Using a Pedagogical Content Framework to Determine the Content of Case-Based Teacher Professional Development in Science

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Introduction

Practitioners and policy makers alike recognize the need for professional development in science that is steeped in content yet grounded in practice. But what does such professional development look like? And what can it help teachers to learn?

This paper describes an approach to developing teachers' pedagogical content knowledge in science. The approach is characterized by four underlying principles:

1. Pedagogical content knowledge is crucial to good teaching and high levels of student learning.
2. In order to develop pedagogical content knowledge, teachers must have opportunities to learn subject matter content in combination with student thinking and instructional strategies.
3. Analytic group discussions of real classroom episodes can stimulate shifts in teachers' pedagogical content knowledge, attitudes, beliefs, and practice.
4. In order to successfully develop teachers' pedagogical content knowledge, courses must target specific pedagogical content outcomes, not just outcomes for subject matter content, student thinking, and pedagogy.

Using the example of an empirically validated professional development project, *Science Cases for Teacher Learning,* this paper (a) models the application of this approach to developing teacher pedagogical content knowledge in science, (b) describes the design and learning outcomes of a sample in-service course for elementary teachers, and (c) shares lessons learned.

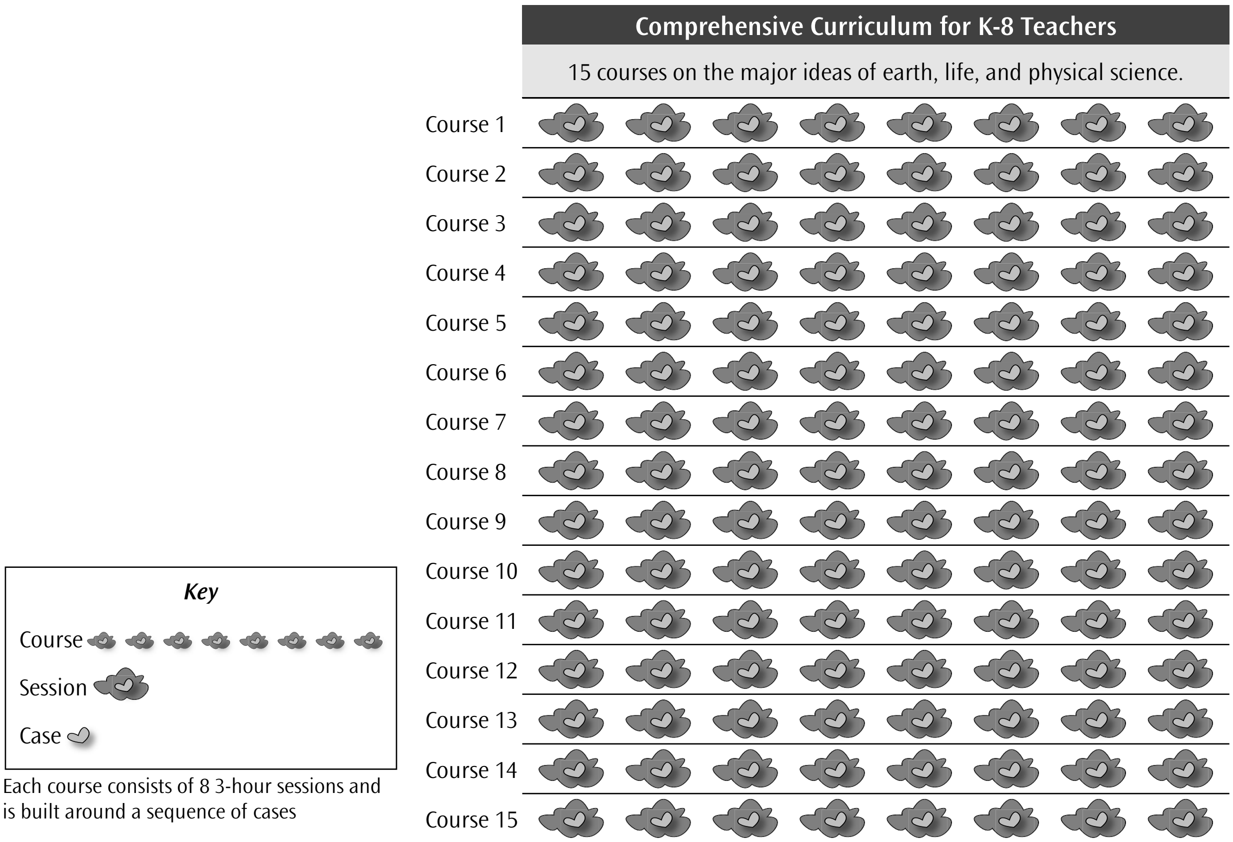
Science Cases for Teacher Learning

The fundamental goal of the *Science Cases for Teacher Learning* project is to foster teachers' pedagogical content knowledge in science. A series of in-service courses for teachers is being developed toward this end. All of the course materials and activities are designed not only to strengthen teachers' knowledge about science content and their repertoires of pedagogical strategies, but also to bring about "the integration or the synthesis of teachers' pedagogical knowledge and their subject matter knowledge that comprises pedagogical content knowledge" (Cochran, 1992, p. 4).

At present, materials for two courses have been written (*Electric Circuits* for teachers of grades 3-6, *Magnets and Magnetic Force* for teachers of grades 3-6). Materials for 13 others are planned or in development. Together, the materials will form a comprehensive pedagogical content curriculum for K-8 teachers (15 courses on the major ideas of earth, life, and physical science).

The pedagogical content courses are organized by topic and grade level (e.g., the teaching of electric circuits in grades 3-6). Each course is built around a sequence of cases (one case per session, eight sessions per course, a total of 24 hours of professional development per course).

The cases describe real classroom events that took place during science lessons: events that perplexed, surprised or disappointed the teacher



Each course consists of 8 3-hour sessions and is built around a sequence of cases

in whose classrooms they originally occurred. Narratives of these episodes are written by classroom teachers and contain student work, student-teacher dialogue, teacher behaviors and the teacher's thoughts. The resulting cases are then used to stimulate analytic group discussions among teachers in groups guided by teacher-facilitators. The power of the case approach lies in the coupling of these discussions with purposeful hands-on exploration and structured reflection.

Teacher educators who have led the courses have found them to be an important and unique support for teacher learning. The materials have been used with practicing teachers in both summer institutes and school-year settings. In addition, the courses have served as core curriculum for teacher leaders, content specialists, and beginning teachers.

For example, since 1998 the *Science Cases* program has worked with more than 500 teachers and provided in excess of 10,000 hours of professional development (impacting an estimated 12,000 students). Research demonstrates dramatic improvements in science achievement for these students, along with measurable outcomes for their teachers and classrooms (Heller & Kaskowitz, 2002, Heller & Kaskowitz, 2003). An especially encouraging result is that low-performing students make the biggest gains.

Design of the professional development

The design of the professional development is guided by the underlying principles stated at the beginning of this paper. These principles, coupled with a conceptual framework relating the features of the professional development to the intended outcomes, make up the professional development model on which the program is based.

Conceptual Framework			
Critical Features of Science Case Discussion Method	**Teacher Outcomes**	**Classroom Outcomes**	**Student Outcomes**
Exploration of Scientific Meanings. Teachers discuss, investigate, and think carefully about the meaning of specific science concepts in each case.	Rich and accurate understanding of the science concepts in the cases; confidence and positive attitude toward learning, doing, and teaching science.	Discussion and activities focus on the meaning of science concepts. Science content meets grade-level expectations in accuracy and coverage.	Accurate understanding of science concepts in the cases; grade-level appropriate knowledge of science content; ability to observe, look for patterns, and draw conclusions.
Focus on Student Thinking. Teachers examine and interpret student work, talk, and behaviors in each case to determine what students understand and are thinking.	Heightened attention to student thinking; understanding of what is important for students to know about the content; knowledge about what makes science learning difficult for students.	Instruction and assessment elicit and build on student thinking and deal directly with what is difficult for students; curriculum addresses what is important for students to know about the content.	Ability to avoid or move beyond misconceptions and errors; skill in thinking and communicating scientifically.
Critical Analysis of Practice. Teachers analyze the effectiveness and coherence of instructional practices, activities, materials, and scientific representations in each case.	Pedagogical reasoning is analytical, complex, and detailed; ongoing reflection about the effectiveness of instructional practices, activities, and materials; skill in making science comprehensible to students.	Instructional practices and materials communicate and develop the meaning of science concepts; coherent, structured sequences of inquiry activities; instructional decisions are adjusted as a result of ongoing analysis of student understanding.	In-depth understanding of science concepts; ability to represent scientific meanings in a variety of ways.

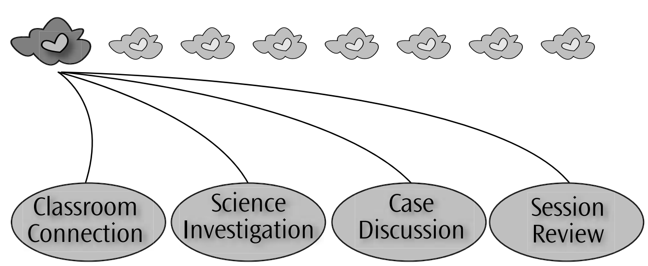
Conceptual framework

The conceptual framework (as shown above) highlights major features of the professional development in the first column (Exploration of Science Meanings, Focus on Student Thinking, and Critical Analysis of Practice) and points to ways in which each feature is meant to be reflected in outcomes for teachers, classrooms, and students in the second, third, and fourth columns, respectively. For example, Exploration of Science Meanings is intended to strengthen teachers' understanding of science concepts, which would influence student opportunities to learn through the way those concepts are taught, which would affect students' understanding of the concepts.

The value of the conceptual framework lies in its ability to shape the design and evaluation of project courses. At the same time, the view that it presents of the professional development is highly simplified. For example, the features of the professional development are in truth overlapping and inextricably interrelated, as are other columns and rows in the conceptual framework.

Major activities

The features of the professional development are implemented in each session through a sequence of four activities. Typically, each session begins with a Classroom Connection, followed by a Science Investigation, Case Discussion, and Session Review as shown in the figure below.



A description of each activity is provided below, along with a sample syllabus showing their order and priority. To help explain how the various activities build on one together, examples are drawn from a specific course and session *(Electric*

Circuits, a course on the teaching of this topic in grades 3-6, Session 1).

Session Activities	
Classroom Connection	20 minutes
Science Investigation	
Groups of three	30 minutes
Whole group	30 minutes
Quick Write	5 minutes
Break	15 minutes
Case Discussion	
Groups of three	30 minutes
Whole group	30 minutes
Session Review	15 minutes
About the Next Meeting	
Classroom Connection & Readings	4 minutes
Housekeeping	1 minute

Classroom Connection. Before each three-hour session, teachers read a case of real-life science teaching, along with content notes explaining the underlying science. They also complete short assignments, known as Classroom Connections, to connect what they learn in the sessions to the science ideas and learning of their own students. Assignments vary from session to session and include student interviews, analysis of commonly taught lessons, and experimentation with new teaching strategies.

In one Classroom Connection assignment, teachers examine the ideas of children in their own classrooms. As homework between sessions, participants interview 2-3 students from their class and take notes on what each child says and does. Teachers begin the interview by piquing the child's interest, for example by using a battery and wire to make a bulb light. Next they invite the student to do the same, using an identical set of materials. The teacher then asks, "What do you think is happening to make the bulb light?"

Results of the interview assignment are discussed at the beginning of the next session. Guiding questions are used to facilitate the conversation:

Q: How were the ideas of your students like and unlike the ideas of other students (e.g., students in the case and students interviewed by other teachers)?

Q: What does this tell you about how students think about circuits?

As the conversation unfolds, an important connection emerges for members of the group. The ideas of students in the case are like those of students in their own classrooms. Thus the discussion of cases can provide important insights into the teaching of their own students. The conversation also prompts participants to examine and rethink fundamental assumptions of what children can learn and the ways in which that learning can take place.

Science Investigation. The power of the Science Investigation lies in the coupling of analytic group discussions with purposeful hands-on exploration and structured reflection. Teachers replicate the instructional activities experienced by students in the case. The goal is to develop an adult understanding of the underlying science, uncover different ways of thinking about those ideas, and experience science inquiry first-hand.

Teachers work in groups of three to do and discuss the hands-on activities described in a handout. With guidance from a facilitator, the group explores common areas of interest and confusion. Together they interpret the hands-on evidence, discover different ways of interpreting the data, and explore the logic behind common yet incorrect student (and adult) ideas about the science.

For example, in one Science Investigation teachers find as many ways as they can to light a bulb using a battery and a wire. Many are surprised to find a bulb can be lit in more than one way using the same materials. Comparisons of the circuits that lit and did not light the bulb point out the connections needed to light a bulb. Participants summarize their findings (A bulb in a circuit will light if…), then use their summary statements to predict if the bulbs in different circuits will light.

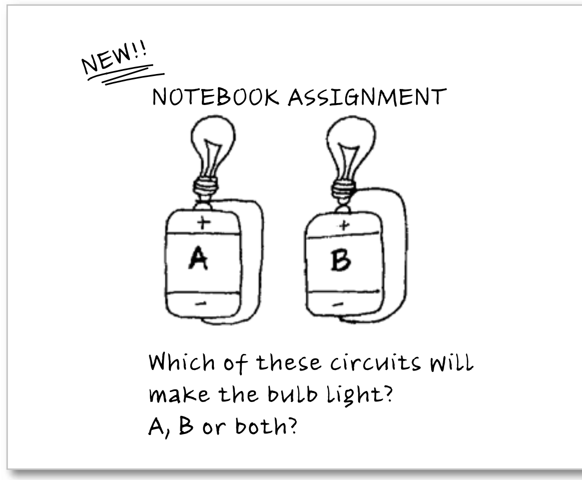
The handout deliberately presents several circuits that are complete but do not make the bulb light (e.g., short circuits). Confronted by these circuits, participants grapple with the distinction between lit and complete circuits. They ask, “A lit bulb is evidence of a complete circuit. But is the opposite true? Is an unlit bulb sure-fire evidence of an incomplete circuit?”

Case Discussion. Following the Science Investigation, teachers work in groups of three to examine the student thinking presented in a case and critically analyze the instruction. A handout of guiding questions prompts teachers to think deeply about classic instructional strategies and the way in which students respond to those strategies. With guidance from a facilitator, the group engages in a whole-group discussion to draw upon the experience and thinking of their peers. Confronted with a wide array of evidence-based opinions and beliefs, teachers critically analyze their own teaching practices and reexamine personal beliefs about the teaching and learning of science.

For example, the case *Circuits are Circles* chronicles a teacher’s struggle to help her fourth graders understand three critical science concepts: (1) a complete electric circuit is required for electricity to light a bulb, (2) electricity can produce light and heat, and (3) a complete circuit can be constructed in more than one way using the same materials. Students begin the unit with a classic activity: find as many ways as you can to make a bulb light using a battery and wire. Concerned that some students may need help getting started, the teacher provides a hint, “Circuits are like circles, unbroken paths for electricity to flow from one end of the battery to the other.”

With the teacher’s help, students find many ways to make their bulbs light. They also make important discoveries about complete circuits and the connections needed to light a bulb. For example, Monica discovers that electricity can produce heat, not just light. As she explains to another student, “A short circuit is when your fingers get hot. There’s a circle but the light is off.” Kevin and Aron determine that the bulb must be connected at two points to light (the jacket and the tip) because of hard-to-see circuitry inside the bulb.

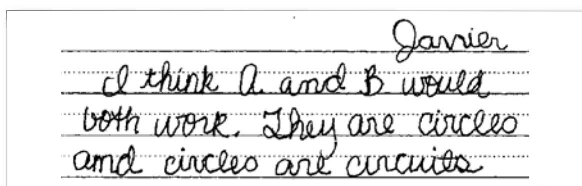
Wanting to drive home the point that a bulb needs to be part of the circuit, the teacher assigns a quick write.



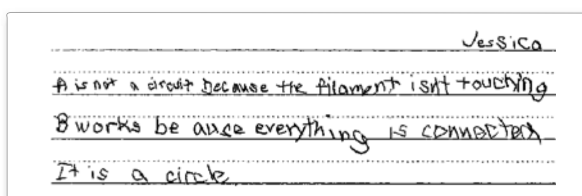
Although children constructed these very circuits, most students incorrectly predict that both bulbs will light. (The bulb in Circuit A does not.)

A review of children’s notebooks shows that students are focusing on different features of the circuits.

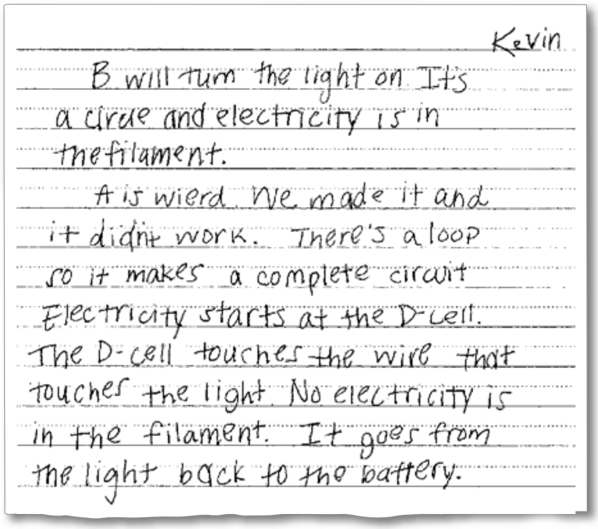
Like Javier, many students make the mistake of focusing on shape.



Others show a budding understanding of connections.



A few students talk in terms of complete circuit and flow of electricity.



Kevin

B will turn the light on It's a circle and electricity is in the filament.

A is wierd. We made it and it didn't work. There's a loop so it makes a complete circuit Electricity starts at the D-cell. The D-cell touches the wire that touches the light. No electricity is in the filament. It goes from the light back to the battery.

Disappointed yet undeterred, teacher ponders what to do next. As she writes in the case, "It seems more time is needed on complete circuits. But what exactly should we do next? Is simply spending more time building and comparing circuits what's needed? Or should I introduce a series of structured tasks? And if so, what should they be?"

In the discussion of this case, questions such as the ones below are used as a springboard for talking about the student work and teaching.

Q: What did Kevin and Aron discover about the circuitry inside a bulb? Why might other students have missed such a discovery?

Q: Students pay attention to several different features of circuits: shape, connections, and the path of electricity. Look at the words, actions and work of students in the case to see what they gained from each approach. What do you think is limiting, confusing, or potentially misleading about each?

Q: At the end of the case, the teacher asks, "What is the instructional value of short circuits?" How would you answer this question?

Each question prompts teachers to integrate and transform their knowledge of science, student thinking, and instruction. For example, the first question directs teachers to examine and compare the ideas of Kevin, Aron, and other students in the case as they think about the circuitry inside a bulb. To do so, teachers must draw on their own understandings of the bulb, understanding typically developed during the Science Investigation. They must also consider the ways in which different students interpreted (or misinterpreted) the same hands-on evidence. Discussion of such topics lead naturally to questions about the thinking and instruction of one's own students.

Session Review. At the end of each session, participants reflect on their work as a learning community. Rubrics and Likert scales springboard the review process, generating data that is considered by the entire group. The review process is designed to show what was effective and what might be changed to improve the learning experience of all.

For example, the first Session Review of a course centers on the group's *process* for learning. Participants rate the extent to which they agree with each of the following statements about the session.

Q: I had the opportunity to comment, whether or not I contributed during the discussion.

Q: We pushed ourselves to question our own assumptions and beliefs about teaching and science.

Q: Group members built on each other's ideas. The discussion had depth.

Q: Different points of view and alternative solutions were given respectful consideration.

Q: The facilitator enhanced the quality of the case discussion.

Participants' responses are tallied in a worksheet, which the group then uses to describe and interpret the data. The facilitator guides the group to consider questions such as, "What items do most participants either 'agree' or 'strongly agree' about? Are there items where we mostly 'disagree' or 'strongly disagree?' Are participants split in their responses to some questions (some people agree while a significant number disagree)? Are there any surprises?" Finally the group talks about how to improve future sessions, based on their overall response.

Other Session Reviews focus on the *content* of the group's learning, for example, their Exploration of Science Meanings, Focus on Student Thinking, and Critical Analysis of Practice. Participants use a rubric to rate the quality of the session along one or more of these three dimensions. A four-point rating system is used. Features of the session are rated "Beginning," "Making Strides," "Well on our Way," or "Reaching Great Heights."

Participants' responses are tallied in a worksheet, which the group then uses to describe and interpret the data. Individuals with different viewpoints share why they rated the session as they did, giving specific examples to support their rating. Doing so helps teachers digest the rubric and understand what it is they are trying to do and how. It also prompts a whole-group negotiation about the purpose and process of its collective learning. As the group develops consensus from session to session, the rubric serves as a measuring stick, helping the group to monitor and talk about it's own growth and progress over time.

Outcomes of the professional development

Specific outcomes for teacher learning are determined for each session and course. Outcomes typically fall into one of four groups:

- *Major ideas of K-8 science.* Ideas that represent a central event or phenomenon in the natural world, have rich explanatory power, apply to everyday situations and contexts, can be linked to meaningful learning experiences, and are developmentally appropriate for students at the grade level specified.
- *Common ways of teaching those ideas.* The most widely-used ways of representing and formulating science ideas to make them comprehensible to others (e.g., hands-on activities, models, metaphors, illustrations, examples, explanations, and demonstrations).
- *Parts of the idea frequently understood, missed, or misunderstood by students.* The components of an idea that students find easy or difficult to learn and why. For example, the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of frequently taught topics and lessons.
- *Tradeoffs of the common teaching approaches above.* The benefits and limitations of instructional strategies as revealed by an in-depth analysis of what is being taught, how, and to whom. The consideration of such tradeoffs in real-life classrooms leads to informed, context-dependent decision-making and the use of professional judgment.

An example of the outcomes for a typical session is provided below. The following are the intended outcomes for the Science Investigation and Case Discussion described earlier:

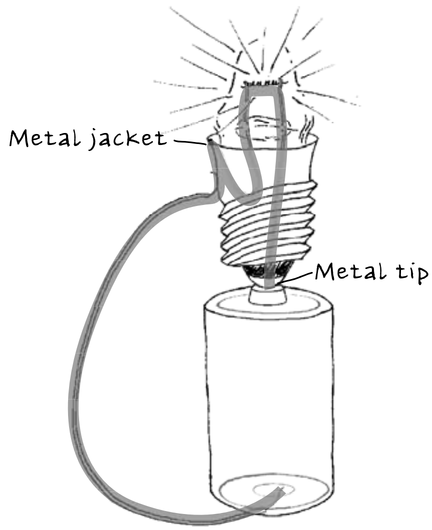
Outcomes for the Science Investigation
As teachers compare the circuits that did and did not light the bulb, an important discovery is made about the connections needed to light a bulb:

> *A bulb will light if there is a continuous path for electricity to travel from one end of the battery to the other end of the battery AND the bulb is connected at the jacket and the tip.*

This discovery typically gives rise to a closer examination of the circuitry inside a bulb. Teachers ask, "How are the parts of a bulb connected? What must the bulb be connected at the jacket and the tip?" What they discover is that:

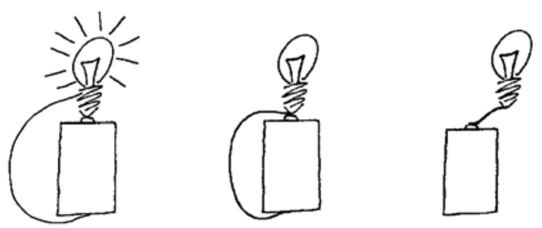
> *The parts of a light bulb are connected so there is only one continuous path for electrical current to flow into and out of the bulb. The*

endpoints of this continuous path are at the jacket and the tip, which is why the bulb must be connected at these points to light.



Teachers also consider the implications of a short circuit. In such circuits, electrical current flows, producing heat but no light. With guidance from the facilitator, teachers come to two important realizations:

> *A lit bulb is sure-fire evidence of a complete circuit, but the opposite is not true. An unlit bulb can occur in both complete and incomplete circuits (for example, the short circuit).*
>
> *The fact that an unlit bulb is NOT reliable evidence of an incomplete circuit is an important limitation of using light as evidence of electricity.*



A list of the Science Investigation Outcomes can be found in the materials for facilitators, along with an in-depth explanation relating them to the hands-on work (*Electric Circuits Facilitator Guide*, Session 1, p. 12).

Outcomes for the Case Discussion

As teachers analyze the instructional strategies and sequence depicted in the case, they develop a more nuanced view of the teaching, one that is grounded in a deep understanding of the science and the ideas of students.

Prompted to compare the work of different students in the case, teachers come to two important realizations:

> *In order for students to accurately predict if a circuit will light, they need to know which features of a circuit to pay attention to (for example, connections among the parts, not shape).*
>
> *In order for students to understand why a bulb needs to be connected at the jacket and the tip, they need to trace the continuous electrical path through an entire circuit (battery, bulb, and wires). Simply seeing what's inside the bulb is not enough.*

These discoveries typically give rise to a heated discussion of an analogy used in the case, "A complete circuit is like a complete circle." Evidence-based discussion of the tradeoffs of this instructional strategy yields an important realization. As with any analogy, the circuit circle analogy has benefits and limitations.

> *The circuit circle analogy nicely communicates the need for a continuous electrical path, but wrongly gives the impression that shape is an accurate predictor of whether a circuit will light a bulb.*

Close examination of student ideas and instructional strategies in the case prompts teachers to consider the instructional value of short circuits. Based on their own experience in the Science Investigation, participants readily acknowledge how confusing these circuits can be. But through reflection about the case and their own learning, many come to see the important role they can play in the teaching of complete circuits.

> *The instructional value of short circuits lies in their ability to challenge the common misconception, "If a light is off, there is no electricity in the circuit."*

A list of the Case Discussion Outcomes can be found in the materials for facilitators, along with in-depth analyses of the student work and instructional strategies presented in the case *(Electric Circuits Facilitator Guide,* Session 1, p. 18).

Pedagogical content frameworks

Courses typically cover 60 or more outcomes for teacher learning (roughly eight outcomes per session, eight sessions per course). To simplify/streamline course development, the outcomes are organized in a series of pedagogical content frameworks. Each framework makes explicit the learning outcomes for a single professional development course.

The outcomes are grouped in a matrix of columns and rows to highlight the relationships among them. Table X presents the learning outcomes for the first session of *Electric Circuits*, a course on the teaching of electric circuits in grades 3-6. In the first column of the framework are the major science ideas that teachers learn. In the second column are the ways in which those ideas are commonly taught. In the third and fourth columns, respectively, are the most common science ideas of students and the tradeoffs of the typical teaching approaches.

Grouping the outcomes in this way highlights important relationships among them. For example, the following is a major idea of an electric circuits course for grade 3-6 teachers: "Electricity can produce light and heat." It is common for teachers to communicate this idea by having students use a battery and wire to light a bulb. Students often interpret this to mean that a lit bulb is sure-fire evidence of electricity in the circuit. (True.) But they are also likely to

	Major science ideas	Common ways of teaching those ideas	Parts of the idea frequently understood, missed, or misunderstood by students	Tradeoffs of the common teaching approaches
Session 1	• A circuit is complete if there is a continuous path for electricity to travel from one end of the battery to the other end of the battery. • Electricity is invisible but we can see and measure the results of its flow: light, heat, sound, and magnetic effects.	• Use a battery and wire to light a bulb in as many ways as you can. Complete the following sentence: A bulb will light if…	• A bulb will light if there is a continuous path for electricity to travel from one end of the battery to the other end of the battery AND the bulb is connected at the jacket and the tip.	• In order for students to understand why a bulb needs to be connected at the jacket and the tip, they need to trace the continuous electrical path through an entire circuit (battery, bulb, and wires). Simply seeing what's inside the bulb is not enough.
			• A lit bulb is sure-fire evidence of a complete circuit, but the opposite is not true. An unlit bulb can occur in both complete and incomplete circuits (for example, the short circuit).	• The fact that an unlit bulb is NOT reliable evidence of an incomplete circuit is an important limitation of using light as evidence of electricity. • The instructional value of short circuits lies in their ability to challenge the common misconception, "If the light is off, there is no electricity in the circuit."
		• A complete circuit is like a complete circle.	• Only circular circuits make the bulb shine.	• A circuit metaphor for circuits communicates the need for a continuous electrical path, but wrongly gives the impression that shape is an indicator of whether a circuit will light a bulb. • In order for students to accurately predict if a circuit will light, they need to know which features of a circuit to pay attention to (for example, connections among the parts, not shape).

over-generalize the idea, and incorrectly conclude that the opposite is true as well. (It is not. An unlit bulb can occur both when electricity is in the circuit and when it is not. For example, the bulb in a short circuit does not light, yet there is electricity in the circuit. The evidence for this is heat.) This common yet incorrect idea points out an important limitation of using light as the sole evidence of electricity. It also illustrates the instructional value of short circuits to challenge the common misconception, "If the light is off, there is no electricity in the circuit."

For reasons of space, the outcomes for only one session of a course are shown. The pedagogical content framework showing outcomes for all eight sessions are available upon request.

Research results

No matter how carefully the professional development experience was designed, we couldn't claim it worked without evidence. Target outcomes in the conceptual framework were investigated using a combination of data collection methods, including written surveys, content tests, interviews, and focus group discussions to look at both the process and the project's outcomes. Small-scale but intensive longitudinal studies were conducted, relying in part on tests given both before and after the courses to different cohort groups of teachers and their students. The studies also included comparisons between project and control groups.

The findings of the study were as follows:

Teachers who participated in Science Cases courses demonstrated better knowledge of science content, a striking increase in their pedagogical content knowledge, especially in their attention to student thinking, and reported changes in their teaching practices. For example, teachers were better able to describe students' conceptual difficulties, give examples of how these difficulties showed up in student work or performance, and more often made explicit links between specific student difficulties and instructional interventions. More participating teachers taught grade-level appropriate curriculum to their students than they had previously and than their colleagues did in comparable classrooms. Teachers shifted from having students engage in isolated activities and unstructured hands-on exploration to structured sequences of inquiry activities, and teachers learned to use with their students the kinds of questioning strategies that group facilitators modeled.

We also found that students whose teachers took part in Science Cases courses learned more science. For example, a sample of 166 students of participating teachers scored significantly higher on a science content pre- to post-test, but comparable students of nonparticipating teachers showed no pre- to post-test gains. Students of all abilities taught by participating teachers showed significant gains from pre- to post-test. Particularly encouraging was that low-performing students showed the most dramatic increase.

These results provide convincing evidence that teachers who participated in Science Cases courses made significant gains in their science content knowledge, along with positive changes in their pedagogical content knowledge and teaching practices that supported improved student learning (Daehler & Shinohara, 2001; Heller & Kaskowitz, 2002, Heller & Kaskowitz, 2003).

The results also provide impressive evidence of the efficacy of the overall approach to professional development.

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