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Learning to Teach Science: Strategies that Support Teacher Practice

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Abstract

This article notes that in order to teach science to young children, teachers need Pedagogical Science Knowledge (PSK). PSK includes an understanding of science content and inquiry processes, knowledge of children and how children learn, and skills for facilitating children's experiences in ways that support their active inquiry and conceptual development. The article then discusses a course that was designed to build teachers' PSK—Foundations of Science Literacy (FSL). This course combines face-to-face instruction with mentoring and performance-based assignments. FSL incorporates six key elements shown to be instrumental in supporting teacher learning: (1) an approach to inquiry-based science teaching that is well defined and well structured, (2) carefully selected science content, (3) a hands-on, inquiry-based approach to teachers' own learning, (4) opportunities to apply new learning through analysis, (5) performance-based assignments, and (6) ongoing mentoring. The article concludes with a discussion of FSL's impact and the challenges of taking a professional development program such as FSL to scale.

Introduction

Over the past several decades, an alarm has been raised, warning of the state of science education in the United States for children at all grade levels (Grigg, Lauko, & Brockway, 2006). Not only do our children underperform in science achievement when compared to students in other countries (Gonzales, Guzmán, Partelow, Pahlke, Jocelyn, Kastberg, & Williams, 2004), but the naïve ideas about science phenomena they bring with them to kindergarten frequently survive unchanged through high school and even college (Bishop & Anderson, 1990; Schneps & Sadler, 1988). As this information compels us to question our approach to science teaching, simultaneously, standards for student learning in science are rapidly expanding. It is currently understood that, in order for students to be considered "fully proficient in science" (Duschl, Schweingruber, & Shouse, 2007), they must be able to (1) know, use, and interpret scientific explanations; (2) generate and evaluate scientific evidence and explanations; (3) understand the nature and development of scientific knowledge; and (4) participate productively in scientific practices and discourse (Duschl et al., 2007).

What does this mean for the ongoing discussion about our approach to science teaching? It means that effective science teaching needs to embrace knowledge and science processes and practices, as well as provide multiple opportunities for students to use these processes and apply them across many experiences. Teachers need to use investigations and the data they generate to promote thinking about how and why phenomena are happening.

There is a growing understanding of the role that early childhood education can play in building science literacy. Infinitely curious about the world around them, children constantly observe and explore, take in new information, and generate their own ideas about how the world works. It is now widely known that cognitive stimulation in the early years is critical for brain development and that young children have cognitive capacities far beyond what was previously believed (Shonkoff & Phillips, 2000).

Unfortunately, many early childhood teachers are unprepared to promote science inquiry and learning in their classrooms. The way science was presented to them as students—a static collection of facts to be transmitted by the teacher and memorized by students—does not translate to teaching young children. All too often inservice training has encouraged the use of science activities and/or environmental approaches, such as science tables, at the expense of longer-term inquiry-based investigations. Additionally, teachers lack confidence in their own abilities to engage in science and to support the science learning of their students. If Head Start, prekindergarten, and child care teachers are to promote science inquiry in their classrooms, we need to answer some big questions: What do teachers need to know and be able to do? How can we effectively build a workforce that has this capacity?

What Do Teachers Need to Know and Be Able to Do?

In the following excerpt from an assignment in an Education Development Center (EDC) course, Jane, a child care teacher in Rhode Island, explains her rationale for an investigation she has planned, introducing two of her 4-year-olds and their exploration of the forces that move water. Consider what she knows and is able to do:

> I chose this particular challenge and set of questions because I felt that most of the children in my group were ready for a more in-depth study of water flow. Through my observations, conversations, and group discussion, I believe almost each child in my group would agree that water flows downward with ease. Most children have also come to know that water can travel upward, but not without the assistance of an outside force. They are getting quite skilled with squirt bottles, basters, funnels, and tubing, also. I felt introducing the wire wall, along with ‘T’ and ‘Y’ connectors might be just the challenge to set their minds racing with ideas on how to conquer this more challenging task. I had noticed both Maia and Ashley at different times working at the water table using basters and tubes. In fact, I had documented Maia’s exploration on a panel with pictures and wording where she had created a fountain. She attached a funnel to the end of a baster and held it upside down. When she applied ample pressure to the baster bulb, she created a “fountain.” I thought that she would become very engaged in another water exploration and be anxious for some new discovery. Ashley, who typically is quiet, can become very animated and enthusiastic when involved at the water table. As she and Maia worked side by side, she detailed a lot of what was happening.” (Jane Parfitt, assignment package 2, EDC Foundations of Science Literacy course, 2006).

It is clear from this brief excerpt that Jane understands something about the forces that influence water flow and how to make these phenomena accessible to young children. She has carefully selected materials and staged their introduction to provide new challenges to the children, building on previous experiences. She is able to assess children’s understanding using observations of the ways they use the materials, examining the documentation she has encouraged them to create, and by noting the observations and ideas they share in discussions. Clearly, her assessment of the children’s understanding is the foundation for planning new inquiry. Finally, she notes her use of documentation to promote the children’s inquiry.

We refer to this knowledge and skill as Pedagogical Science Knowledge (PSK). PSK includes an understanding of science content and inquiry processes, knowledge of children and how children learn, and skills for facilitating children’s experiences in ways that support their active inquiry and conceptual development. PSK enables teachers to provide a science curriculum that taps into children’s natural curiosity about the world, their early science capacities; it starts them on a path to science literacy.

How Can We Effectively Build Teachers’ PSK?

At Education Development Center, through a U.S. Department of Education (DOE) Teacher Quality Research grant, we developed and tested a comprehensive professional development program for Head Start teachers. Participating teachers made dramatic strides in their teaching practice, displaying new understanding of and ability to use pedagogical science knowledge. We are now testing the efficacy of this intervention with a second DOE grant.

Foundations of Science Literacy (FSL), a six-month, credit-bearing, college-level course, combines face-to-face instruction with mentoring and performance-based assignments. FSL focuses on physical science because this domain represents a treasure trove of opportunities for both adults' and children's active, hands-on, inquiry-based investigation. It also offers the opportunity to bolster teachers' confidence in both learning and teaching science.

The success of FSL depends on both its clear articulation of the science content and PSK and an instructional design that carefully scaffolds the teachers' transition from learning PSK to using it in their classrooms. FSL incorporates six key elements shown to be instrumental in supporting teacher learning:

1. An approach to inquiry-based science teaching that is well defined and well structured (Loucks-Horsley, Hewson, Love, & Stiles, 1998; Snow-Renner & Lauer, 2005)
2. Carefully selected science content (Garet, Porter, Desimone, Birman, & Yoon, 2001)
3. A hands-on, inquiry-based approach to teachers' own learning (Loucks-Horsley et al., 1998; Wenglinsky & Silverstein, 2006)
4. Opportunities to apply new learning through analysis (Heibert, 1999)
5. Performance-based assignments (Wenglinsky & Silverstein, 2006)
6. Ongoing mentoring (Heibert, 1999)

Clearly Articulated Content and Pedagogical Science Knowledge

Carefully Selected Science Content. A "less is more" approach to science content (Gonzales et al., 2004) allows us to go deeply in building teacher understanding of fundamental science concepts. Using water as the central topic, the focus is on the "big ideas" related to the physical characteristics of matter and the forces that underlie its behavior. In FSL, teachers explore this content through three subtopics—water flow, drops and streams, and sinking and floating. Teachers are first introduced to the content at an adult level and then, through instruction, guided discussion, and video analysis, they translate this knowledge to appropriate content and learning goals for young children. For example, through the drops and streams subtopic, participating teachers learned about the cohesive and adhesive properties of water. Having understood that children will not grasp these concepts at the molecular level, teachers learned that children can, however, make careful observations of how the shape of a drop can change when more drops are added. Children can also observe how drops bead up, flatten, and/or become quickly absorbed on different surfaces.

Well-Defined and Structured Approach. Two teaching frameworks provide illustrative handles for talking about PSK. The first framework is a set of science inquiry skills that defines the activities of the learner, processes used to build new understanding. The second is an Engage-Explore-Reflect teaching cycle, which describes the activities of the teacher. The cycle serves as a guide for planning and facilitating experiences and conversations that are designed to support inquiry.

The Inquiry Framework defines an explicit set of inquiry skills used during science investigations and which, over time, are internalized by the learner. Raising questions, exploring, carefully observing, describing and recording, analyzing, and theorizing are all skills central to the work of scientists as well as students of science, whether they are teachers or children. Not a static list of processes, inquiry has a dynamic nature and the relationship of the skills within and across related investigations over time. For young children to effectively use inquiry, the guidance of a teacher is essential. At the outset of FSL, teachers question whether or not children have the capacity to represent their experience through drawing, as well as their ability to engage in conversations in which they describe observations and compare them to earlier predictions. Building new understanding of children's ability to use inquiry is a central goal in

FSL—and a challenge, given that many early childhood teachers have limited understanding of young children's capacity to inquire and build skills of inquiry.

A second framework, the Engage-Explore-Reflect cycle, provides a means for teachers to organize and structure individual investigations, incorporating the key components of engaging children's attention and stimulating their ideas for upcoming explorations (Engage), hands on exploration and investigation (Explore), and reflecting on new experiences and information (Reflect). FSL builds connections between these components and the inquiry diagram, providing explicit guidance on supporting specific inquiry skills within each phase of the cycle. For example, during Reflect, the key skills emphasized are representation, collaboration, and theory making. Concrete guidance for using this approach is provided, not only in course content but also in the course textbook *Exploring Water with Young Children* (Chalufour & Worth, 2005).

Scaffolded Instructional Design

Hands-On, Inquiry-Based Approach to Teachers' Own Learning. Key to the success of FSL is the attention paid to the science. In each of the four sessions, hands-on, inquiry-based investigations play a central role, allowing teachers to experience the physical characteristics and behavior of water firsthand. These explorations, along with preliminary and follow-up discussions, help teachers make connections between their own experiences and the underlying science concepts, generating ideas that are based on evidence. Opportunities to hypothesize, plan, observe, document, and analyze data build an appreciation for the power of inquiry as a means of approaching their own learning as well as children's.

As Figure 1 shows, teachers engage in these hands-on, inquiry-based explorations with focused attention; their excitement is evident in their curiosity about what the water is doing and the budding theories generated by their observations. For example, during one session on water flow, teachers vigorously debated about what was happening as water and air flowed through the holes in a submerged container. Shouts of "That's not true! The water can't be coming out!" and "That's not what happened when I did it!" stimulated further investigation and interest in the science underlying their experiences.

Figure 1. Teachers learn to use force to move water.

Teachers' experiences with the science not only support their own understanding but also strengthen their facilitation of children's experiences. As they work with children, they make connections between their own and children's experiences with the same phenomena. Because they can now relate to what children are observing and doing, and also understand the science at the heart of children's experiences, they are better able to guide children's learning by engaging them in conversations that help children articulate their own ideas.

Opportunities to Apply New Learning through Analysis. In FSL, video vignettes are carefully selected and presented in a structured context that guides teachers to better understand and apply each aspect of PSK. Videos of real classrooms provide an essential link between course content and application by providing opportunities for teachers to practice assessing children's science experiences and understanding. The videos also model effective teaching strategies and give teachers the chance to discuss alternate approaches to facilitation.

Teachers are given multiple opportunities to practice what they are learning about facilitating inquiry through analysis of these vignettes. For example, after a discussion about ways to interpret children's thinking about water flow from their exploratory behavior, teachers watch a video of a child manipulating the movement of water through clear tubing. This prompts a discussion about the child's current ideas about water movement and the science that the child is experiencing. During a second viewing, teachers' attention shifts to the teacher and her interactions with the child, and a group analysis identifies useful interventions as well as some that may hinder the child's exploration. Video is also used to build understanding of the teachers' role as a facilitator of the Engage-Explore-Reflect cycle, including examples of teachers leading engage-and-reflect conversations, supporting children as they represent their observations through drawing, and interacting with children at the water table. Active viewing of the videos gives teachers the power to identify useful teacher strategies for supporting discussion and representation, as well as to suggest ones that the teacher in the video could have implemented.

Children's work samples provide another view of children's inquiry and a second opportunity to practice assessing what children understand. The illustration provides one example of how these samples give teachers an opportunity to assess children's thinking and learning.

Performance-based Assignments. Modeled after the portfolio tasks we developed for the Early Childhood Generalist Assessment for the National Board for Teaching Standards, FSL's four performance-based assignments, one after each session, ask the teachers to plan, implement, document, and analyze investigations related to the science they have just learned in the previous session. For example, after two sessions on flow, teachers are asked to guide children through a focused investigation of water flow. The assignment requires teachers to explain how their particular focus reflects children's interests and questions, to describe their plan for each phase of the E-E-R cycle, and to identify their plan for assessing children's learning. Teachers then implement the investigation, using video to document children's inquiry and the teacher's facilitation. Finally, they use a set of questions to guide their reflection on the teaching and children's learning. Teachers use the video as evidence of children's learning along with collected samples of children's work. The assignments not only provide a vehicle for teachers to try out some of their new learning, they also build their reflective capacity. One teacher explained how observing herself and the children on video provided insight into her own teaching and children's inquiry:

> I initially felt that I had been ignoring Faye for Tyler who required much more one-to-one facilitation. However, after watching the video several times, I do not think that intervening with Faye at that moment would have been the more successful course of action. She is obviously very comfortable exploring both on her own and in conjunction with other children in a small group. (J. Morrell, assignment package 2, EDC Foundations of Science Literacy course, 2006)

Ongoing Mentoring. Instructors, serving as mentors, provide on-site support to teachers in between sessions. The goal is to

- clarify and reinforce content introduced at class sessions
- help them procure materials and enrich their environments for science learning
- support them with planning E-E-R cycles

- observe teacher facilitation and give feedback
- provide guidance for difficulties teachers may be having
- encourage teachers' reflection on what children are doing and learning

Mentors also help teachers to plan future investigations that reflect children's interests and questions. Mentoring is essential to the success of participants' classroom application and assignment preparation and is seen by teachers as instrumental to their own learning. Since mentors often meet with teachers in groups, collaboration is bolstered within centers. One overarching goal of the mentoring component is to help teachers reflect on their own science teaching. As one teacher said,

> This experience really gave me a chance to work alongside the children and begin to observe where they are in terms of their science thinking and exploration. This was very helpful for me in terms of trying to figure out what I am supposed to be doing. As a result of our last mentor discussion, I really forced myself to take a step back and watch the children do what they wanted to do instead of trying to fit their thinking into some kind of mold I "thought" they were supposed to be falling into. (J. Morrell, assignment package 2, EDC Foundations of Science Literacy course, 2006)

FSL's Potential

As part of our research on the impact of FSL, we observed science instruction in classrooms and collected data on science teaching in both intervention and control classrooms using the Science Teaching and Environment Rating Scale (Chalufour, Worth, & Clark-Chiarelli, 2003). This tool uses a combination of observation and teacher interviews to examine science teaching across five critical domains: (1) creating a physical environment for inquiry, (2) facilitating direct experiences, (3) promoting use of inquiry skills, (4) planning in-depth science curriculum, and (5) assessing science understanding. Early childhood teachers who participated in FSL displayed strong gains in their ability to present and facilitate authentic inquiry-based science experiences and scored better than comparable teachers who did not have FSL, as shown in Figure 2.

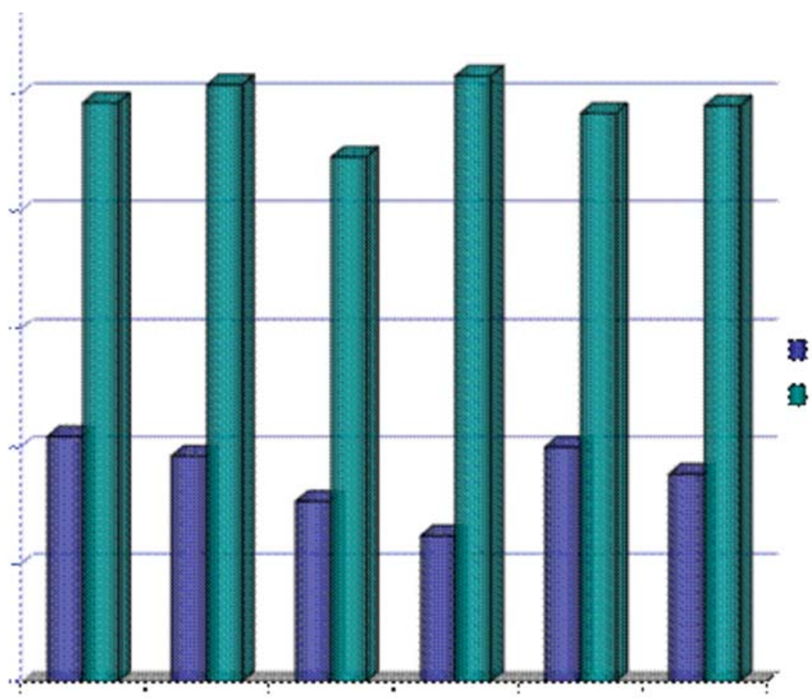

Figure 2. Teachers' growth in five domains and overall. The domains from left to right are (1) creating a physical environment for inquiry, (2) facilitating direct experiences, (3) promoting use of

inquiry skills, (4) planning in-depth science curriculum, (5) assessing science understanding, and (6) overall. Green = FSL teachers; blue = control group.

While the research data show one picture of teacher learning, another view is provided by the writing one teacher did for her assignment. She describes a reflective conversation, illustrating her growing ability to interpret children's experience with science phenomena and help them make meaning of what they are seeing and doing:

> In our reflect conversation, Tyler was able to explore the relationship between air and water, and how they occupy a given space, like a bottle. Our reflect discussion challenged Tyler's thinking even more. We used a squeeze bottle and observed what happened when the bottle itself was squeezed. Tyler noticed that "the water level gets higher." When I asked him "Why do you think that happens?" his reply was that "the space is getting smaller and there is no hole in the bottom so it (the water) can't go down." (J. Morrell, assignment package 2, EDC Foundations of Science Literacy course, 2006)

This quote richly portrays this teachers newly developed pedagogical science knowledge. She has the knowledge she needs of the science concepts, the ability to observe and assess the child's current understanding, and the skill to ask a question that connects his experience with the relevant science concept.

The Challenges Ahead

We have begun to answer some questions about the "what" and "how" of an effective professional development program in early childhood science. However, success with a cohort of 50 does not hold the same challenges as taking a professional development program to scale. Our instructional approach for both children and teachers is unique, and we have depended on instructors who have been a part of our work over the past 10 years. We have not yet taken on the challenge of recruiting and training new instructors. In addition, recruiting teachers for an intense and demanding intervention can be difficult. Not all teachers or programs are willing to take on an intervention of this intensity. The college credits are appealing to many, but the amount of work is difficult to incorporate into their busy lives. Many early childhood teachers hold second jobs or are trying to gain an AA or BA degree by taking several courses a semester. These circumstances have made scheduling class time and recruiting willing teachers difficult.

Finally, there are some limits to what FSL offers. Anecdotal evidence has suggested that many FSL teachers continue to use their new learning after participation in the course, but we have not studied sustainability. In addition, after all this effort, teachers have learned a limited amount of physical science. We know nothing about a teacher's capacity to teach new science topics as a result of this course. These are some of the important questions for future research.

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