

## Evolving the Physics Mindset

### Changing perceptions and attitudes toward the teaching and learning of physical science

By Ekaterina (Katya) Denisova, Christine Bell, and Kristin Covaleskie

One significant challenge we face in the K–5 world is the inadequate preservice preparation and subsequent insufficient inservice professional development offered to elementary teachers of science (Hrepic et al. 2006). This article describes one aspect of a professional development (PD) model designed by an NSF-funded initiative. The initiative offered a complex system of supports to participating elementary schools: a rigorous *Next Generation Science Standards*-aligned curriculum with emphasis on integration of science, literacy, and engineering; and a Professional Learning Community (PLC) for teachers of science. This included weekly instructional coaching, peer visitations, and opportunities for teachers to reflect on their practice, share feedback, and discuss best teach-

ing strategies in a face-to-face setting. Despite such emphasis on the *pedagogy of science*, it was obvious that without solid foundation in the *content of science*, we would not be able to achieve significant results. There was a clear need to design professional development focused on the fundamental concepts of the natural sciences. Four courses called “STEM Academies” were designed to meet this need: Physical Science STEM Academy, Earth/Space Science STEM Academy, Life Science STEM Academy, and Engineering STEM Academy.

The goal of the STEM Academies is to prepare teachers to teach science and encourage them to transition from a lecture format to an authentic way of learning science by doing science. We knew from the research (Nilsson and Driel 2008) that elementary teachers

often view physics as “difficult and abstract, resulting in difficulties to transform the content to the students,” so we decided to make the Physical Science STEM Academy the first course in the sequence of four. In order to most effectively develop both subject matter knowledge and pedagogical content knowledge in physics, we selected and developed STEM Master Teachers to teach the course. By putting elementary teachers in front of a class of other elementary teachers, who work with the same student population and face the same challenges within the urban education setting, we empowered the entire group to change attitudes toward, and increase their confidence of, the teaching and learning of physics.

Participants must complete 45 seat hours in order to obtain credit for the course. “Credit” is comprised of three AUs (Achievement Units honored by Baltimore City Schools) and three CPD credits (Continuing Professional Development, honored by the Maryland State Department of Education); STEM Master Teachers receive credits as well for facilitation. The course has been offered in both school-year and summer course formats. School-year courses run for three hours, bi-weekly, in evenings from September to March; summer courses are comprised of compressed six-hour sessions, hosted across seven days. Teachers, grades kindergarten through sixth (in order to allow for both vertical and horizontal content discussions), enroll to either individually develop their own content knowledge, or to support their



PHOTOS COURTESY OF THE AUTHORS

**An instructional coach engages a master teacher in a coaching session.**

work with the newly developed science curriculum—for which post-session coaching is offered. Upon successful completion of Physical Science STEM Academy, participants are encouraged to continue on to the other STEM Academy content courses. We have shared the Physical Science course outline online (see NSTA Connection).

In this article, to illustrate the evolution of this unique professional development series, we give examples of learning explorations from three Physical Science course topics: electrical circuits, atomic structure, and properties of light. Please refer to the concept map to see, in detail, *Next Generation Science Standards (NGSS)* vertical conceptual progressions within the three topics (see NSTA Connection). This course has been designed for elementary teachers but focuses on the foundational physical science ideas, which are not taught (according to NGSS) until middle and high school. Course development centered on the belief that, by exposing our participants to the core scientific principles, we are equipping elementary teachers to be able to: engage in vertical planning with their secondary peers, which is especially critical for K–8 and K–12 schools; be prepared for deeper-reaching student questions; and, most important, develop a quality understanding of the vertical progression of physical science content taught in the elementary and later years.

### EVOLVING THINKING

After the first year of implementation, the instructional coach and Master Teachers worked on shifting from “good activities” to instruction driven by the research on common student misconceptions (Stepans 2003). We also focused on the pedagogical principal of conceptual change (Hewson 1992), which gives the participating teachers the opportunity to gain an in-depth understanding of their own learning process of science ideas.

In many ways, we have found that elementary teachers hold conceptions about physical phenomena similar to those of students, although expressed in more sophisticated language. As the vast majority of elementary-certified teachers have only taken two required sciences (which rarely include physics) in their undergraduate studies, our audience generally holds the same conception package as the children they teach. Elementary teachers are frequently unable to readily identify, no less unpack and correct, student misconceptions. This makes teaching physical science to young children especially daunting and frequently skipped altogether.

Our strategy was to explicitly focus on changing teachers’ perceptions and misconceptions about teaching physics concepts—accurately and without fear. This undertaking was vital to the course’s success but also an extremely delicate task, as adults have had a significantly longer period to cement

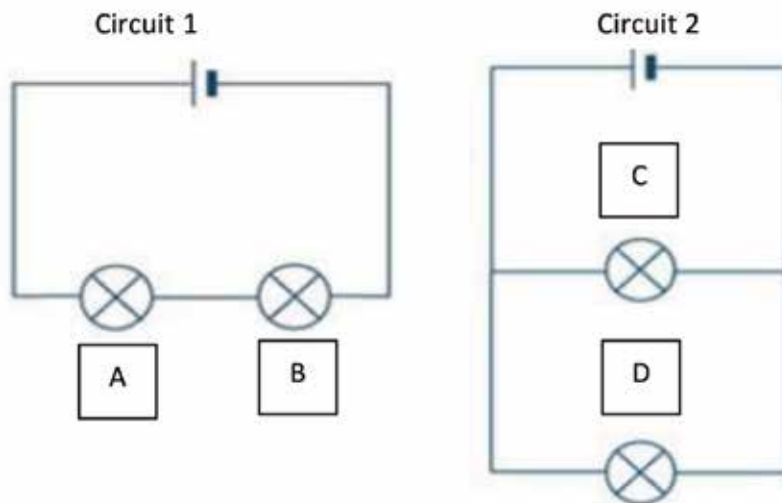
misconceptions into “truths,” thereby making them less open to hearing otherwise and more embarrassed to discuss their true thinking, in the event that it is flawed.

In order to target our participants’ thinking about each session’s topic, we employed Page Keeley’s *Uncovering Student Ideas* (NSTA) (Keeley 2011) formative assessment probes. We structured our sessions to both begin and end with these probes: at the start of each class, participants complete the probe without discussion, then tuck it away as exploration begins. At the end of each class, participants revisit their responses, editing and/or changing their thoughts as appropriate, before we discuss the answers as a whole-group. Participants are pushed to share not only their new thinking but also (perhaps, more important) how their thinking had *changed*. It is this change that excites and ignites learners (younger and older) in their quest to gain more.

FIGURE 1

#### Sample assessment.

“Compare the brightness of bulbs A and B in circuit 1 with the brightness of bulbs C and D in circuit 2. Which bulb or bulbs are the brightest?” (Department of Physics and Astronomy, Appalachian State University 2016).



To facilitate this conceptual change, our model incorporates ongoing hands-on exploration; use of models, analogies, and metaphors; and explicit metacognitive thinking and discussion—all of which have been proven to combat misconceptions in scientific thinking. “My favorite part is working with the teachers when they are doing hands-on,” shares one of the Master Teachers. “That is when they are seeing the ‘ahas,’ when they are making their discoveries, and the pieces are starting to click together for them. Often, I find that they are doing all of the learning right there, and then we come back together, and they summarize their learning and they already got what I needed them to know. So, that’s the best part for me—when I don’t have to ‘teach it’! For me, as a learner, that’s the best way to learn. Listening to someone teach content is not how I want to learn, and so that is not how I want to teach.”

Of course, these aha moments did not come easily. Over the many cycles of the course, we continuously revisited and revised, as necessary, the pre/post assessment, the session lessons themselves, and the targeted misconceptions. The roundtable dialogue remained focused on participant performance and the many revelations uncovered through in-session content discussions. Data was analyzed, lessons were dissected, feedback was given, edits were suggested, and possible outcomes were weighed; in the end, a natural evolution took place—the unnecessary pieces fell away, more effective program attributes developed, and a system of quality professional development emerged—one much more likely to endure the challenges associated with traditional elementary science teacher inservice programs. What follows is a discussion of some of the changes that occurred across the different implementation cycles.

### EVOLVING ASSESSMENT

After the first implementation of the

course, the assessment used to measure content knowledge growth was re-evaluated. Though NGSS-aligned, the assessment itself had been designed prior to any lessons, and it was discovered that many of the questions were too challenging based on the content that was delivered. Other questions were deemed appropriate for content but required some modification. One example of a modified assessment question references the brightness of a light bulb (Figure 1, p. 75).

The content delivered in session included bulb brightness in different types of circuits; however, the schematic diagrams such as those presented in the assessment were not utilized. During class, teachers were encouraged to design their own models to represent their understanding, and most used a simple diagram showing wires and bulbs. Analysis of the post assessment showed only 6% of the teachers in the course recorded a correct response for this question; thus, we decided to change the diagram, keeping the fundamentals of the content the same. For the subsequent implementations of the course the question was changed as shown in Figure 2.

Once the diagrams were changed to more closely represent course application of wires and bulbs, 75% of the participants recorded a correct response. Since most of the time learning about electric circuits was spent in physically building circuits using wires and bulbs, our participants were much more comfortable with the representations as physical objects, as opposed to the schematics, making this model of a circuit significantly more accessible to them.

### EVOLVING CURRICULUM

As the course evolved, we focused on changing our teaching approaches to make sure participants were receiving proper content at an appropriate difficulty level. One example of this type of adjustment is reflected in the evo-

lution of the lesson on atoms. Understanding the structure and behavior of atoms is key in understanding circuits and electromagnetism, topics studied later in the course. We found, after one implementation, that our initial 30-minute mini-lesson on atoms did not adequately prepare participants to apply atomic concepts when studying currents and electromagnetism. In reflection, we made an inaccurate assumption about teacher background knowledge on this subject. During these 30 minutes, participants explored the Bohr model of atoms and reviewed how to read a periodic table; in the subsequent lessons, however, participants struggled to understand electric and electromagnetic phenomena as they lacked an understanding of electron behavior.

For future implementations of the Academy, we extended the lesson on atoms to a full 2½ hour session. We kept the examination of the Bohr model as an introduction to atomic structure; however, we also used online simulations (PhET) to encourage participants to explore the behavior of atomic and sub-atomic particles. In this virtual world, participants are able to examine the behavior of the valence electrons, which is essential to understanding the concept of electromagnetism. Evidence of improved understanding was seen in subsequent lessons, as participants could call upon the background knowledge they gained on atoms earlier in the course.

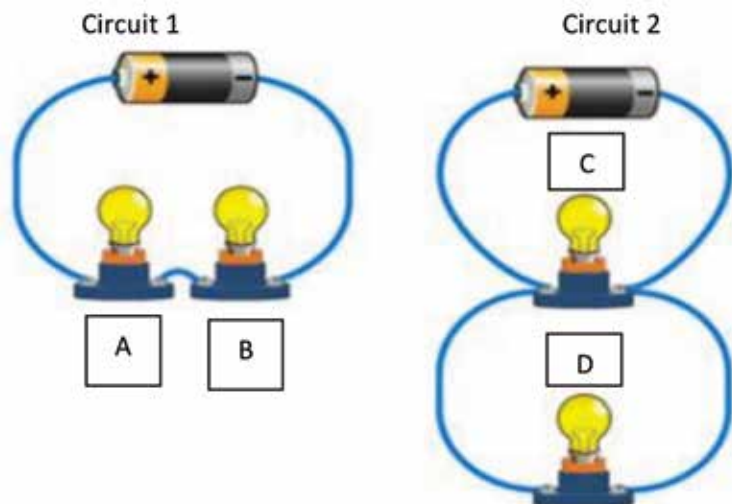
### EVOLVING PEDAGOGY

In the initial implementation of the course, the topic of light (reflection and refraction) was “explored” predominantly with the use of PowerPoint slides and two-dimensional drawings; this approach was selected in the absence of an understanding of participants’ prior knowledge and/or misconceptions about the topic, as well as Master Teacher discomfort in how to effectively develop content through

FIGURE 2

### Revised assessment.

“Compare the brightness of bulbs A and B in circuit 1 with the brightness of bulbs C and D in circuit 2. Which bulb or bulbs are the brightest?” (Department of Physics and Astronomy, Appalachian State University 2016)



pedagogical inquiry. Outcomes were disastrous; participants experienced great confusion, and therefore frustration, in their attempts to understand the content, and the session ended with many unanswered questions. We knew we had to completely revamp our strategy and return in the following session ready to re-teach.

In response, for future course offerings, we fully revised the light session. Using a series of lab stations, the participants are now asked to explore the phenomena of reflection and refraction, in order to draw their own content conclusions. This approach yielded one of the best lessons of the Academy—and it is almost completely participant-driven. Small groups of teachers are each assigned one of the labs to “explain” to the class using whiteboarding, a pedagogical strategy at the center of most of our sessions. Using self-created diagrams and their own vocabulary to explain the phe-

nomena has dramatically changed participant understanding. Whiteboarding, as a facilitation tool, is used regularly as a way for participants to demonstrate their reasoning processes, with a focus on debating conclusions from evidence, as well as a way for Master Teachers to gain insight into participant thinking, including misconceptions (Wenning 2005). During these presentations, the Master Teachers occasionally interject to add scientific vocabulary, but the vast majority of teaching and learning is done by the participants themselves. See an example of an inquiry investigation in the Appendix.

### RESULTS AND REFLECTIONS

We wanted to set our PD program apart from conventional teacher professional development opportunities in our district, which had historically

involved practicing “fun” activities that teachers can take to their classrooms for immediate use. While these sessions may seem useful on the surface, they do not result in an increase in actual content knowledge for teachers. When asked how the Physical Science STEM Academy differs from other professional opportunities, a first-grade teacher said, “The idea of teaching teachers so that they know the content fluently is massive. Not a lot of PD does that. A lot of PD is pedagogy, which we need, but again you can’t teach something effectively if you don’t know it.”

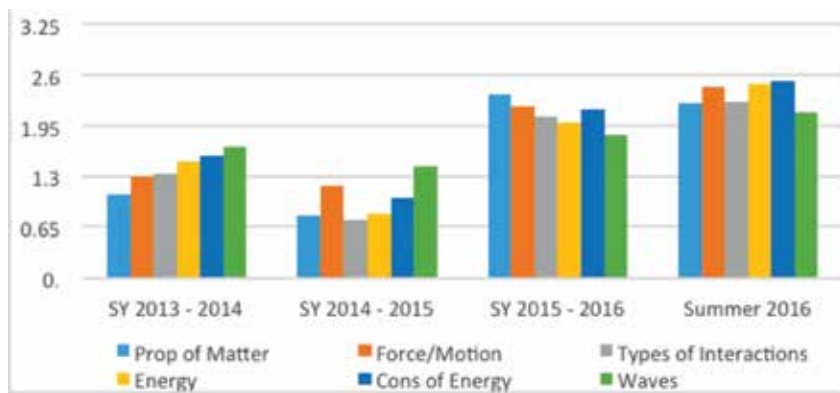
Science is a foreign language to many adults, including teachers. Just as a teacher would not be expected to teach German to students if they do not speak the language, we cannot expect teachers to teach science if they do not fully know its ideas. Elementary teacher comfort level in science is low, particularly in the “hard” sciences such as physics. Part of our course evaluation and analysis includes teacher attitudes and comfort levels with the different topics covered during the Academy. We found that teachers who successfully completed the course increased their overall comfort in every area of the Academy, but particularly in those most unfamiliar areas like forces/motion, energy, and waves.

Perhaps the biggest compliment to the course is the increase in comfort participants report having in respect to teaching physical science concepts. End-of-course surveys include comments such as: “I feel comfortable that I could do Physical Science STEM in my after-school program” and “I gained more knowledge as per science content and I shifted a lot of misconceptions. I also learned some strategies to teach science which were indirectly given in the sessions.” Figure 3, p. 78, presents the change in teacher comfort levels for each of the topics covered in the Physical Science STEM Academy.



FIGURE 3

## Changes in teacher comfort level.



Participants were asked, on the first and last day of the Academy, to rank their personal comfort level in each topic on a 4-point scale.

Though the data reflects different groups of teachers, there are some trends to note. The last implementation graphed, summer 2016, shows the greatest increase in comfort levels. We attribute this to the overall growth of the Master Teachers' facilitation effectiveness, but also to the ever-increasing quality of our curriculum and assessments, which were gradually "engineered" and evolved over time. "Teaching science for young learners can be a challenge. Prior to taking the Physical Sciences class, experiments and many hands-on activities seemed too difficult or time consuming to use in my first-grade classroom. The class helped me plan my science lessons to be both engaging and rigorous. I now have a greater content background

knowledge which helps me plan and engage my young learners." These results reflect the change that effective professional development can bring about—in the perceptions and attitudes of teachers, in the accuracy of content knowledge, and in the overall quality of science instruction for our youngest learners. ●

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## NSTA Connection

View the course outline, an optics activity, and the flow chart at [www.nsta.org/SC1903](http://www.nsta.org/SC1903).

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**Ekaterina (Katya) Denisova** ([EDDenisova@bcps.k12.md.us](mailto:EDDenisova@bcps.k12.md.us)) is the Principal Investigator of the project "STEM Achievement in Baltimore Elementary Schools" (SABES), Science Department Chair at Carver VoTech High School in Baltimore City Public Schools in Baltimore, Maryland, and Physical Science STEM Academy content expert/instructional coach.

**Christine Bell** ([CMBell@bcps.k12.md.us](mailto:CMBell@bcps.k12.md.us)) is a SABES Master Teacher (Physical Science) and a fifth-grade teacher at Hamilton Elementary Middle School in Baltimore City Public Schools in Baltimore, Maryland.

**Kristin Covaleskie** ([KCovaleskie@bcps.k12.md.us](mailto:KCovaleskie@bcps.k12.md.us)) is a SABES Master Teacher (Physical Science) and a fourth-grade teacher at Northwood Elementary School in Baltimore City Public Schools in Baltimore, Maryland.