reflections</td>
<td>Teachers completed written PCK reflections for the five concepts we were tracking during the project. The project team developed a rubric to score evidence of PCK in these reflections. The same rubric was used to code the videos and certain interviews for evidence of the components of PCK. The rubric is in Appendix B.</td>
</tr>
<tr>
<td></td>
<td>• Classroom practice videos</td>
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<td></td>
<td>• Interviews</td>
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<tr>
<td></td>
<td>• Content knowledge component (PCK-CK)</td>
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<tr>
<td></td>
<td>• Pedagogical knowledge component (PCK-PK)</td>
<td></td>
</tr>
<tr>
<td>Classroom Practice</td>
<td>• Classroom practice videos</td>
<td>We used the pedagogy of inquiry, propositional knowledge, PCK, and reformed teaching subscales from the RTOP to measure changes in classroom practice over time.</td>
</tr>
</tbody>
</table>

Concurrent with our primary data analysis, we conducted a confirmatory factor analysis that suggested that our PCK items were correlating strongly with just two factors which we named as:

Content Knowledge (PCK-CK) and PCK-PK - a mix of Pedagogical Knowledge and Contextual Knowledge.

We used the following three features of practice and knowledge to represent PCK-CK:

- Depth, breadth, and accuracy of the science content communicated
- Connections within and between science topics and the nature of science
- Multiple modes of representation or examples

These four characteristics of practice and knowledge were used to score evidence of PCK-PK:

- Rationale linking instructional strategies to student learning
- Strategies for eliciting student prior understandings
- Strategies to promote metacognition
- Understanding how student variation impacts instructional decisions

We then used the aggregate scores for the two components (factors) of PCK as continuous variables in the statistical tests described in the next section.
Results and Discussion
Do we know if the intervention (defined as the use of educative curriculum materials supported by a multi-year, multiple component transformative professional development program) made any difference? Both our quantitative and qualitative data analyses indicate that the intervention had a positive effect on teachers’ knowledge and practice in general, and their content knowledge in particular. Further, teacher’s content knowledge was positively correlated with student achievement. In this paper, we will focus the discussion of results on the evidence that the intervention had an effect on teachers. See Gess-Newsome et al (2012) for more details about the relationship of the teacher variables to student achievement.

We had hypothesized that our intervention would increase teacher’s academic knowledge, improve their PCK, and change their practice to be more inquiry-oriented. To test these hypotheses about teacher knowledge and practice, we conducted t-tests between the baseline and end-of-project measures for Academic Content Knowledge, General Pedagogical Knowledge, the Content Knowledge component of PCK, the Pedagogical Knowledge component of PCK, and teaching practice. All of these t-tests produced statistically significant differences from baseline to end of the project with large effect sizes for all variables indicating that the intervention did have a positive effect on knowledge and practice. These results are listed in Table 5.

Table 5. Impact of the Intervention on Teacher Knowledge Bases and Practice

<table>
<thead>
<tr>
<th>Knowledge Base or Classroom Practice</th>
<th>df(^3)</th>
<th>T</th>
<th>p</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic content knowledge (ACK)</td>
<td>39</td>
<td>8.008</td>
<td>&lt; 0.001</td>
<td>1.73</td>
</tr>
<tr>
<td>General pedagogical knowledge (GenPK)</td>
<td>17</td>
<td>4.659</td>
<td>&lt; 0.001</td>
<td>1.39</td>
</tr>
<tr>
<td>PCK-Content knowledge component (PCK-CK)</td>
<td>26</td>
<td>7.842</td>
<td>&lt; 0.001</td>
<td>1.43</td>
</tr>
<tr>
<td>PCK-Pedagogical knowledge component (PCK-PK)</td>
<td>26</td>
<td>7.131</td>
<td>&lt; 0.001</td>
<td>1.10</td>
</tr>
</tbody>
</table>

\(^3\) Teachers varied widely in how much of the data they submitted so our N for each form of data varied widely also.
### Considering Improvement in ACK

Because the project intervention did not focus specifically on improving teacher’s ACK, we were curious what the teachers thought contributed to the relatively large increase in this knowledge base. During their end-of-project interviews, the teachers credited their enhanced ACK most often to the nature of the curriculum and the CFG work during the summer professional development program. In particular they noted that the focus of curriculum materials on big ideas and the connections among those big ideas helped them place their isolated pieces of content information in a context. Similarly, multiple teachers said that the CFGs helped them identify connections and see relationships not only between activities and lessons, but also between the small, medium, and large concepts in biology.

The MFTB subscales are organized differently from the structure of the curricula used in this project as well as the structure of the professional development, but even on this independent measure, we see significant increases in all areas of biology as defined by ETS. The t-test results from the baseline to end-of-project MFTB scores for the whole test and each ETS subscale showed the greatest t and lowest p values for the total test. Figure 2 shows the change over time of the total test scores including two intermediate time points between the pre- and post-project administration of the test. The statistically significant differences occur between Time 1 and Time 3 and Time 1 and Time 4, indicating that there may be a role for time in creating change in knowledge particularly in the context of an intervention that included the implementation of new curriculum.
Figure 2. Teacher content knowledge scores increased significantly for the total test between Time 1 and Times 3 and 4.

**Considering Changes in General Pedagogical Knowledge (GenPK)**

During their post-program interviews when teachers were asked to comment on the changes in their own thinking and practice that they noticed over the two years of the program, two related themes emerged regarding how their thinking had shifted:

- Many teachers said they were keeping student learning at the center of their teaching.
- Teachers claimed to be giving more thought about where students should be at the end of the course and how to get them there, rather than planning day to day.

As one teacher said, “My own thinking has shifted to valuing the importance of basing all instructional decisions on student learning.” This change in thinking was accompanied by a shift in practice as the majority of teachers noticed that they were now spending the majority of their classroom time being a facilitator. In addition, the structure of a class period now included time for students to reflect on their learning. Most teachers indicated that they were learning effective questioning and assessment strategies that helped them focus on student learning.
Considering Changes in PCK – Pedagogical and Content Components (PCK-PK and PCK-CK)

Many teachers commented during their post-program interviews that before this project they originally thought that a teacher’s content knowledge was the most important feature of what a teacher brought to the classroom, but they now recognized the importance of PCK-PK and PCK-CK in helping to make that ACK useful in service of student learning. In particular, the teachers reported a new understanding of the importance of PCK knowledge and skills.

Creating explicit and logical conceptual flows and linking ideas for lessons, as this teacher indicates, had become much more important: “What I liked about [the project] was that you learn about the cells and then you continue on through. Or whatever topic; it was continued on throughout the curriculum. So I liked seeing how to keep the topic going even after I had finished it.” For another teacher, the idea of a coherent flow was more evident in how the lessons linked together and helped her/him understand the difference in educative materials: “This is pretty well connected and I can see where the connections are. I can see how a lot of the activities build on one another. It is a pretty well thought out program, better than a typical textbook.”

For many of the teachers understanding their own students and how those students best learn was a significant piece of PCK development. In particular during the post-program interviews, the majority of teachers remarked that identifying, exposing, and addressing student prior knowledge was one the major new skills they had developed during the project.

Most of the teachers added their own ideas to create explicit links to their lessons and to connect to their students by using real-life situations to get their students excited about the content and make it more applicable to their lives. It was not new for the teachers to add examples to their daily lessons, but for many teachers it was new to think about connecting the examples conceptually to strengthen the flow of a series of lessons and to think about how to make it highly relevant to their students.
Finally, the majority of the teachers commented on the role of reflection for improving their teaching practice. They also admitted that this did not come easily to them, especially since we asked them to reflect in writing. Those who were willing to be reflective often preferred to reflect orally in response to our questions.

**Considering the Impact of the Intervention on Teaching Practice**

In line with the quantitative data analysis, the majority of teachers indicated that they had adopted more inquiry-based practices. In particular, they said that they

- Used significantly less time for lecturing and having students take notes. Or as one teacher said, “Before, it was ‘stand and deliver.’ Now, I’m more of a facilitator.”
- Used more data collection and analysis from the lessons, rather than content lectures, to help students understand concepts.
- Placed more emphasis on asking students for evidence to support their conclusions. According to one teacher: “They [my students] are getting the same information but they got it by actually thinking about it instead of somebody telling them.”
- Found that the curriculum materials enabled students to know where they were headed, helped them stay focused, and enabled them to make connections: “You could see the light come on in some of the kids...you see them making those bridges from one thing to another.”

For teachers whose content background was weaker (56% of the participants had fewer than 15 credits in biology) using educative curriculum materials was a strong support, as indicated by comments such as these:

- “Teaching with fidelity was my security blanket. It helped me organize the content.”
- “I didn’t know what I was doing so I just did exactly what they said.”
- “That made a big difference... engaging the students, ... using those techniques to ... see about their prior knowledge. I was not into that prior to this; there was never a strategy to it, an order to it.”
• “The book and the PD were essential. They gave me the content and the pedagogy to walk into the classroom knowing what I was going to teach and why I was teaching it.”

• “I got content knowledge, pedagogical knowledge, learning how to teach, and an understanding of the reasons why you do things a certain way. [It helped me] to understand and think about what I am doing and why.... I think about it now throughout my day, not just in biology.”

For many teachers, their students’ acceptance of the curriculum was rewarding and made it easier for the teachers to stick with the program.

• “They [students] say, ‘I think this is the first time I have really learned science,’ especially with the inquiry and the labs.”

• “The kids liked science. ...They would be shocked that class went by so fast. That means they are involved, they are engaged, they like it and they are learning.”

• “I have had more students say 1) this was their best class, and 2) they never learned stuff in science until this class....They finally saw connections throughout the entire year. I’ve never had kids say that to me before and I had easily 50 or 60 kids saying things like that.”

On the flip side, some teachers indicated that the approach of these inquiry-oriented programs was just too different for their students and as a result “It is really a struggle because they have been taught to memorize things and spit it back out for a test. That is what our district wants. It is a struggle because they don’t want to think. They want you to tell them because that is what they are used to.” Or put another way, one teacher said that her challenge “has been to get students to think about how they think, to think about what they know. They are not used to doing that, they don’t want to do that, and they don’t see the point of doing that.”

While the majority of teachers felt that they made significant changes to their practice, they also acknowledged a number of barriers that impacted their fidelity to the curriculum implementation. Four factors were noted most often as barriers that made it difficult to teach with greater fidelity: time,
availability of lab materials, their personal beliefs about what was important to teach and/or what students could learn, and a conflict in the goals of instruction (either their own or the districts). In terms of time, all teachers felt that they needed either longer class periods or more class periods to teach their chosen curriculum well. In particular, they did not find that their regular schedule was conducive to helping students construct an understanding of key concepts.

The lack of availability of lab materials was noted by a number of teachers, many of whom also said their districts did not recognize the value of the materials and turned down their requests. We found this barrier perplexing because all of the participants were offered an additional stipend to reimburse them for teaching materials, including lab supplies, as long as they submitted their receipts to the university within a few months of accumulating the expenses. Very few of the teachers took advantage of this option.

Some of the teachers in the program held beliefs about teaching and learning that did not align well with the nature of the curriculum materials and the goals of the professional development. For example, some teachers did not believe that learners construct their own understanding of key concepts, so they would get frustrated with the structure of the lessons in the program. Related to this was a skepticism about the value of attending to prior knowledge. One teacher put it this way, “I don’t know how important the eliciting of prior student knowledge is. Generally within a group you are going to get so many different understandings that you are going to have to adjust.”

The conflict of instructional goals was sometimes a difference in beliefs and sometimes a conflict with policy. Some teachers thought that a better approach to biology than the one promoted by this intervention (content organized by key concepts) was a more traditional approach to the content that began with cells and progressed to ecosystems. One district that had agreed to unconditionally support the participating teachers changed its level of support after the project began. As a result, the teachers had to administer a content test that was closely aligned with the traditional program the other teachers
were using. The test was given midway through the school year when our participants had not taught some of the content on the test so they felt they and their students had multiple disadvantages.

Despite the barriers teachers cited, the majority of participants were clear that their practice had changed since the beginning of the program. Four to five years after the end of the project, we estimate that 50% of the participants are still using the educative materials they implemented during the research project.

*Understanding the Relationships Among the Teacher Variables*

Our analysis of the changes in teacher knowledge and practice showed positive growth in all areas during the two years of the intervention. This positive result caused us to ask more questions to determine what other relationships existed among the variables that might help explain the changes. Our next step was to run correlations between each variable pair (including years of experience). Table 7 presents the results of these tests. Acknowledging the limitations of simple, bivariate correlations, there are several interesting significant positive correlations.

**Table 7. Correlations between Teacher Variables**

<table>
<thead>
<tr>
<th></th>
<th>ACK</th>
<th>Gen PK</th>
<th>PCK-CK</th>
<th>PCK-PK</th>
<th>Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACK</td>
<td>-</td>
<td>.337</td>
<td>.649**</td>
<td>.336</td>
<td>.451</td>
</tr>
<tr>
<td>GenPK</td>
<td>-</td>
<td></td>
<td>.546*</td>
<td>.469*</td>
<td>.810**</td>
</tr>
<tr>
<td>PCK-CK</td>
<td>-</td>
<td></td>
<td></td>
<td>.644**</td>
<td>.770**</td>
</tr>
<tr>
<td>PCK-PK</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td>.656**</td>
</tr>
<tr>
<td>Experience</td>
<td>.339</td>
<td>.420</td>
<td>.207</td>
<td>-.008</td>
<td>.242</td>
</tr>
</tbody>
</table>

*p<.01; **p<.001

We found that academic content knowledge (ACK) has a positive, significant relationship to PCK content knowledge (PCK-CK), but not to PCK pedagogical knowledge (PCK-PK) or practice. We propose that there must be a translation of academic knowledge into content knowledge for practice that accounts for this statistical relationship. We also suspect that these two types of content knowledge (ACK and PCK-CK) may be intertwined and/or that we are measuring the same construct with each measure; therefore we need to examine and rethink the nature of content courses. Content courses
would be stronger for future teachers, and others in general, if the nature of the course emphasized coherence of the discipline in which the depth, breadth, and accuracy of the science content was clear, connections within and among science topics were emphasized, the nature of science were woven into the course, and there were multiple representation and examples used to illustrate key ideas. In our intervention, teachers had minimal exposure to science content taught in a traditional, lecture format and a maximum exposure to a coherent approach to biology with multiple examples described and illustrated in the two educative curriculum programs they were implementing.

Our data analysis also showed that GenPK had a positive, significant relationship to PCK-CK, PCK-PK, and practice. We see this as an indication of a close relationship between general pedagogical knowledge and both the PCK factors. And, as hypothesized, strengthening pedagogical knowledge as well as PCK has a positive relationship with practice. This relationship is not a surprise since we assessed practice using the other subscales of the same instrument that assessed Gen PK.

As further indication of how intertwined all these aspects of teacher knowledge are, we also found that PCK-CK had a positive, significant relationship to PCK-PK. Because we measured PCK-PK by how the teachers addressed misconceptions, attended to metacognition, and articulated goals for instructions it is not surprising that there a relationship between PCK-CK and PCK-PK for teachers involved in our intervention.

Finally, we see that practice is strongly correlated with Gen PK, and both PCK components, but not ACK or experience (Others’ work also supports the idea that there is no significant relationship between academic knowledge and teacher practice but there is a link between ACK and student achievement. We do not find this result surprising as we did see a statistically significant positive correlation between teachers’ ACK and post-intervention achievement score student (controlling for pretest) on the student achievement test. In other words, the greater a teacher’s academic content
knowledge, the greater his or her the students’ mean post-test score after controlling for mean pre-test score.

Because of the positive correlations between variable pairs, we ran a multiple regression of the teacher variables on teacher practice to look for more quantitative evidence of impact of the intervention. Table 8 shows the output of the analysis in which we see that Gen-PK and PCK-CK account for significant amounts of the variation in practice. We propose that because the measures of PCK-CK related to what teachers did in the classroom, as opposed to how they made instructional decisions, it was easier to make a change here that had a direct correspondence to classroom practice.

**Summary and Conclusions**

In summary, the analysis indicates that the two-year intervention that combined the implementation of educative curriculum materials with a transformative professional development program positively influenced teachers’ pedagogical content knowledge (both components) as intended and had additional positive effects on their general pedagogical knowledge and academic content knowledge. In addition, students’ achievement scores in biology increased significantly and that increase has a statistically positive relationship to academic content knowledge.

Qualitatively, teachers explain the changes in their practice as a result of the implementation of the curriculum, which they could not have done with fidelity without the professional development program. So, for our participants the intervention is a tightly woven package of educative curriculum materials and professional development that challenged their thinking about teaching and learning and therefore positively affected their practice.

This intervention was effective, but it was also very expensive in terms of time, money, and the expertise needed to execute the intervention. Given all that, is it worth it? The straight-forward answer is yes, because we have evidence that educative curriculum materials coupled with professional development do improve knowledge and practice, which leads to improved student achievement. But the more complicated answer lies in looking at what we learned about the challenges of developing
stronger PCK. It is in these lessons that this project makes greater contributions to the field because each lesson has a component that can be applied in both preservice and inservice teacher education. As a result this project generated findings and knowledge that extend beyond the role of an intervention based on educative curriculum materials and transformative professional development.

One of these findings is that the teachers in our study group initially lacked a depth and breadth of teaching strategies. This gap was particularly noticeable in two areas: variation of strategies and ability to teach in an inquiry-oriented manner. The teachers noted that they did think they knew a great enough variety of strategies to feel well-prepared to attend to the range of student variation in their classrooms. This concern became more pronounced as the teachers became more knowledgeable about the instructional model for the curriculum materials that was grounded in a constructivist approach to learning. The teachers quickly learned to surface students’ prior conceptions but did not always know what to do with or about the conceptions they had discovered. The teachers who used the curriculum materials with greater fidelity had fewer challenges in this area, but most of the teachers were concerned about the struggle to attend to the range of student variation in the amount of class time available.

Most of our teachers thought that they understood what scientific inquiry was when they joined the project. And it was true that they could recognize an inquiry-oriented activity when we used one, however, this recognition did not translate to having a strong inquiry orientation in their teaching practice. As they implemented the two curriculum programs that were part of the project intervention, our teachers began to see that developing a classroom culture of inquiry was much different than using an occasional inquiry activity. This was also one of the more challenging changes as indicated by teachers’ frustration with the sequence of the curriculum materials that had the students doing labs to discover key ideas, rather than being told the information by the teacher and then completing a verification lab.
A second finding that emerged from our work is that our teachers, and probably others, lack an understanding of the concept of “effective teaching” as defined by the literature on PCK. In other words, they did not have the professional knowledge to easily be able to articulate a rationale for why they were sequencing lessons as they were or why they chose certain strategies to teach particular ideas. This was especially evident when we asked the teachers to identify the prior knowledge or misconceptions they thought their students might have about one of the key concepts in biology and what they would do to help students move to a new understanding. Similarly, our teachers were largely unfamiliar with strategies designed to increase students’ metacognition. Through their work in this project, most of the teacher implemented the use of science notebooks or journals and included opportunities for student reflection.

Third, we found that very few of our teachers had a conceptual framework for the discipline of biology in their heads. Consequently they had no way to describe how one piece of specific content knowledge related to another. This was an area that changed dramatically over the two years of the professional development program. In year one the teachers were very verbal about their disdain for the CFGs. By the end of the project most of the teachers continued to say they did not like creating the CFGs, but added that it was probably the single activity that most changed how they thought about biology. During year two, while working through a lesson on photosynthesis and making connections to the concept of matter, energy, and organization, one veteran teacher suddenly exclaimed that she had always thought photosynthesis was just photosynthesis and now she understood how it fit into the bigger picture of biology.

This last teacher’s comment helps illustrate why it is so important to expose teachers to highly educative curriculum materials in their preservice and inservice programs. When these materials are introduced to teachers in the context of their preparation and support for being an effective teacher then the features can be highlighted and incorporated into their practice, rather than being perceived as
an overwhelming verbose and complicated set of teacher materials. Educative curriculum materials have the advantage of offering concrete examples of a range of instructional strategies with a rationale for their use; an increased recognition of the importance of student incoming knowledge and misconceptions; integrated and carefully sequenced lessons focused on the knowledge and practices of inquiry; and a carefully constructed conceptual flow of key ideas through a discipline.

We began this article with the assertion that PCK exists more as a theoretical construct in the educational research literature than as a clear operationalized quality that can be easily measured and studied. In this study we did measure and study two components of PCK (PK and CK) along with general pedagogical knowledge and academic content knowledge. It would not be accurate to say any of these variables, especially those related to PCK, were easily measured, yet we did find a way to measure meaningful aspects of PCK in the context of our intervention. In doing so, we have gained some insight into the complexity of teacher practice and knowledge as defined by PCK, GenPK, and ACK. It is clear to us that PCK as well as GenPK and ACK can be improved over time with a carefully planned intervention and as a result we can improve student achievement. It is also clear that highly-educative curriculum materials with coordinated transformative professional development are one of the keys to making those improvements.
References


Appendix A:
Collaborative Lesson Planning Template

CLS Group Names: __________________ Date Written: ________ Date Taught: ______

<table>
<thead>
<tr>
<th>Program Name:</th>
<th>Unit Name:</th>
<th>Activity Name:</th>
</tr>
</thead>
</table>

Focus Question:

<table>
<thead>
<tr>
<th>Instructional Sequence</th>
<th>Teacher Does</th>
<th>Student Does</th>
<th>Purpose/Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2</td>
<td></td>
<td></td>
<td></td>
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<td>Step 3</td>
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<td>Step 4</td>
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<td>Step 5</td>
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<td></td>
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<tr>
<td>Step 6</td>
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</tbody>
</table>
Appendix B: PRIME PCK Rubric and Scoring Instructions

Standards and assumptions to use in applying the Rubric:

- Assume that the teacher’s use of language reflects the accuracy of his/her understanding. As a general rule, DO NOT “read between the lines” and assume that the teacher understands some point, but did not explain it well in writing: base the score on actual evidence and not on assumptions. A possible exception would be if the response to another question makes it clear the teacher did understand the concept. In that case, make a note in the “evidence” column that “teacher’s response to Question x indicates s/he does understand this point.”

- As a general rule, when assigning scores reviewers should rely more on the teacher’s responses to the questions and their rationale for the steps in the classroom procedures than the “what the students do/what the teacher does” lists.

- For the “nature of science” sub-row in the CK row, count NOS examples in the procedure and responses to questions, even if the teacher does not explicitly call them examples of NOS or science as inquiry, etc. Consider both the abilities of scientific inquiry and the understandings of scientific inquiry as part of the NOS.

- Note that if a teacher does not describe a lesson that addresses the requested concept (the first sub-row in the CK row) it is likely that most of the following rows and sub-rows will end up scoring 0. That is, DO NOT score subsequent rows based on the inaccurate concept the teacher selected.

- Don’t count “examples” unless the teacher explicitly states them, even if you know they’re in the materials used. Analogies count as examples (e.g., a baggy or dialysis tubing as examples of cell membranes), but score a 2 or 3 ONLY if the teacher explicitly connects them to the relevant concept (i.e., it may be obvious to us & the teacher that dialysis tubing represents the cell membrane, but is it obvious to students?).

- If the teacher responds “nothing” or “not much” to a question about what students know about a concept, or what they struggle with, score the response as a 0.

- If the teacher reports using a strategy that should elicit prior student knowledge, but his/her rationale does not indicate that this was the purpose of the strategy, score this as a 0.
The PRIME PCK Rubric is a comprehensive framework designed to assess the Professional Knowledge for Teaching (PCK) of educators. It evaluates teachers' understanding of content knowledge (CK), the role of concepts in the discipline, and their ability to articulate interconnections and provide examples.

### Table: PRIME PCK Rubric

<table>
<thead>
<tr>
<th>DIMENSION OF PCK</th>
<th>LIMITED 0</th>
<th>BASIC 1</th>
<th>PROFICIENT 2</th>
<th>ADVANCED 3</th>
<th>SCORE/EVIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK: Understands concept &amp; role of concepts in the discipline</td>
<td>All or mostly inaccurate: Selected lesson does not address requested concept OR Selected lesson addresses requested concept, but there is a glaring inaccuracy or many small inaccuracies</td>
<td>Somewhat inaccurate: Selected lesson tangentially addresses requested concept OR Selected lesson addresses requested concept, but there are a few small inaccuracies</td>
<td>Mostly accurate: Selected lesson accurately addresses requested concept and there are only 1 or 2 small inaccuracies OR Selected lesson accurately addresses concept with no inaccuracies, but responses are too brief to be considered “advanced”</td>
<td>Completely accurate: Selected lesson accurately addresses requested concept with no inaccuracies, large or small</td>
<td>Score</td>
</tr>
<tr>
<td><strong>--Accuracy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>--Interconnections</strong></td>
<td>None of the possible connections between concepts and subconcepts are expressed</td>
<td>Few of the possible connections between concepts and subconcepts are expressed</td>
<td>Some of the possible connections between concepts and subconcepts are expressed</td>
<td>Many of the possible connections between concepts and subconcepts are expressed</td>
<td>Score</td>
</tr>
<tr>
<td><strong>--Examples</strong></td>
<td>No appropriate, accurate examples provided</td>
<td>Potentially appropriate, accurate examples of the concept provided but are not explicitly connected to the concept</td>
<td>One appropriate, accurate example of the concept provided and explicitly connected to the concept</td>
<td>More than one appropriate, accurate example of the concept provided and explicitly linked to the concept</td>
<td>Score</td>
</tr>
</tbody>
</table>

The rubric categorizes teachers' performance into levels of accuracy, from Limited to Advanced, with clear criteria for each level. It also assesses the level of detail in reflection and interconnections, along with the appropriateness and accuracy of examples provided.
### DIMENSION OF PCK

<table>
<thead>
<tr>
<th>SCORE/EVIDENCE</th>
<th>LIMITED 0</th>
<th>BASIC 1</th>
<th>PROFICIENT 2</th>
<th>ADVANCED 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dim: CxK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understands how student variations impact instruction</td>
<td>No evidence of understanding of students' common prior conceptions/difficulties and how they might impact instruction</td>
<td>Narrow understanding of students' common prior conceptions/difficulties and how they might impact instruction</td>
<td>Adequate understanding of students' common prior conceptions/difficulties and how they might impact instruction</td>
<td>Sophisticated understanding of students' common prior conceptions/difficulties and how they might impact instruction</td>
</tr>
</tbody>
</table>

### DIMENSION OF PCK

<table>
<thead>
<tr>
<th>SCORE/EVIDENCE</th>
<th>LIMITED 0</th>
<th>BASIC 1</th>
<th>PROFICIENT 2</th>
<th>ADVANCED 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dim: PK</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relationship between rationale to teaching strategies</td>
<td>No rationale provided OR A rationale that does not establish a relationship between strategies and student learning</td>
<td>Simplistic rationale that establishes a weak or partial relationship between teaching strategies and student learning</td>
<td>Adequate rationale that establishes an accurate, but limited relationship between teaching strategies and student learning</td>
<td>A sophisticated rationale that establishes a comprehensive relationship between teaching strategies and student learning</td>
</tr>
</tbody>
</table>

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**---Completeness/ Soundness**

<table>
<thead>
<tr>
<th>Score</th>
<th>Total CxK Score:</th>
<th>Total PK Score:</th>
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</thead>
</table>

**---Strategies**

<table>
<thead>
<tr>
<th>Score</th>
<th>Total CK Score</th>
<th>Total CxK Score</th>
<th>Total PK Score</th>
<th>PCK Score</th>
</tr>
</thead>
</table>

**Note:**

- **CxK:** Total CxK Score:
- **PK:** Total PK Score:
Acknowledgements

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Kristin Anderson, NAU – recruitment and program development
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Vanessa Kesler, Independent consultant – data analysis
Molly Stuhlsatz, BSCS – data analysis
Chris Wilson, BSCS – data analysis