Perspectives on Deepening
Teachers' Science Content Knowledge:
The Case of the Southwest Pennsylvania Math Science Partnership

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Abstract
The Southwest Pennsylvania MSP's work in deepening teacher content knowledge has scalability and sustainability at its core. The project focuses its efforts on preparing teacher leaders, involving national experts from groups such as the BSCS National Academy of Curriculum Leadership and the Exploratorium's Institute for Inquiry. Over the course of two years, elementary teacher leaders (1) learn about science as a discipline, especially the role of inquiry in generating new knowledge; and (2) deepen their disciplinary content knowledge and pedagogical content knowledge in selected areas of science. Prospective teacher leaders learn forces and motion content and consider classroom applications of what they are learning in the context of commonly-used student instructional materials. They learn about electricity by engaging with case materials developed by WestEd, which include analysis of student thinking instructional strategies for teaching that content. In turn, these teacher leaders engage other elementary teachers in their districts in defined learning experiences, drawn from the professional development materials and strategies they themselves had experienced.

Project Context

SW PA MSP is a comprehensive K-12 mathematics and science MSP funded in 2003. It involves districts in urban, suburban, and rural settings across the 11 counties surrounding the city of Pittsburgh. Institutions of Higher Education (IHE) partners range from small private colleges to larger universities, all of which are more heavily focused on teaching than research. K-12 partners include 45 local control K-12 school districts ranging in size from 1,000 to 7,000 students. The lead agency is the Allegheny Intermediate Unit, a publicly funded regional service agency, which also works with three other Intermediate Units as partners.

The logic model in Appendix A portrays the approach taken by SW PA MSP. The particular interventions chosen grew out of the nine-year experience of the Math & Science Collaborative as it worked regionally to strengthen mathematics and science education. Particular attention was paid to the NSF-funded urban and local systemic initiatives, as they served as pilots of a number of key research-based approaches.

With its multi-county, multi- Intermediate Unit focus, addressing K-12 mathematics and science, and intentionally relying on a limited number of staff to promote sustainability, it was important that the initiative use an approach that would work effectively at scale. In the SW PA MSP, mathematics and science coordinators, alongside IHE faculty, engage in extensive discipline-focused training by "expert partners" in field-tested adult learning curricula. However, rather than providing the professional development directly to the thousands of mathematics and science educators in the many participating districts, the MSP coordinators and IHE faculty develop district-appointed teacher leaders who then guide their colleagues in well-defined professional learning experiences within the district. There is no assumption that the teacher leaders are experts. While suggested characteristics of teacher leaders are outlined to guide district selection, the teacher leaders present the full spectrum of background and experience, with varying levels of mathematics and/or science expertise.

The SW PA MSP considered it crucial to work with teacher leaders over an extended period in order to develop the knowledge, skills, and confidence they would need to facilitate high quality professional development in their districts. Teacher leaders participate in a series of academies, each of which focuses on specific factors that impact teacher effectiveness, including deep content knowledge, an understanding of how students learn, effective lesson design, and formative assessment strategies. Beginning with five days of inquiry-based experiences and discussion, the sequential experience of SW PA MSP Academies was designed to ensure that teacher leaders would have multiple opportunities throughout the summer academies and school year follow-ups to build the habits of mind that learning is both life-long and essential for professional growth.

Focus on Elementary Science

At the beginning of the project, secondary teacher leaders were the primary focus of the professional development efforts. They participated in a High School Science Teacher Leadership Academy based on key findings from *How People Learn*, exploring the nature of science via examples from multiple science disciplines. Next, the MSP staff developed a Middle School Science Teacher Leadership Academy in order to provide a similar experience for middle school science teacher leaders in MSP districts. The rationale for this plan was to provide a consistent approach to science instruction at the secondary level. This approach to leadership development was met with such a positive response that administrators from various MSP districts requested similar professional learning for their elementary staff.

In order to design an effective elementary academy, it was important to identify the professional development needs for elementary teachers in the region. In the needs assessment the MSP conducted, physical science was identified as the area of greatest need. Forces and motion was selected as the initial focus content both because it is an important component of the Pennsylvania Physical Science Standards and because students perform poorly in this area on standardized assessments.

Many of the participating districts utilize research-based materials such as *Full Option Science Systems* (*FOSS*), *Science and Technology for Children* (*STC*), and *Science Companion* to develop the content of forces and motion within their physical science strand. Accordingly, the elementary academy was designed as a hybrid that maintained a focus on inquiry (based on the High School Academy) while addressing the content of forces and motion taught in the districts.

The first Elementary Science Teacher Leadership Academy (ESTLA) combined the forces and motion content and attention to student instructional materials with experiences from nationally-recognized expert partners including, the *National Academy of Curriculum Leadership* from BSCS and the *Institute for Inquiry* from the Exploratorium. This purposeful orchestration provided a common foundation for all teacher leaders and in-depth experiences to strengthen their disciplinary content, pedagogical content knowledge, and knowledge of science as a discipline.

The sixty-hour ESTLA focused on Immersion into Inquiry and Effective Instruction. As in the other academies, *How People Learn* was the foundation upon which the academy was developed. The key findings from the *How People Learn* research summary support the authentic engagement of teachers as active learners of both content and pedagogy. Immersing the teacher leaders in meaningful experiences enables them to integrate and test their preconceptions while establishing conceptual frameworks that merge new information into a useful, retrievable body of knowledge. Our goal is to achieve this integration through Teacher Leadership Academies that allow multiple passes through important concepts using varied vehicles. Academies also provide frequent connections to the classroom via implementation of tasks/lessons and analysis of resulting student work. This approach provides opportunities for meaningful reflection and metacognition, setting the stage for learning to transfer into classroom practice (*How People Learn*, 2000).

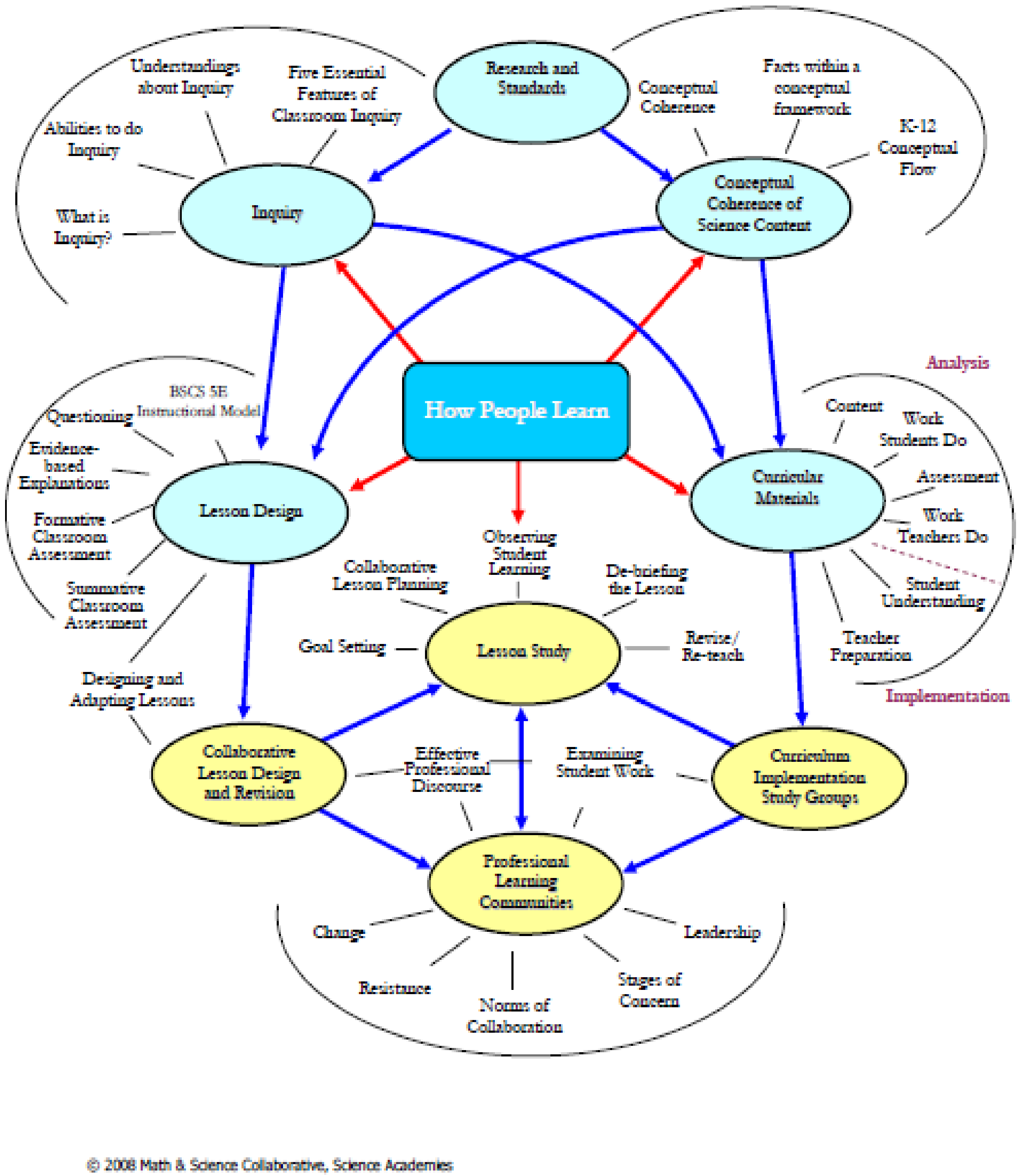
We believe that in order to teach science well, teachers need to have an understanding of science as a discipline, especially the role of inquiry in generating new knowledge. The ESTLA had an emphasis on inquiry as described in the NSES Teaching Standard B, the Abilities to Do Inquiry, Understandings About Inquiry, and The Five Essential Features of Inquiry. To develop an understanding of the nature of science inquiry, teacher leaders watched a video of a *FOSS* lesson from the Balance and Motion module and identified what the students and teacher were doing, both physically and cognitively. The teacher leaders then cited evidence from the video of particular key features of inquiry, including learners engaging in scientifically oriented questions, giving priority to evidence in responding to questions, formulating explanations from evidence, connecting explanations to scientific knowledge, and communicating and justifying explanations. (*National Science Education Standards Inquiry Addendum*, 2000)

During the ESTLA, a series of carefully-designed lessons was used to engage teacher leaders in physical science content. These lessons were developed using the 5E experiential learning cycle: Engage, Explore, Explain, Elaborate, and Evaluate, with the expectation that the teacher leaders would later use this instructional model in the professional development they provided to teachers in their districts. As teacher leaders progressed through the 5E lessons, they developed a deeper understanding of science concepts related to forces and motion because they were provided with multiple opportunities to construct meaning. Teacher leaders then took “A Trip Through Time” using the SW PA MSP Science Curriculum Framework to trace conceptual development of the Physical Science and Nature of Science Knowledge Networks from kindergarten through twelfth grade. (*SWPA MSP Science Curriculum Framework,* 2006)

During the follow-up sessions, participant understanding of physical science content continued to be deepened through 5E lessons on Sliding Friction. This topic was selected because the end of summer session post-test indicated friction as the weakest area of teacher content knowledge. Teacher leaders also engaged in Collaborative Lesson Design and Revision (*National Academy of Curriculum Leadership* from BSCS) selecting topics pertinent to their current curriculum timeline. Then they examined the student work generated from these lessons.

Teacher leaders were expected to share their learning and facilitate on-site sessions via Professional Learning Communities within their school districts. To support them with this charge, teacher leaders were supplied with investigation materials, Power Point slides, and access to MSP Science Coordinators. In addition, school-year follow-up sessions incorporated components designed to support teacher leaders by sharing additional information, including “Change Process” (Hall & Hord, 2001, Harvey, 1995) and leadership strategies, to further build their Professional Learning Communities. (Science Academy Concept Map, 2008)

Science Academy
Concept Map



Description of Content Deepening Experience

Following the completion of the first year academy described above, the teacher leaders engaged in a week-long summer academy and five follow-up days throughout the school year. The summer academy immersed teacher leaders in the 30-hour, research-based *Understanding Science - Electric Circuits* module developed by WestEd (Shinohara, Daehler, & Navakoski, 2005). This professional development program was selected because it is consistent with the research on *How People Learn* (NRC, 2000); the foundation for all of our academies. In particular, the program is designed to help K-8 teachers learn major science concepts, examine student thinking about those concepts, and reflect on their own teaching to improve their practice by focusing on pedagogical content knowledge. Teachers investigate the disciplinary content at a level beyond what their students would experience. "To develop pedagogical content knowledge, teachers must have opportunities to learn science content knowledge in combination with analysis of student thinking about that content and instructional strategies for helping students learn that content." (Shinohara, Daehler, & Heller, 2004) Engaging in these activities enabled teacher leaders to deeply explore this area of physical science and appreciate the value of thoroughly understanding science content in order to effectively analyze the consequences of specific instructional approaches. In addition, the teacher leaders were getting experience in using the professional development materials and strategies that they would later be expected to implement in their districts.

The *Understanding Science – Electric Circuits* portion of the Year 2 Academy occurred four times during the summer of 2007 at different locations, both to accommodate the geographic spread of the teacher leaders and to help develop the capacity of SW MSP partners to facilitate this professional development. Staff from WestEd facilitated the first two sessions, and MSP science coordinators together with IHE faculty facilitated the subsequent sessions. This approach enabled the science coordinators and IHE faculty to partner with expert WestEd presenters in order to be prepared to facilitate this module with fidelity in the remaining two sessions.

The *Understanding Science - Electric Circuits* summer academy consisted of eight sessions, each designed to be completed in three hours. The sessions addressed the concepts of complete circuits, electrical current, voltage, and resistance, and how they affect series and parallel circuits.

Each session followed the pattern designated in the WestEd materials. Teacher leaders began the session by reading a classroom case study about teaching the content, written from the teacher's perspective. Content background notes were provided for each session for teacher leaders to reference. The teacher leaders then conducted a small group science investigation (about 30 minutes), followed by a large group discussion of the science content. Teacher leaders engaged in both of these as adult learners, doing hands-on activities around the content in small groups, and talking about the science during the large group discussion around student work. The teacher leaders then discussed the case study in their small groups, followed again by a large group discussion. Every session ended with a session review, which asked teacher leaders to reflect on their learning of both the science content and student thinking regarding that science content. Experiencing the science content first would, we believed, deepen their understanding of electric circuits, thus allowing the teacher leaders to more deeply analyze the samples of student work. This approach was intended to build their confidence and ability to address the range of student thinking about important science concepts in their own classrooms.

Sessions one through eight were carefully scaffolded to develop deep conceptual understanding of electric circuits. Session four served as a mid-point culminating session, integrating teacher leaders' understanding of what makes a complete circuit, the role of electrical current, electrical resistance, and batteries in a series circuit. Sessions five through eight built on the previous sessions, extending the understanding to parallel circuits.

Session One

The goals of Session One included helping teacher leaders to understand complete circuits, explore common student (and teacher) ideas about complete circuits and light, consider how to best help students understand complete circuits, and evaluate the pros and cons of using light as evidence of electrical current.

Prior to starting the science investigation on complete circuits, the teacher leaders read the applicable case study, written by an elementary classroom teacher, describing how the topic was presented in the classroom. Although the case studies described reasonably sound instructional practice, they were not intended to model exemplary teaching; instead they provided teacher leaders with a glimpse of a classroom where students were learning this content. By reading about the teacher's instructional decisions in response to evidence of students' thinking, the teacher leaders had the opportunity to benefit from the case study teacher's reflections and learnings. The reading also engaged teacher leaders with the science content in a relevant context.

Teacher leaders were asked to read the content notes that accompanied each case study ahead of the session. These notes included an overview of science concepts and vocabulary pertinent to the session, provided in a format that was accessible to learners with varying degrees of prior knowledge, thus providing a common entry point for the teacher leaders prior to the small group investigation, permitting all teacher leaders to engage in the discussion.

The Science Investigation began with a 30-minute exploration, during which teacher leaders completed a number of tasks in small groups. In Session One, teacher leaders were given a battery, wire, and bulb (the materials necessary to construct a circuit). They were then asked to find ways to light the bulb and to draw each attempt as they explored a variety of configurations. This step was an important one in their learning process as it provided examples, and non-examples, that would later help them to build the concept. Next, teacher leaders were encouraged to discuss patterns they saw in their drawings that lit the bulb and compare them to their drawings of the configurations that did not light. They analyzed a chart illustrating a variety of possible circuits and indicated whether or not the circuits would light. Teacher leaders then reflected on their experiences by discussing the tradeoffs of using light to indicate whether electrical current is flowing in a circuit, including answering several true/false statements, and discussing the pros and cons of using light as evidence of electrical current flowing through a circuit.

The large group discussion for this session began with activities to help teacher leaders further clarify the focus concept: that a complete circuit is a continuous path and there are different types of complete circuits. For example, a lit bulb and/or heat are indicators of a complete circuit. Teacher leaders explored how a bulb will light if there is a continuous path for electrical current to travel from one end of the battery, through the bulb and back into the other end of the battery, with the bulb being connected at the jacket and the tip. After exploring a variety of possible circuit configurations, each group posted an example of a circuit that did and did not light, and then shared observations of any patterns they recognized. A large wall chart depicting the circuitry inside a light bulb and a dissected light bulb, allowed teacher leaders to identify the different parts of the light bulb. Teacher leaders came up to the chart and traced the flow of electric current through the light bulb, reinforcing the idea that the light bulb has to be connected to the circuit at the jacket and the tip in order for electric current to flow through the filament and cause the bulb to light. Teacher leaders summarized which of the circuits from the small group discussion resulted in a lit bulb. They traced the path of electric current through each of the circuits, indicating which of the circuits got hot. Next, they classified the various circuits as complete or incomplete, and, finally, they identified which of the circuits were short circuits.

These activities helped to address several misconceptions teacher leaders may have had, in particular the common misconception that all complete circuits light the bulb. By contrasting and carefully examining characteristics of circuits that light the bulb (complete circuits with connections at the tip and the jacket of the bulb, allowing current to flow through the filament), and circuits that do not light the bulb (incomplete circuits or complete circuits that do not connect at the jacket and tip), several misconceptions were dispelled. In particular, teacher leaders realized that light is not the only indicator of a complete circuit. Short circuits are complete circuits, but the bulb is not connected at the tip and the jacket, so electric current does not flow through the filament, resulting in the circuit getting hot, instead of lighting the bulb.

During the next hour or so, teacher leaders revisited the classroom case study for this session. All case studies follow a similar format. They provide summaries of the electric circuit lessons and describe how they unfolded in the classroom. They are written from the teacher's point of view, containing a description and rationale for instructional moves, as well as student responses to these moves. The teacher leaders discussed how the students in this particular class were thinking about electric circuits as they considered specific lines from the transcript of the case study.

In small groups, teacher leaders examined the discourse between the teacher and students regarding circuits that light and do not light the bulb. They also discussed examples of student work, both drawings of electric circuits and explanations of why a particular circuit would or would not light. Based on this student work, small groups of teacher leaders commented on what they thought these students correctly understood about electric circuits (circuits that light the bulb, the flow of electric current through a circuit, the connections at the battery and the bulb necessary for a complete circuit to light the bulb, and the circuitry of a light bulb).

The teacher leaders were then asked to discuss the pros and cons of using the "circuit circle" methaphor with students, and whether an emphasis on how the parts of a circuit are connected helps students deepen their understanding, or creates dissonance. They reflected on the case study teacher's instructional decisions, which in some cases appeared to reinforce the misconception held by many students that complete circuits must result in a lit bulb. Then, the teacher leaders brainstormed instructional strategies that would help the students move past this misconception.

The large group discussion of the case study utilized several enlarged posters of student work. In this work, students compared two circuits and explained their thinking about which circuit(s) would light. The facilitator guided the discussion by focusing the group on one student’s work at a time, allowing teacher leaders to carefully examine the student’s thinking.

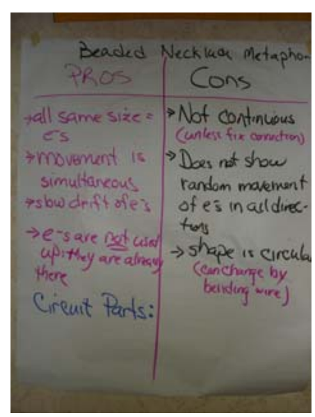
Two different colors of marker were used to indicate correct and incorrect thinking on the student’s work and questions about the students’ understanding were written on the posters in a third color. As the discussion of the student work progressed, teacher leaders gained insight into student thinking about electric circuits and solidified their own understanding.

A Session Review at the end of each session provided teacher leaders with the opportunity to reflect on their learning, including how they were learning as a group and how their content understanding improved. In addition, teacher leaders reflected on their understanding the discipline of science based on what they had experienced.

Sessions Two Through Four

Session Two was designed to help teacher leaders understand electrical current and examine common student and teacher ideas about current. Teacher leaders demonstrated their understanding as they illustrated key characteristics of current in series circuits through drawings using arrows and lines. They also distinguished between current and energy, and examined how they may be used interchangeably in electricity curricula. Finally, the teacher leaders applied their understanding of the content as they evaluated the benefits and limitations of commonly-used models and metaphors for current.

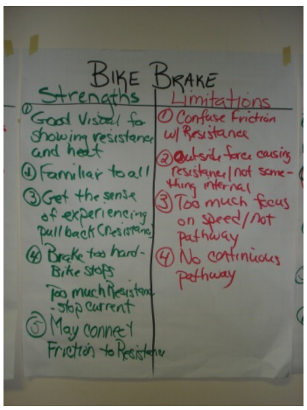
The teacher leaders prepared for Session Two by reading the appropriate case study and content notes. Next, they engaged in the science investigation in small groups where they explored bulb brightness and current in series circuits, drew these circuits and illustrated current flow in the circuits. As the investigation proceeded, teacher leaders recorded and discussed their findings, engaging in sense-making of the science concepts, and evaluated the use of a necklace model as a concrete way to imagine current moving through a circuit. The necklace model consists of beads strung together like a string of pearls. In this model beads can represent how electrons move through an electric circuit. Teacher leaders discussed the pro’s and con’s of this model. The consensus was that it accurately represented the continuous flow of current through an electric circuit but was limited in representing individual electron movement.



Teacher leaders came together for a whole group discussion where they engaged in further sense-making by building on each other’s ideas about electrical current and the benefits and limitations of the necklace model. The ideas expressed were publicly charted.

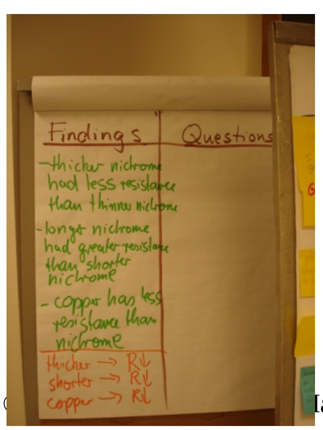
During the case discussion, teacher leaders drew upon their deepened understanding of the science content as small groups worked together to explore key concepts as they relate to student misconceptions about electrical current in series circuits. They also talked about the tradeoffs involved in using other models and metaphors used to illustrate how current moves in a circuit, the pros and cons of teaching about current with energy, and helping students make sense of abstract ideas such as electric currents. After the small groups had time to share, the whole group reconvened to share their ideas. A rich discussion resulted as charts displaying the student work from the case study were analyzed and marked up to show accurate and inaccurate student thinking and further models (ping-pong ball model, water model) were evaluated to determine their benefits and limitations in addressing student misconceptions and advancing student understanding about electric current in series circuits.

Session Three focused teacher leaders on the key concept of resistance and how it affects electric current. Their understanding of conductors and insulators and their relationship to resistance in series circuits was expanded and a new metaphor (bike brake metaphor) was introduced as a representation of resistance. After investigating resistance, conductors, and insulators, and engaging in sense-making about these concepts, teacher leaders were asked to consider the pros and cons of teaching elementary students about resistance.



After reading the case study and content notes for Session Three, teacher leaders participated in a science investigation, working in small groups as they tested the resistance of a variety of conductors and insulators, organizing them on a continuum from most insulating to most conductive. The teacher leaders recorded their findings and used evidence from their work and information from the content notes as they discussed whether a series of statements about resistance, conductors, and insulators were true or false; they also rewrote any ambiguous or false statements to make them correct based upon their content understanding. Within their small groups, teacher leaders then explored other factors that affect resistance such as thickness and type of wire used in a circuit (nichrome vs copper, thick vs thin). After recording their findings and discussing a series of prompts about how resistance is affected by the factors they explored, the teacher leaders investigated how resistance is affected by various lengths of light bulb filaments and related the brightness of the bulb to the amount of resistance in the filament. They drew conclusions based upon their findings and supported them with evidence from their investigation.

The group reconvened at this point and began to delve deeply into the science content as they created a public continuum comparing resistance in conductors and insulators. Once this continuum was completed, the group summarized the information from the chart, posting their findings as summary statements and any further investigable questions that arose. Finally, teacher leaders expressed their understanding of the impact of the various resistance factors in a circuit through equations such as:



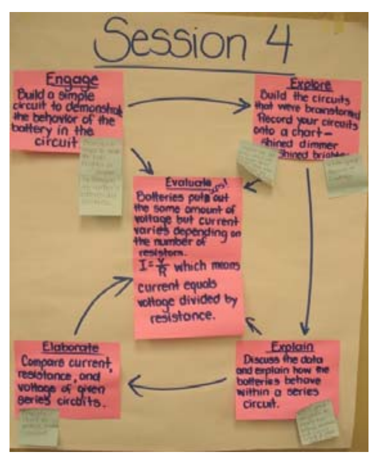
$R_{total} = R_{wires} + R_{bulb} + R_{switch}$ where R_{wires} approaches zero and R_{switch} approaches zero. Therefore, in a simple circuit consisting of a battery, bulb, wire, and switch, it is correct to say that $R_{total} = R_{bulb}$. Equations relating the resistance of other factors in a circuit were also derived. The teacher leaders' understandings about the key concepts for this session were significantly deepened as evidenced by their work and pre/post test results.

Session Four was a culminating experience, connecting the concepts of voltage, current, and resistance. The session was designed to facilitate teacher leaders in their understanding of the role of batteries in series circuits, the voltage of a battery and the current it produces in different circuits, and the relationship among current, voltage, and resistance (Ohm's Law) through observable phenomena. Their enhanced deepened content understanding allowed teacher leaders to consider instructional implications that might address the misconceptions students have about what batteries do, and evaluate the trade-offs of battery-centric and bulb-centric mental models of current in circuits.

First, teacher leaders read the appropriate case study and content notes. They then worked in small groups as they investigated bulb brightness and batteries in series circuits, starting with a simple circuit and brainstorming ways to make the bulb brighter or dimmer. They tested their ideas, recorded their findings, and drew conclusions based upon the evidence collected. Teacher leaders then explored the relationship between voltage, current, and resistance by taking the evidence from their first investigation, information from the content notes, and Ohm's Law. They completed a chart on Ohm's Law while considering prompts that focused them on the number of batteries and voltage, the number of bulbs and resistance, and the brightness of the bulb and current. The large group completed a similar Ohm's Law wall chart and discussed their understandings. From this chart, teacher leaders were able to derive and apply Ohm's Law, explaining observable phenomena about series circuits in terms of current, voltage, and resistance.

SW PA MSP Adaptation

Mid-week, SW PA MSP inserted an opportunity for teacher leaders to build on their prior knowledge by reflecting on the four sessions they had experienced thus far. Each group was asked to diagram one of the first four sessions as a 5E model. This process allowed teacher leaders to revisit and apply the inquiry process and learning cycle they experienced during the first leadership academy year to their deepened content understanding. They developed a greater appreciation for the 5E model as they came to a new understanding of how effective it is to learn content in this way.



Finally, the teacher leaders participated in the session four case study discussion. The discourse focused on students' understandings and points of confusion about what batteries do, their mental models of current and instructional decisions they would suggest for the students whose work they examined. They connected these decisions to their 5E models in the appropriate areas.

School Year Follow-Up

In the school year after the week-long summer experience, teacher leaders participated in five follow-up days (30 hours) focused on formative classroom assessment to elicit student thinking and enable instructional decisions that support student learning. The content addressed in the *Understanding Science - Electric Circuits* module was revisited, and teacher leaders practiced implementing effective formative feedback. Using student work from some of the case studies, they practiced writing comments that consisted of individualized information for each student. They first analyzed the complexity of student thinking and then worked as a group to write a targeted feedback comment that would assist the student in progressing toward a deeper level of understanding. After analyzing a few students' work samples, the teacher leaders posted their feedback comments and identified commonalities among them, making note of the two distinct parts of the effective comments, both where the student is and how the student can improve. The goal in revisiting this content and thinking critically about the research behind formative classroom assessment was to enable the teacher leaders to think about how all students can show significant learning advantage with formative assessment.

Evidence of Impact

Pre-and post-tests of teacher content knowledge provided by WestEd were completed by 58 (92 percent) of the 63 teacher leaders. Evaluators ran a dependent t-test to determine statistical significance. 55 (95 percent) of the 58 teacher leaders made significant gains, with a t- test value of 16.40391. In addition, on the final evaluation of the five-day Electric Circuit module, teacher leaders responded to questions about the experience as a whole, and what tools, ideas, notions, processes and/or concepts were most helpful and why. Responses focused on the utility of in-depth exploration of a particular area of content and the opportunity to apply what they were learning to the analysis of student work. Responses from teacher leaders to questions posed during follow-up sessions indicated that teacher leaders are now more focused on utilizing formative assessment strategies and providing respectful tasks for their students.

Closing Thoughts

The SW PA MSP was designed to facilitate the ongoing development of teacher leaders, focusing on key components of teacher effectiveness, including not only deep content knowledge but also strong pedagogical content knowledge, and an understanding of the nature of science inquiry. As noted above, the professional development was both well-received and effective. Accordingly, we are now offering additional modules from the WestEd *Understanding Science* program. We are also continuing to incorporate our teacher leaders' student work into many aspects of each academy, as that material has provided rich fodder for collegial discussion around student thinking and understanding of important science concepts.

We found that teacher leaders were able to think deeply about instructional approaches that help students learn, retain and transfer knowledge, when their learning began with a solid understanding of inquiry. The value of having a foundation in inquiry was evident in comments from teacher leaders who had experienced the Year One Teacher Leader Academy featuring inquiry, and facilitator observations, anecdotal summaries, and session evaluations documented that value. As well as being more comfortable engaging in these inquiry-based investigations, teacher leaders demonstrated deeper levels of analysis of the content, process, and student thinking. As a result, SWPA MSP has retained the focus on inquiry for all first year teacher leadership academies with an emphasis on re-visiting and building upon these ideas throughout subsequent sessions.

It is widely acknowledged that teacher effectiveness is the single most determining factor of student success. The two aspects of effectiveness involve the “what” and the “how.” Effective science instruction is possible only when teachers are both comfortable with the content they teach AND can successfully utilize an inquiry-based approach to instruction. Teachers are able to appreciate the importance of intertwining content and process when they experience it as a learner first, and then are able to view it from the teaching perspective. We have found it important to have debriefing sessions where learners who are becoming leaders are helped to reflect on, and make sense of, their own learning.. This process enables teacher leaders to recognize the carefully crafted nature of the inquiry-based materials, and ultimately transfer what they are learning to both classroom and professional learning community settings, implementing the instructional materials with fidelity.

Developing teacher leaders is a means to an end; the ultimate goal is to help all teachers provide all students with the opportunity to learn at high levels. Based on the SW PA MSP experience, the keys to a successful teacher leader model are (1) to provide ongoing opportunities for teacher leaders to deepen both their content understanding and their pedagogical content knowledge so they are comfortable with their charge to facilitate in-district sessions with their colleagues; (2) to help teacher leaders become aware of the change process; and (3) to establish a critical mass of teacher leaders with an opportunity to collaborate, sharing their successes and challenges, and receiving continuous support to nurture and sustain their in-district professional learning communities.

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Appendix A
SW PA MSP Logic Model

Resources / Inputs	Intervention Strategies / MSP Activities	Outputs	Short-term Outcomes	Mid-term Outcomes	Long-term Outcomes
Inputs that support NSF funding PDE funding MSP staff and coordinators Intermediate Units **Inputs that guide** Leadership Action Teams Student achievement data District development matrix Strategic action plans Project Teams MSP Cabinet Evaluation processes	**Professional Development for Leadership** Leadership Action Academies Teacher Leadership Academies On-site Academies Content-deepening Seminars *Lenses on Learning* **Curriculum Alignment & Pedagogical and Course Refinement** Curriculum Frameworks Teacher Fellows **Support for and Dissemination of Research-based Resources & Tools** Network Connections Educator Networks *Journal* and *Coordi-net*	Teacher leaders Principal leaders Changes in attitudes, understanding, and awareness of content and pedagogy Refined courses Use of curriculum frameworks Increased interactions among IHEs, IUs, and K-12 schools and districts Application of research-based pedagogy in classrooms	Increase in challenging courses Changes in instructional practices at both IHE and K-12 levels Aligned curriculums Effective leadership Increased partnerships Increased awareness of cultural differences Use of data in decision-making	Changes in district policies and practices Increase in teacher content knowledge Effective use of data in decision-making Strategic allocation of resources Collaborative relationships	Increased K-12 students' knowledge of mathematics and science Increased quality of the K-16 educator workforce Sustainable coordination of partnerships in the IUs, feedback loops between K-12 districts and IHEs, improved math and science learning experiences for all undergraduates

→ Increased capacity for change within K-16 →