Utilizing a Written Assessment to Measure Growth in PCK for Elementary Science Teachers’ Involved in a Large-Scale Experimental Study

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Introduction

Over the past decade researchers from WestEd and Heller Research Associates have partnered to investigate the development of teachers’ pedagogical content knowledge (PCK) in science as a result of their participation in professional learning that is intentionally designed to strengthen teacher PCK. In early studies, data were collected via pre-/post-interviews from a small number of teachers. Later, paper-and-pencil instruments were developed to accommodate large sample sizes in causal studies. Most recently, through the use of classroom video and teacher interviews, we are investigating ways in which teachers utilize or “enact” professional knowledge when engaged in content-specific teaching. This outline summarizes the methods, data, and findings from a two-year randomized experimental study (completed in 2012) that addressed links in the causal chain from the teacher professional learning to student outcomes. The related PCK research questions include:

1. Did the professional learning produce changes in teacher PCK?
2. Is there evidence that professional learning impact on PCK accounts, in part, for the impact on student outcomes?
3. What changes in teacher PCK may have contributed to increases in student science achievement?

Study Design

The randomized experimental study looked at the direct effects of three in-service teacher professional learning courses on teacher knowledge, as well as the causal links to student outcomes. Modeled after the WestEd Making Sense of SCIENCE series, the three courses all had identical electric circuits content and collaborative science investigations, but different approaches to developing pedagogical content knowledge (PCK), including discussions of written cases (*Teaching Cases*), analysis of student work from teachers’ current classes (*Looking at Student Work*), and reflection on teachers’ own science learning (*Metacognitive Analysis*).

Teacher PCK was assessed through written questions that were developed by the research team and pilot tested with elementary teachers who were external to the study. For the PCK questions, teachers were asked to interpret student strengths and weaknesses in their understanding of electric circuits on the basis of samples of student work, and to describe instructional strategies for addressing those difficulties (e.g., “What might the teacher do next to move this student toward a more accurate understanding of complete circuits?”). In addition, teacher and student content knowledge was measured by multiple-choice test items, and the quality of explanations and applications of that content knowledge was measured with open-ended items (Heller, Daehler, Wong, Shinohara, & Miratrix, 2012).

While this study was carried out prior to the development of the Consensus Model of Teacher Professional Knowledge and Skill (TPK&S), it is helpful to situate our work in this newer model of PCK. Using this lens, we see our written Teacher PCK instrument as providing insight into teachers’ Classroom Practice, similar to how a flight simulator is an indicator of a pilot’s performance. In a flight simulator, pilots respond to the information provided and draw on their prior knowledge and skill to take action. Within Classroom Practices the model defines a teacher’s Personal PCK as, “the *knowledge* of and *reasoning* behind, and *planning* for teaching a particular *topic* in a particular way for a particular *purpose* to particular *students* for enhanced *student outcomes.*” Similarly, our written Teacher PCK instrument situates teachers in a classroom context (e.g., teaching electric circuits to 4th graders), and then asks them to engage in several authentic tasks — analyzing a sample of student work and planning next steps in instruction to address that student’s understanding. Indeed, teachers’ responses are shaped by the amplifiers and filters of their own beliefs, knowledge, and experiences from their own classrooms with their own students.

Our written Teacher PCK instrument focuses on the act of *planning* to teach a particular student with the explicit purpose of enhancing that student’s outcome, however it does not provide information about a teacher’s *reasoning,* a key element of Personal PCK. In addition, we do not see our written Teacher PCK instrument as a direct measure of a teacher’s Topic Specific Professional Knowledge (TSPK) (e.g., the knowledge of instructional strategies, content representations, understanding of students of a specific age group), because the task is situated in a scenario that requires teachers to apply their general TSPK to plan an action or enactment.

An interesting affordance of our study design is the possibility to compare the “simulation” data about Classroom Practices provided from the written Teacher PCK assessment with classroom videos and pre-/post-instruction interviews that provide direct information about teachers’ actual Classroom Practices with regard to their Personal PCK and their Pedagogical Content Knowledge and Skills (PCK&S).

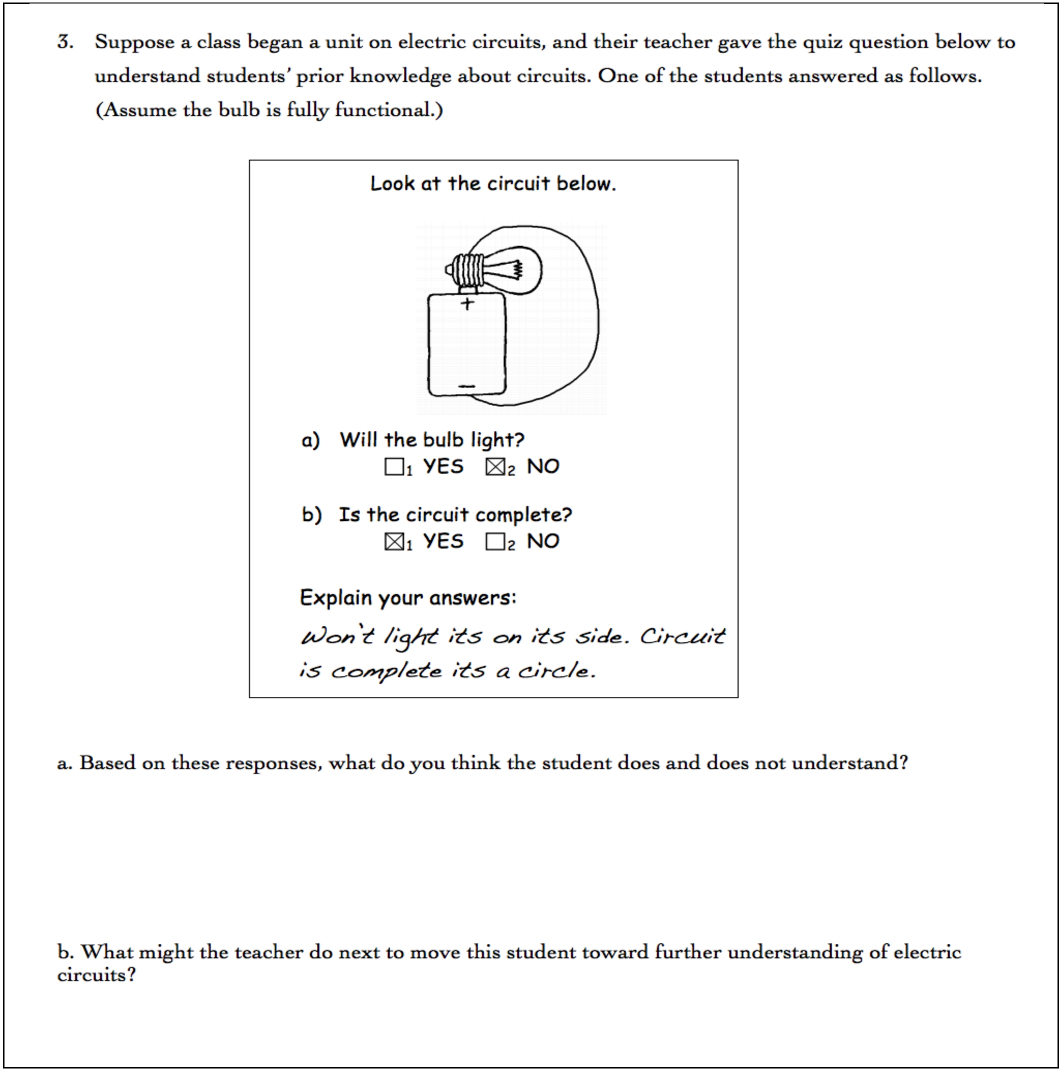
Data collection

The study was implemented at eight sites in six states across the U.S. with 39 districts, over 280 elementary teachers, and nearly 7,000 students. Interventions were delivered by local staff developers trained at facilitation academies to lead teacher courses in their regions. Data were collected before and after the implementation of two rounds of professional learning courses. Each of the three interventions was a 24-hour electric circuits course delivered in eight three-hour sessions. All participating teachers completed a written Teacher PCK assessment, and a subset of 30 teachers participated in classroom videotaping and interviews.

Written Teacher PCK instrument

Teachers were presented with a classroom scenario and asked to complete a two-part task: they analyzed a sample of student work and then create instructional next steps to support the fictitious student's learning. Analysis of teachers' Personal PCK was conducted based on their responses to question 3b. (See Figure 1.)

Figure 1. *Excerpt from written Teacher PCK instrument.*



3. Suppose a class began a unit on electric circuits, and their teacher gave the quiz question below to understand students' prior knowledge about circuits. One of the students answered as follows. (Assume the bulb is fully functional.)

Look at the circuit below.

a) Will the bulb light?
☐1 YES ☒2 NO

b) Is the circuit complete?
☒1 YES ☐2 NO

Explain your answers:

Won't light its on its side. Circuit is complete its a circle.

a. Based on these responses, what do you think the student does and does not understand?

b. What might the teacher do next to move this student toward further understanding of electric circuits?

Classroom Observations and Interviews

Two consecutive lessons for each of the 30 intensive study teachers were observed and videotaped as they taught lessons about electric circuits. Teachers were interviewed immediately before and after the observations. Audiotaped interviews focused on the rationale for lesson design decisions and teachers' perceptions of what occurred during the classroom. During the post-observation interviews, teachers reflected on short video clips of classroom moments recorded by the observers. (See Appendix A for interview protocol.)

Data analysis — written Teacher PCK instrument

Teachers' responses to the written PCK instrument were analyzed for how they applied their teacher professional knowledge base (TPKB) along with their topic specific professional knowledge (TSPK) for the purpose of (a) *analyzing student work,* as evidenced by their identification of common misconceptions and gaps in understanding and (b) *planning teaching to enhance student outcomes,* as evidenced by their explicit selection and sequencing of multiple, accurate, and grade-appropriate strategies to support student understanding (e.g., engaging students in observable phenomena, utilizing drawings and other representations, explaining underlying mechanisms to explain "why") of a specific topic (e.g., complete circuits). These elements of PCK, informed by Shulman's (1986) original formulation, were incorporated into a coding scheme for analyzing teachers' responses.

Our analysis included nine separate codes, across several categories including: *teacher explanation* (code 1), *student investigation* (code 2) and *sense-making activities* (codes 3–9), as shown in Table 1. Each written response received between 0 and 2 points in each of the coding categories, and a single PCK score was determined by summing the points for each code identified. One rater conducted a blind scoring of the teachers' written responses to the instructional strategies prompt. As a reliability check, a second rater scored a random sample of 15 percent of the full set of responses, each receiving scores for each of the 9 codes, totaling 270 score judgments. On this sample, the raters disagreed on only 6 scores, or 2.2 percent of the judgments.

Table 1. *Coding and Scoring of Written Question, "3b. What might the teacher do next to move this student toward further understanding of electric circuits?"*

Coding category	Sample responses	Point value
1. Teacher explains, shows, or demonstrates (e.g., how/why a bulb will or will not light, how current flows, or short circuit).	*Teach them about conductors and insulators.* *I would show the student how the light bulb works*	1
2. Student investigates (e.g., use materials to build circuits and find ways to light a bulb).	*Have student create the circuit.* *Provide the same materials from test question for the student to manipulate.*	1
3. Teacher asks student to explain the observed phenomenon (e.g., draw, describe or trace flow of current by pointing).	*The teacher might put up multiple drawings of simple circuits with the bulbs in various locations and orientations (up or sideways). Have students trace path of electricity and highlight connection points on the bulb and battery.*	2

Coding category	Sample responses	Point value
4. Teacher asks student to draw or talk/write about what works and what doesn't work, or what lights what's complete.	*Investigate and collect data by drawing what circuits will and will not light the bulb. Write a statement after comparing and contrasting the results above which explains the contributing factors that lit the bulb and didn't light the bulb.*	2
5. Teacher has student(s) use a model or a metaphor for current.	*Role play or further demonstrate "circuit."*	2
6. Teacher and/or student(s) discuss *why* they observe what they do.	*Discuss why this circuit won't light.* *The teacher might have the student build this picture to find out if their predictions were accurate and then discuss the results.*	2
7. Teacher uses at least one domain-specific representation that targets a weakness in the student's understanding (e.g., shows picture of inside of bulb, draws arrows to indicate path of current).	*Show innards of bulb.* *Students need to understand how a light bulb works. The point of entry must be different from the point of exit. Flow of current in a bulb goes base to filament to jacket or vice versa.*	2
8. Teacher addresses student understanding by emphasizing connections or contact points on the bulb and battery.	*Explain bottom of the bulb/sleeve are both needec to be connected by wire/battery to complete circuit and light the bulb.*	2
9. Teacher addresses student understanding by focusing on short circuit, warmth in circuit, or features of complete circuit.	*Ask, why is it getting hot? Do a lesson on short circuits.* *Recording what a circuit must have to be complete would help further understanding.*	2

Note. Total score is computed as the sum of points for all categories.

Utilizing this approach, PCK scores were determined on pre- and post-tests for a total of 249 teachers, across three treatment conditions and a control group. The following response illustrates how these codes were applied. Teacher #1002 wrote:

> *Ask the student to make this circuit [the one shown in the problem, which does not light]. Then using the same materials, make the circuit light, comparing Circuit 1 to Circuit 2 and tracing the path of electrical current, and including the inside of the light bulb (filament) to understand what makes a circuit complete.*

Teacher #1002 demonstrated a high level of Personal PCK in this simulated classroom scenario. The teacher's response was specific to the content domain and directly targeted the student's understanding. For example, the teacher would have the student investigate the phenomenon directly by "ask[ing] the student to make this circuit [the one that doesn't light]" (code 2) and "using the same materials, make the circuit light" (code 2). Then, the teacher pointed to several different instructional strategies to engage the student in sense-making activities, such as "tracing the path of electrical current" and "comparing Circuit 1 and Circuit 2" (codes 3 and 4). The teacher addressed a weakness in the student understanding by using at least one domain-specific representation (i.e., including the inside of light bulb) (code 7) and focusing on the features of a complete circuit (code 9). By summing the points for each identified code, Teacher #1002 earned a PCK score of 9 points, which was among the highest in the sample of 249 teachers.

Results — written Teacher PCK instrument

Analysis of 249 post-test responses to the written Teacher PCK instrument, from treatment and control groups combined, showed a range of teacher PCK scores from 0 to 10 points. Approximately one quarter of these teachers received a PCK score of 1 point, while nearly 60% of the teachers had PCK scores of 3–5 points, and only 10% of teachers received 6 points or greater.

Our research led us to ask, "Are there characteristic differences in teachers' instructional approaches for those with lower and higher PCK scores?" and "Did the professional learning produce changes in teacher PCK?" To address these questions, we first analyzed teachers' responses according to their mention of three different instructional strategies (e.g., teacher explanations, student hands-on investigations, and sense-making activities). We gave particular attention to *engaging students in sense-making,* as all three interventions modeled extensive sense-making strategies during the identical science investigations for teachers. In addition, the Teaching Cases intervention provided classroom examples and artifacts of sense-making, which served as a classroom proxy. Looking at Student Work included formative assessment tasks that required students to explain their science ideas. While Metacognitive Analysis did not provide any direct connections to elementary students' classrooms, teachers were asked to reflect on their own sense-making experiences on the same topics taught to their students (e.g., electric circuits).

We also analyzed the extent to which teachers *specified conceptual learning goals* related to the topic-specific domain of understanding electric circuits. This analysis seemed apropos, as Personal PCK is also about teaching a particular topic to particular students (e.g., complete circuits to 4th graders), which requires teachers to apply their Teacher Professional Knowledge and Skill (TPK&S) to identify content-specific and age-appropriate conceptual learning goals. A teacher's ability to articulate such goals is key to planning instruction that supports student understanding and enhances student outcomes related to those goals. Analysis of teachers' instruction strategies and articulation of specific learning goals revealed several interesting differences between treatment and control teachers, as well as between the three different interventions, as shown in Table 2.

Table 2. *Percent of Teachers Giving Each Category of Response to Written Pedagogical Content Knowledge Question, by Experimental Condition.*

Response to, "What might the teacher do next to move this student toward further understanding of electric circuits?"	**Teaching Cases**	**Looking at Student Work**	**Meta-cognitive Analysis**	**Control**
n	67	60	53	69
Teacher *only* has student do hands-on investigations	10.4	8.3	13.2	**39.1**
Teacher has students do hands-on investigations *and* sense-making activities	**29.9**	13.3	17.0	10.1
At least one sense-making strategy	**47.8**	26.7	22.6	15.9
More than one sense-making strategy	**14.9**	6.7	5.7	4.3
At least one conceptual learning goal	70.1	**78.3**	62.3	36.2
More than one conceptual learning goal	19.4	**25.0**	18.9	7.2

Teacher has students do hands-on investigations. Two patterns emerged in relation to teacher responses that included having students work directly with bulbs, batteries, and wires. One set of responses included only mention of student hands-on work (code 1) (for example, "I would have them build it."), with no reference to strategies for helping students make sense of what they observed. Nearly 40 percent of the control teachers responded in this way, whereas fewer than 15 percent of any intervention group teachers did so. The second response pattern involved mention of student hands-on work, but with explicit reference to strategies for helping students make sense of what they observed. The largest proportion of Teaching Cases responded in this way, 30 percent, as compared with 10 percent of control teachers and 13–17 percent of teachers in the other two intervention groups.

Teacher engages students in sense-making activities. This category corresponds to mentions of strategies and representations that would engage students in understanding what they observe (such as by tracing the current through the circuit, or creating a T-chart to compare drawings of circuits that did and did not light the bulb). First, looking at mention of at least one such strategy, Teaching Cases again produced the highest proportion, close to 50 percent, whereas the other two intervention groups ranged from 23–27 percent, and only 16 percent of control teachers described meaning-making activities for students. Second, looking at responses that contained more than one such strategy, Teaching Cases again produced the highest proportion, 15 percent, whereas the other two intervention groups ranged from 6–7 percent, and only 4 percent of control teachers described multiple meaning-making activities for students.

Teacher specifies conceptual learning goal. The final category of response focused on mention of specific conceptual understanding of science content that the teacher wanted the students to understand. The interventions that most strongly led to teachers mentioning at least one specific conceptual learning goal for their students were Looking at Student Work (78 percent of teachers) and Teaching Cases (70 percent of teachers), followed by 62 percent of Metacognitive Analysis teachers. These proportions were approximately double those of the control teachers.

Data analysis — classroom observations and interviews

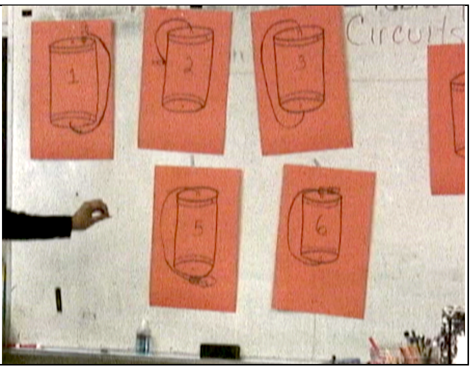
We are currently analyzing classroom video and related interviews from a subset of 30 study teachers to learn about their PCK&S in action and pedagogical reasoning about the observed lessons. The videos are being rated by 3 independent raters using a rubric consisting of a 5-point scale for each of the following five dimensions of classroom practice related to PCK&S in action (See Appendix B):

Dimension 1: Students are cognitively engaged in science
Dimension 2: Classroom experience is focused on conceptual understanding of core science ideas that have explanatory power
Dimension 3: Domain-specific representations are used to support sense-making
Dimension 4: Students are engaged in scientific sense-making practices
Dimension 5: Teacher elicits and attends to student thinking

Together, these dimensions provide information about the extent to which teachers were able to use their Personal PCK to actively engage students in sense-making around core science concepts, which we believe lead to the observed enhanced student outcomes (e.g., student achievement). We anticipate that responses to the written PCK items will serve as an indicator of the PCK&S reflected in teachers' classroom practice, with teachers who had higher scores on the written items also having higher scores on the video rubric.

In the example that follows, we use an episode from Teacher 1002's classroom observation to illustrate how we might see aspects of Personal PCK elicited by the written item in the PCK&S in action that we can infer from the classroom video.

Teacher 1002 was observed for 2 consecutive days during her lessons about electric circuits. Prior to the observation, the class worked in small groups to experiment with materials to find ways to a light bulb in a simple circuit. Students constructed configurations of complete circuits that made the bulb light and others that did not (short circuits). The first day of the video observation captured a lesson that built on the prior circuit-building work. At the beginning of the lesson, the teacher displayed diagrams of six circuit configurations and asked students to work in small groups to predict whether the bulb would light and explain why.

Draw each of these circuits in your notebook. Talk about it with your group and figure out, do you think this will light the light bulb? I'm going to call on you and ask you what you think, and I want you to tell me why. So make sure you discuss it with your group. (Teacher 1002, Day 1, 13:15–14:07)	

During the whole-class discussion that followed students' small group work, the teacher elicited student thinking about contact points and the flow of current:

Teacher: So, tell me why you think it will work. What makes it work?
Student 1: Electricity is flowing
Teacher: But how was it connected that makes it work, [Student name]? (Teacher gestures toward the circuit diagram on the board)
Student 1: The wire is on the part . . . on the negative
Teacher: So, because you have the wire on the negative end (Teacher points to the negative end of the battery in the circuit diagram on the board), go ahead
Student 1: And the other part is attached to the light bulb that is on the positive side. (Teacher traces the wire from the negative side of the battery to the light bulb as described by the student)
Student 1: The energy is flowing through…through the wire and making the bulb light.

(Day 1, 24:20–24:57)

Teacher 1002's class ratings along the 5 dimensions of classroom practice were highly consistent with the high level of Personal PCK reflected in her written response. This teacher described multiple strategies for engaging students in sense-making (codes 2, 3, 4, 6), including use of domain-specific representations (code 7). In the classroom enactment, we see that students were, in fact, engaged in the scientific practice of explaining why bulbs would or would not light (dimension 3), and used representations to make sense of the contact points needed to light the bulbs (dimension 4). The written PCK response included a strong focus on key concepts (codes 7, 9), and in the classroom the activity was highly focused on the core ideas of current flow in complete circuits (dimension 2). Overall, the large number of student sense-making activities listed in Teacher 1002's written response is consistent with the classroom observation in which students' work and ideas play a central role (dimension 5), and students were highly engaged in science and were primarily responsible for their own learning (dimension 1).

While Teacher 1002's written response and actual classroom enactment shows consistency across PCK ratings, we do not yet know the degree of correlation between the instruments, as the analysis of classroom videos is not yet complete. However, a crosswalk between the coding categories for the written PCK Instrument and the dimensions from the Classroom Observation Rubric suggests that similar aspects of Personal PCK are being evaluated, as shown in Table 3.

Table 3. *Crosswalk between Written PCK Instrument and Classroom Observation Rubric*

	Written PCK Item	**Classroom Observation**
Focus on Sense-making	Sense-making actions (1, 3, 4, 5, 6) Domain-specific representations (7) Lack of "students do" as only" action (2 only)	Students are engaged in scientific sense-making practices (Dim 3) Domain-specific representations are used to engage students in sense-making (Dim 4)
Focus on Concepts	Identifies conceptual goals (7, 8, 9) Domain-specific representations (7)	Classroom activity is focused on conceptual understanding (Dim 2) Students are cognitively engaged in science (Dim 1)
Student-centered Environment	Lack of "teacher tells" as only action (1 only) Describes student actions (2, 3, 4, 5, 6)	Students are cognitively engaged in science (Dim 1) Teacher elicits and attends to student ideas (Dim 5)

Conclusion

This study demonstrates it is feasible to use a written measure to assess key aspects of teachers' Personal PCK in large-scale studies. While the written instrument primarily focuses on the act of *planning* to teach (a particular *topic* in a particular way for a particular *purpose* to a particular *student* for enhanced *student outcomes)*, the instrument could be modified to also provide information about teachers *reasoning*. Analysis of teachers' responses is notably weighted toward science instruction that (a) targets core science concepts and (b) incorporates activities and representations intended to help students make sense of phenomena and goes beyond teacher explanations only or engaging students in hands-on investigations absent of sense-making opportunities.

It is both a limitation and a benefit that the written PCK instrument utilizes a scenario-based instance of teaching rather than direct observation of teachers' practices in situ in the classroom. Perhaps the most significant benefit of the written PCK instrument is that it is far less labor intensive and time consuming to administer and score than classroom observations. However, rather than providing direct observations of a teacher's enacted PCK, the written PCK instrument serves as a proxy for the classroom and provides information about how teachers apply their general Topic Specific Professional Knowledge (TSPK) (e.g., the knowledge of instructional strategies, content representations, understanding of students of a specific age group) to plan an action or enactment, thus evidence of Personal PCK.

Further analysis is needed to determine if teachers' written responses about hypothetical scenarios correlates with the Personal PCK demonstrated in their actual classroom practices. While it is reasonable to expect that teachers' who demonstrate higher levels of Personal PCK in the classroom would also demonstrate higher levels of PCK on a written measure, the reverse may not necessarily hold true. Given that skill in teaching develops through practice, we anticipate seeing more advanced PCK for some teachers' written responses than in their classroom practices. As with other simulations, the written PCK tasks are also limited in that they restrict the scope of the demands placed on the teacher.

As a footnote, findings showed (a) only *Teaching Cases* and *Looking at Student Work* improved teacher PCK, (b) impact on student test scores is only partly accounted for by teachers' content knowledge and is significantly predicted by teacher PCK, and (c) the *Teaching Cases* course was especially effective at increasing teachers' explicit focus on conceptual learning goals for students, references to engaging students in active roles, and strategies for helping students make sense of science ideas. The findings suggest there is value in investing in professional learning opportunities that integrates teacher content learning with analysis of teaching and learning.

Heller, J. I., Daehler, K. R., Wong, N., Shinohara, M., & Miratrix, L. (2012). Differential effects of three professional development models on teacher knowledge and student achievement in elementary science. *Journal of Research in Science Teaching, 49*(3), 333-362.