Theory Guided Professional Development in Early Childhood Science Education

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CHAPTER 1

THEORY GUIDED PROFESSIONAL DEVELOPMENT IN EARLY CHILDHOOD SCIENCE EDUCATION

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ABSTRACT

The importance of early and developmentally appropriate science education is increasingly recognized. Consequently, creation of common guidelines and standards in early childhood science education has begun (National Research Council (NRC), 2012), and researchers, practitioners, and policy makers have shown great interest in aligning professional development with the new guidelines and standard. There are some important issues that need to be addressed in order to successfully implement guidelines and make progress toward accomplishing standards. Early childhood teachers have expressed a lack of confidence in teaching science and nature (Torquati, Cutler, Gilkerson, & Sarver, in press) and have limited science and pedagogical content knowledge (PCK) (Appleton, 2008). These are critical issues because teachers' subject-matter knowledge is a robust predictor of student learning outcomes (Enfield & Rogers. 2009; Kennedy, 1998; Wilson, Floden, & Ferrini-Mundy, 2002) and is seen as a critical step toward improving K-12 student achievement (National Commission on Mathematics and Science Teaching for the 21st Century (NCMST), 2000; NRC, 2000). We argue that the same is true of preschool teachers.

This chapter discusses: (a) theories and practices in early childhood science education (i.e., preschool through 3rd grade) in relation to teaching for conceptual change, (b) research on methods of professional development in early childhood science education, and (c) innovative approaches to integrating scientific practices, crosscutting concepts, and disciplinary core ideas with early childhood professional development.

Keywords: Professional development, Science, Learning standards, Scaffolding, Systems thinking

THEORIES AND PRACTICES IN EARLY CHILDHOOD SCIENCE EDUCATION

Theories of Conceptual Change

Children are born with powerful capacity for learning, and interactions with the physical and social world are necessary for concept development. Young children's abilities include domain-general learning mechanisms, including an explanatory drive that motivates children to explore and make sense of the world; an orienting response, which ensures that novel stimuli are observed and explored; representational capacity and memory, which allow children to store and retrieve information about their experiences in the world; ability to compare new experience with existing representations; and ability to manipulate and experiment with physical objects. Young children also have "first principles," domain-specific skeletal knowledge structures pertaining to specific cognitive domains such as the animateinanimate distinction, physics, category, number, biology, and language (e.g., Vosniadou, 2009). Children build upon first principles by using both domain-general and domain-specific learning processes and by using support from older children and adults. As children compare their understanding of the world with each new experience, they construct theories, sometimes called "naive theories" about the world. Children can test some theories on their own, but they often need an adult who is attuned to their theories and who can provide opportunities to test them.

From a constructivist perspective, children actively construct cognitive representations or "schemas" through their experiences and interactions with the world. In Piaget's conceptualization, children *assimilate* new knowledge when information is consistent with their existing schema (Piaget, 1977). However, when new information is inconsistent with children's existing schema, disequilibrium occurs because the child's current conceptualization of a particular phenomenon no longer works. The child needs to restructure his schema, a process Piaget referred to as *accommodation*, and this is an opportunity for teachers to scaffold children's experiences by providing well-attuned supports for the construction of new conceptual knowledge (Vygotsky, 1978). For example, a child may have a concept of "mammal," as a warm-blooded creature that has fur and feeds milk to its young. When confronted with a mammal that superficially resembles a different class (e.g., a platypus that resembles a bird or a dolphin that resembles a fish), the child will need to accommodate, refining the concept of mammal to include these exemplars. Children actively compare new information with past experiences and knowledge, determine what is consistent with their naive theories, and strive to understand inconsistent information through the process of equilibration (Piaget, 1977). An important role of teachers from a social constructivist perspective is to scaffold children's learning by helping link previous experiences and existing knowledge (e.g., "Remember when we watched the bears on the den cam and the cubs were drinking the mother's milk? Do you remember what we call an animal that feeds its young milk?") to new knowledge ("Dolphins feed their young milk too, just like bears. Do you remember what else is special about mammals? Yes, they breathe air, and what else? Are they warm-blooded or cold-blooded? How can we find out?"). Children actively seek to make meaning of the world by comparing new experiences to previous experiences and knowledge.

Methods of Teaching for Conceptual Change

Naive theories have limits, however. Formal science instruction may be a relatively recent development in human history, but science has been an important part of cultural knowledge that has been taught and learned across generations. For example, knowing how to preserve food is very important information for survival, and children routinely learned such skills as drying, pickling, curing, or making cheese. This is science knowledge that children have learned from more competent and knowledgeable adults, and children are ready learners, but they would not have discovered this knowledge by exploring on their own through the process of discovery science (Mayer, 2004). This knowledge was discovered and refined across generations and cultures and by using tools that were not necessarily available in everyday life, or available for use in children's explorations (e.g., using microscopes to identify food-spoiling bacteria).

Supporting Metacognitive Skills

According to Vosniadou (2009), children's theories do represent "a relatively coherent body of domain-specific but implicit knowledge" but differ from scientific theories in that they are not well-formulated, explicit, or socially shared (p. 548). Children consider their theories to be true facts about the world rather than hypothetical. Promoting metacognition is necessary when teaching for conceptual change because successful revisions of naive theories, in the face of incompatible information, requires both the construction of a new theory as well as understanding one's own explanatory frameworks (Vosniadou, 2009). To accomplish these goals, instruction must be designed to create "cognitive conflict" that can produce counterevidence that can catalyze disequilibrium, thus giving children the opportunity to examine their current belief structures (Vosniadou, 2009). Existing conceptual understanding influences future learning (Enfield & Rogers, 2009), and therefore it is critical to have accurate concepts upon which to build.

The National Academy of Sciences has identified specific strategies and pedagogical practices for teaching children how to construct scientific knowledge: (a) teaching for conceptual change, (b) promoting metacognitive understanding, and (c) engaging students deeply with core concepts (Michaels, Shouse, & Schweingruber, 2008). Teachers must be attuned to children's implicit theories in order to plan experiences to build upon or challenge those theories. Ongoing multidimensional assessment strategies can provide teachers with key insights about children's theories. Examining children's visual representations and listening to their explanations can yield valuable data about children's understanding, as well as provide opportunities for children to practice engaging in the language and tools of science. It is important to listen carefully and paraphrase to ensure understanding. Science journals can be used both to assess children's conceptualizations and to expand and challenge their existing understanding when teachers have children reflect on their representations. Giving children opportunities to demonstrate what they have done (i.e., make an object sink or use a ramp to accelerate an object) and to explain why they used the strategy that they chose can also help children examine their own thinking and make implicit reasoning explicit. "Show me how ..." or "show me what ..." questions enable children to nonverbally represent their experiences and understanding. Teachers can use behavior reflections to interpret the child's actions and to check for understanding. Too often, teachers rely solely on verbal explanations (Vosniadou, 2009) and, while asking children to explain their thinking can be an effective strategy, some concepts can be better represented through drawings or models that children create and then explain. Constructing models and explanations is a strategy that helps children to be reflective on both the concepts, and their own thinking about the concepts.

Young children are capable of engaging in inquiry, but different scientific reasoning skills require different levels of executive function and metacognition. Executive function is typically conceptualized as the coordination of working memory, inhibitory control, and attention or set shifting. Executive function is a central competency that is necessary for analyzing problems and testing hypothesis. It is necessary to hold in memory both a predicted outcome and an observed outcome in order to compare them. This is characteristic of three-year-olds who are typically at the first level of reflective consciousness in which they can hold in mind and use two rules about a single dimension (i.e., sorting by color) but cannot switch dimensions (Gropen, Clark-Chiarelli, Housington, & Ehrlick, 2011). Such children can make predictions and accurate observations, but have difficulty coordinating working memory, inhibitory control, and attention shifting to distinguish their initial hypothesis from their observation. Children reach the second level of reflective consciousness around four years of age, at which time they can integrate incompatible pairs of rules into a single system (Gropen et al., 2011). In terms of executive function, they can inhibit experiential processing and use analytic processing to holding rules in working memory. This allows them to reflect on and recognize the distinction between their prediction and observation, and therefore they can revise their hypotheses. Teachers can support children's development of executive function (Diamond, Barnett, & Munro, 2007), for example, by drawing attention to dimensions relevant to a correct prediction (i.e., slope of a ramp related to speed of a marble) and by providing extended opportunities to engage in cycles of inquiry. Gropen et al. (2011) argue that hypothesis testing and revision in preschool is "pedagogically relevant" (p. 302) both because it provides a context for practicing inhibition, working memory, and reflection, and it also provides teachers with key information about children's knowledge and reasoning.

Inquiry-Based Teaching

A meta-analysis of inquiry-based science teaching in elementary, middle, and high school demonstrated that inquiry methods resulted in greater science learning (Furtak, Seidel, Iverson, & Briggs, 2012). They did not analyze studies of elementary grades separately, but did differentiate between cognitive components of inquiry and levels of guidance.

Cognitive components included: (a) conceptual structures and cognitive processes, (b) epistemic knowledge or understanding of the nature of science, (c) social processes, including collaboration, communication, and argument, and (d) procedural components, including methods of discovery. Levels of guidance compared included traditional (mainly didactic) instruction, teacher-led inquiry, and student-led inquiry. Comparison of the cognitive components revealed the largest effect size for the epistemic domain, followed by a combination of epistemic, procedural, and social domains. Comparison of the types of guidance revealed that teacher-led inquiry had the largest effect size when compared with traditional instruction, followed by studentled inquiry when compared with traditional instruction. Simultaneous analysis of cognitive components and type of guidance revealed that the most effective programs had teacher-led inquiry that included epistemic, procedural, and social components. This suggests that teachers need sufficient preservice preparation or professional development in science epistemology or "nature of science" as well as social and procedural dimensions of science in order to effectively guide students' inquiry.

A study specifically focused on inquiry in kindergarten compared traditional science instruction with teacher-led inquiry that included epistemic, social, and procedural components (Samarapungavan, Mantzicopoulos, & Patrick, 2008). Evaluation of learning included portfolio assessments and a quantitative measure of science content and process knowledge. Students in the inquiry classrooms performed significantly better than students in the traditional classroom on all measures of science process and content knowledge. Using multiple modes of assessment was especially revealing; students in the inquiry group were better able to identify and generate relevant research questions in the context of the inquiry process (as documented in the portfolios) than in the decontextualized assessment of science process. Students in the inquiry group engaged in science discourse with peers and their teachers, constructed arguments using prior knowledge and their observations, represented their learning using multiple modes of communication, and demonstrated proficiency in conceptual knowledge. Teachers in the inquiry group were surprised about students' level of engagement in learning and the complexity of science concepts and vocabulary that they learned. This line of research underscores the importance of science discourse in early childhood classrooms. Teachers can facilitate discussions in which children explain their scientific reasoning. Such discussions help children begin distinguishing between their own and others' beliefs. In order to do this, it is necessary to include sufficient science content in early childhood curricula, so that when children engage in scientific conversations there is an object for their intersubjectivity and they can begin to distinguish between appearance, reality, and beliefs of different individuals (Gropen et al., 2011).

Fostering Reflective Discussions

Creating a scientific ethos within early childhood classrooms is necessary for fostering science process skills (Kirsch, 2007). Science is a social enterprise and norms, values, and meanings related to science learning are mediated through interactions. A classroom environment that values skepticism, open-mindedness, examination of evidence, and listening to multiple perspectives can help children develop important scientific "habits of mind." Children learn from other children both when they explain their own reasoning process and when they listen to others' perspectives. Teachers can support metacognition and perspective taking when they invite children to explain their thinking and when they ask other children to listen carefully ("let's listen to Abbie's idea about what might work"). Children must use inhibitory control, a key component of executive function, to suppress their own perspective and expression while considering the perspectives of others. Encouraging peer learning also changes the power structure in the classroom and helps children understand that answers to problems do not come from authoritative sources, but from their own reasoning and problem solving (Kirsch, 2007). Discussions about reasoning help children begin to understand their own thought processes, an important step toward metacognition and self-regulation of learning. Understanding that one's own knowledge is built from one's own cognitive activity promotes intellectual autonomy. It is important to respect children's ideas in order to both understand their reasoning processes and to support their development of intellectual autonomy and self-regulated learning (Kostelnik, Soderman, & Whiren, 2010).

A great deal of science learning can and does occur beyond the classroom. Teachers can elevate the importance of science by partnering with families and by providing suggestions for activities at home or information about opportunities for science learning in the community (e.g., nature centers, museums, special events, tracking in winter, birding in spring, etc.).

The Fit of Early Childhood Science Curricula with Standards and Guidelines

The importance of early childhood education has come to the nation's attention in a number of ways. The first of eight National Education Goals passed by Congress in 1994 is "School Readiness – by 2000 every child will start school ready to learn." Consequently, 39 states by 2007 had developed or were developing early learning standards (Scott-Little, Lesko, Martella, & Milburn, 2007). Early learning standards or guidelines described content that should be included in classroom instruction and knowledge that young children exhibit through their behaviors. A balance sometimes has been difficult to achieve between the academic content reflected in early learning standards that are designed to enable preschool learning to link with knowledge at kindergarten entry, as well as the more traditional emphasis of preschools on social and emotional skills and development of motor, language, and general cognitive skills.

While more mathematics and science content is gradually being included in the early education settings, greater attention is still being given to language and emergent literacy. One indicator of the relative attention of early language and literacy compared to early mathematics and science learning can be seen in the reviews of research on What Works Clearinghouse, the Institute of Education Sciences' web site that evaluates research findings on early childhood education interventions (called "programs, products, practices, and policies"). Reviews are provided for four interventions for "language competencies" and 17 interventions *each* for phonological awareness and oral language skills. In contrast, there are no science interventions for young children and only 12 mathematics interventions were reviewed, only two of which show any impact on children's learning. Much greater attention must be given to the development of effective mathematics and science interventions and evaluations.

The effects of the lack of attention given to mathematics and science are seen in research reports. Greenfield et al. (2009) studied changes in Head Start children's knowledge gains across the school year using Galileo (Bergan et aI., 2003). Science scores showed no significant gains over fall scores. Scores on all other content areas (language & literacy, social-emotional development, approaches to learning, creative arts, motor development, and physical health) showed significant increases. Preschool children not only have weak knowledge of science at kindergarten entry, they also have known misconceptions about science and mathematics (Seo & Ginsburg, 2004), and there is little evidence of knowledge gains in these areas from early childhood education. Children's understandings of science processes and concepts before kindergarten entry influence how they interpret scientific experiences provided by teachers, and their ideas about science do not change as the result of science instruction (Fleer & Robbins, 2003).

An examination of content standards for science in early childhood can serve as a starting point for understanding how approaches to science education might change. Science standards for prekindergarten to 1st grade in 29 states including Nebraska (Hong et al., 2012) are shown in Table 1.

Standards are shown for physical, life sciences, space/earth sciences, and technology. Specific topics within these content areas include: plants and animals/habitats (Life Sciences), senses and magnets (Physical Sciences), seasons and soil (Space/Earth sciences) and sink, float, dissolve/animals and habitats (Technology). Nebraska Early Learning Guidelines align science topics with behavioral indicators that are appropriate for preschool children, such as describes, classifies, compares, communicates, draws conclusions, explores, experiments, investigates, manipulates, measures, observes, predicts, questions, reflects, uses tools and objects. By considering the content standards and topics as well as behavioral indicators for preschool, kindergarten and 1st grade, ways in which foundational knowledge can build across grades can be used to conceptualize curricula. Such a crosscutting approach can be used to address the criticism of current approaches to science education for young children as "not organized systematically across multiple years of school, (emphasizing) discrete facts with a focus on breadth over depth, and (not providing) students with engaging opportunities to experience how science is actually done" (NRC, 2012, p. ES1).

The emphasis on language and literacy in the early grades has grown, in part because of No Child Left Behind Act (2001). The U.S. Department of Education identified reading as the "threshold to successful learning" (FY, 2004, Accountability Act, p. 45), and teachers are reluctant to take instructional time away from reading and reading-related content. However, educators are describing how science activities can be integrated into other content areas. For example, Brenneman, Stevenson-Boyd, and Frede (2009), Brenneman and Louro (2008), Gelman and Brenneman (2004), Greenfield et al. (2009), and Sackes, Cabe, and Flevares (2009) all describe how science activities support language and literacy skills through opportunities to learn and apply new words, communicate observations, compare and contrast different organisms to note similarities and differences, write and draw about science ideas in journals, and listen to and talk about books with science themes. Through integrating and connecting knowledge across content areas, children gain greater knowledge about science and mathematics, as well as language and reading skills.

Science Materials, Activities, and Interactions in Early Childhood Classrooms

Few studies have specifically examined science materials, activities, or interactions in early childhood classrooms; however, results of these studies indicate that focused and effective science teaching and learning in such classrooms are rare. Early et al. (2010) analyzed two data sets (the NCEDL and SWEEP studies) and found that the largest proportion of

Table 1. Scientific Concepts Included in Science Guidelines/Standards for Preschool to 1st Grade (29 States).

Physical Science	Life Science	Earth Science	Technology
A. Properties of matter	A. Living and nonliving	A. Properties of earth and space	A. Tools
Explores characteristics of matter	Identifying things as living and nonliving based on their characteristics	Classification of natural objects (e.g., seeds, cones, leaves) according to shapes, forms, and textures	Use age appropriate tools to investigate
• Exploring different colors and white and black, shapes of objects, textures (rough/smooth) and feel (hard/soft), and size and weight	• Breathes, moves, grows	Atmosphere (air), mixture of gases, including watcr vapor, and minute particles	Exploring simple tools (e.g., ramps, magnets. magnifying classes, seales, eyedroppers, unbreaka ble mirrors, cups, funnels, tape measures, balls, prisms, etc.)
• Identifying environmental sounds (e.g., cars. airplanes. wind, rain, birds)	• Animals, plants, rocks, buttons	Water and its uses; Sun heat and light; Supporting life on earth; Sound (thunder, wind); Shadows	Correctly use thermometers, balance scales, magnifying glasses, etc. for investiga tion
• Describing the difference between the wet sand and the dry sand	Describing characteristics, patterns, basic needs, and simple life cycles of living things (i.e., plants, animals, and people)	Weather	Use tools to collect data and record information
• Describing how water flows through a tube	• Various patterns and products: e.g., parents and offspring, *describing how puppies are like dogs*, *ducklings are like duck* (e.g., that tree grew really tall; Food, water, sunlight, soil, air, space, temperature)	• Temperature	Uses computer to solve problems
• Experimenting with objects that sink or float in water	• Illustrating complete metamorphosis (e.g.. butterfly, frog)	• Seasons	Natural objects versus man-made objects

Properties and characteristics of liquids, solids, and gas	• *Illustrating incomplete metamorphosis (e.g., grasshopper; Herbivores and carnivores; Compare and contrast complete metamorphosis and incomplete metamorphosis*	• Day and night	Order or stages of animal and plant growth
• Understanding changes when substances are mixed. shaken or cooked	Exploring and describing similarities, differences, and categories of plants and animals (e.g., compares size and shape)	• Sunlight and shade	Describe how things change naturally, age, weight
• Involving in transformation of materials (e.g., cooking, painting)	Understanding changes in the appearance, behavior, and habitats of living things (e.g., plants, spider webs)	• Identifying patterns and routines in daily life	Maintain a balanced ecosystem (Solves problems involving earth and space; Pollution; Recycle, reused, and conserved)
Acting out a melting snowman, popping popcorn, and object rolling down a hill	Asking questions about growth, change, function, and adaptation in plants and animals (i.e., evolution)	• Weather predictions	Natural and man-made things
	Structure and function of living things	• *Identify types of precipitation*	Composition and structure or the universe and the Earth's place in it
	• Five senses	Measuring devices (e.g., thermometer. rain gauge, ruler, cup, bowl; Experiments with windsocks, pinwheels, telescopes, binoculars, kites, magnifying glasses	• Rotation
	• Oral hygiene: how to clean teeth		• History of the earth
	• Human body parts: *heart, lungs, hrain, stomach, muscles, bones*		• *Concept of rotation*
	• Plant parts: *leaves, stems, flowers, roots*		• *Sequence of planets in the solar system*

B. Force, motion, & energy	B. Environment	B. Uses
Force and motion:	Relationships between animals, plants, and the environment (i.e., habitats)	How we use technology and the affect it has on our lives
• Describing the ways that objects can move (e.g., in a straight line, zigzag, up and down, back and forth, round and round, and fast and slow)	• Fish live in water	Promotes safety – begin to understand basic safety practices
• Position vocabulary (e.g., over/under, in/out, above/below)	Taking care of familiar plants and animals	How technology affects our lives
• Forces in nature	• Waters houseplants, feeds pet fish, growing plants, and caring for pets	Relationships among science, technology, environment, and society
• *Understand gravity*	Preserving environment	Apply the concepts, principles, and processes to technological design
• *Magnets: predicting which objects magnets auract (pull) or repel (push): Categorizing properties of materials using magnets*	• Recycling, planting a tree	
Energy:	Neighborhoods	
• Different forms of energy (e.g., light, heat and sound energy)	Population and ecosystems	
• Transfer of energy	Recognizing what it means for a species to be extinct	
• Importance of light and heat		
Investigating sound		
Represents observations of the physical world in a variety of ways		

Note: Italicized concepts were included only in 1st grade science standards.

time spent in learning activities focused on language and literacy (17% of the day), social studies (15%), and art (15%). Science (11%) and mathematics (8%) activities comprised the smallest proportion of the day. It is noteworthy that the codes were not mutually exclusive so it would be possible to be engaged in both literacy and science, for example, so it would not be necessary to "displace" other activities in order to increase the amount of time spent on science. Science activity was defined as exploring or identifying any natural phenomena and this broad definition could include exploration of sand and water. Tu (2006) assessed the availability of preschool science materials, natural science materials, and science activities in 20 preschool classrooms. Half of the preschool classrooms had a science area, but during free choice time teachers spent the smallest proportion of time interacting with children in the science center and the greatest proportion of time interacting with children in the art center. The most frequently observed science materials were vinyl animals (80% of classrooms) and live plants (70%), but teachers never talked with children about the plants in the classroom. Most classrooms had a sensory table (65%) and science posters or charts (60%). Other than plants, few classrooms had natural science materials. Overall, 4.5% of class time was spent in formal science activities (i.e., making play dough), and informal science activities comprised 8.8% of class time (exploring sand with shovels). No incidental science activities ("teachable moments") were observed in this study. Finally, observations of children in 2,500 1st grade classrooms revealed that 50% of instruction time focused on literacy and approximately 10% focused on science (Pianta, Belsky, Houts, Morrison, & NICHD ECCRN, 2007). Taken together, these studies indicate that opportunities to engage in meaningful science learning in early childhood programs are minimal.

RESEARCH STUDIES ON METHODS OF PROFESSIONAL DEVELOPMENT IN SCIENCE EDUCATION

Although there is not a single, agreed-upon definition, professional development is defined, in general, as a variety of training opportunities that aim to enhance the effectiveness of teaching by providing preservice and in-service teachers with guidance and feedback (Buysse, Winton, & Rous, 2009). Research evidence on effective models of professional development in early childhood science education is limited. Therefore, we draw upon empirical findings on effective models of teacher professional development for elementary teachers and for prekindergarten mathematics (Clements & Sarama, 2011; Scher & O'Reilly, 2009; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). Effective science and mathematics professional development emphasize both content and pedagogy (Kanter & Konstantopoulos, 2010; Scher & O'Reilly, 2009), with a focus on children's thinking and conceptual change (Clements & Sarama, 2011; Vosniadu, 2009). Effective science professional development incorporates knowledge of children's conceptions of science phenomena (Enfield & Rogers, 2009). It is necessary for teachers to understand science content to enable them to interpret children's representations and conceptions and to design ways to challenge and expand those concepts. Metacognitive science talk is an important vehicle for developing scientific understanding and reasoning skills. Effective professional development is grounded in and applicable to specific curriculum concepts and materials (Clements & Sarama, 2011).

Research indicates that effective professional development is "multifaceted, extensive, ongoing, (and) reflective" (Clements & Sarama, 2011, p. 140). A meta-analysis of nine professional development studies involving elementary teachers indicated that intensity (more than 14 hours) predicted significant positive effects on student achievement (Yoon et aI., 2007). All of the effective professional development models included "institutes" during the summer, and eight included follow-up academic year support. Students whose teachers participated in the professional development included in the meta-analysis performed better by 21 percentile points on average; the average effect size for studies using randomized control trials was 0.51. These findings emphasize the importance of providing teachers with opportunities to apply new knowledge in the classroom and reflect upon their practices and students' learning, while also providing support for implementing new practices. Follow up mentoring for developing and implementing lessons, as well as guidance of professional challenges has been found to be effective (Ager & O'May, 2001; Joyce & Showers, 2002). Professional development foci often include elements of classroom quality, which are considered in the next section.

Evaluating Classroom Quality: Structure and Process Elements in the Classroom and Impacts on Student Learning Outcomes

A body of research has emerged exploring connections between program quality and classroom learning. Program quality is often characterized by structure and process elements in the classroom (e.g., Pianta & Hamre, 2009). Pianta, Barnett, Burchinal, and Thornburg (2009) define structural elements as "those aspects of the programs that describe the caregiver's background, curriculum, or easily observed or reported characteristics of the classroom or program" (p. 66). Structural elements include the physical space, routines, materials, and other elements that are often related to licensing regulations or accreditation. In contrast, process elements "refer to children's direct experiences with people and objects in the child care setting, such as the ways teachers implement activities and lessons, the nature and qualities of interactions between adults and children ... and the availability of certain types of activities" (p. 66). Together, structural and process elements are critical indicators of classroom quality, but how the elements relate to specific content, such as science, is not usually considered.

While there is no single approach to evaluating classroom quality that considers both structure and process, there are approaches that together provide a more complete picture of quality. The Early Childhood Environment Rating Scale-Revised (ECERS-R, Harms, Clifford, & Cryer, 2005) is a frequently used observation measure of center-based early childhood program quality that includes five subscales assessing structural quality (space and furnishings, personal care routines, activities, program structure, and parents and staff) and two subscales that include both structure and process indicators (language-reasoning and interactions). Examples of indicators on the language-reasoning subscale include: "Some activities used by staff with children to encourage them to communicate," "Staff talk about logical relationships while children play with materials that stimulate reasoning," and "Children are asked questions to encourage them to give longer and more complex answers." Examples of indicators on the interactions subscale include: "Staff assist children to develop skills needed to use equipment," "Staff talk to children about ideas related to their play, asking questions and adding information to extend children's thinking," and "Staff actively involve children in solving their conflicts and problems." These indicators can provide guidance for the kinds of interactions that support children's development and learning, but specific curricular content domains are not addressed in the measure. The modest effect sizes of associations between classroom quality and children's development (e.g., Peisner-Feinberg et al., 2001) and the insignificant associations between classroom environment quality and other cognitive outcomes (reading, mathematics, and cognitive/attention) may have resulted from the lack of content-specific quality indicators.

The Classroom Assessment Scoring System (CLASS, Pianta, La Paro, & Hamre, 2008) is a process-focused measure that assesses the quality of interactions between teachers and children. There are three domains: emotional support, organization, and instructional support. Each domain is composed of three to four dimensions: Emotional Support includes positive climate, negative climate, teacher sensitivity, and regard for student perspectives; Organization includes behavior management, productivity, and instructional learning formats; and Instructional Support includes concept development, quality of feedback, and language modeling. The domain of Instructional Support is particularly germane for student learning. Instructional Support refers to teachers' interactions with children that promote concept and skill development through scaffolding, questioning, and feedback loops. Research evidence links this domain of classroom process to children's academic achievement. For example, Perry, Donohue, and Weinstein (2007) found that 1st grade children in classrooms with higher levels ofInstructional Support made greater academic progress than children in classrooms with lower levels of Instructional Support. Hamre and Pianta (2005) reported that Instructional Support in 1st grade classrooms promoted academic achievement among children at risk for academic difficulty. Kindergarten children in classrooms with higher Instructional Support showed greater academic competence (Pianta, La Paro, Payne, Cox & Bradley 2002). Mashburn and colleagues (2010) examined data from two national samples of public prekindergarten programs and found measures of Instructional Support predicted children's academic and language skills in pre-kindergarten. Interestingly, the ECERS-R scores obtained from the programs were poor predictors of academic and language skills.

It is important to note that neither the ECERS-R nor the CLASS scales are designed to relate elements of classroom quality to learning of specific content. The Preschool Rating Instrument for Science and Mathematics (PRISM) is an observation-based instrument that links teacher-student interactions and classroom materials to preschool children's mathematics and science learning (Brenneman, Stevenson-Garcia, Jung, & Frede, 20 II). The PRISM has six "materials" items (such as, "Materials for counting, comparing, estimating, and recognizing number symbols," "Materials for biological and nonbiological science explorations," and "Materials to support reading about and representing science") and 10 "staff interactions" items (such as "Counting for a purpose," "Science explorations, experiments, and discussions," and "Recording science information"). PRISM was used in a study of public preschoolers along with ECERS-R and measures of vocabulary, math, and science. PRISM and ECERS-R correlations were moderate (0.41) suggesting that the PRISM measures some similar as well as unique information about the classroom environment. Brenneman et al. (2011) reported that the "staff interactions" scores were lower than the "materials" scores. This is interesting because other than "counting for a purpose," which had an average score of 4.08, the other "staff interactions" were much lower (1.54-2.49). These low scores are interpretable in light of the issues raised earlier in this chapter about the amount of attention given to mathematics and science learning in early childhood classrooms. While many activities in these classrooms relate to "counting," there are few activities that build children's thinking and foundational skills around other math and science content. The finding of low average "staff interaction" scores reported by Brenneman et al.

(2011) is similar to the reports on the CLASS (Pianta et al., 2005). Scores on Instructional Support tend to be lower than scores for Emotional Support and Classroom Organization. Teachers seem to consistently create wellorganized classrooms with positive and sensitive teacher-student relations more so than classrooms characterized by the use of analysis and reasoning to promote concept development and interactions involving back and forth exchanges, specific feedback, and open-ended questions. Yet, it is these types of interactions that are needed to build student learning and knowledge.

Quality of Professional Development in Early Childhood Science Education

Research indicates that many preschool to 1st grade teachers feel inadequate and anxious about teaching science and mathematics (e.g., Ginsburg, Lee, & Boyd, 2008; Greenfield et al., 2009; Sutton, Bausmith, O'Connor, & Pae, 2009; Torquati, Cutler, Gilkerson, & Sarver, in press). Further, the majority of early childhood teachers have taken a relatively small number of science and mathematics content courses (pCAST, 2010), typically only those courses required in their undergraduate degree programs. Fulp (2002) found that 42% of elementary teachers in a national survey completed four or fewer semesters of science and fewer than 30% of elementary teachers believed they were well prepared to teach science. While science and mathematics courses are supplemented with methods classes, practicum experiences, and student teaching, the total credit hours related to science and mathematics are relatively low. This is a critical problem because elementary teachers' subject-matter knowledge is a robust predictor of student learning outcomes (Enfield & Rogers, 2009; Kennedy, 1998; Wilson, Floden, & Ferrini-Mundy, 2002) and is seen as a necessary step toward improving K-12 student achievement (NCMST, 2000; NRC, 2000). It is reasonable to assume that that the same is true of prekindergarten teachers. Evidence indicates that teachers use their past experiences in science and mathematics classes as templates for teaching (Lortie, 2002), often giving students the impression that science is scripted and mathematics is procedural, with every experiment providing a correct answer and a single process for arriving at a solution. A scripted use of textbook and cookbook lab materials does not reflect the discovery and investigative nature of science and mathematical practices (Council of Chief State School Officers (CCSSO) and National Governors Association (NGA) Center for Best Practices, 2010). Rather, these methods encourage children to see science and mathematics as collections of facts and problems with single pathways for finding a single solution. Effective professional development must address this problem.

Coaching to Strengthening Pedagogical Content Knowledge, Teaching Efficacy, and Practices in the Classroom

Coaching has been recognized as one of the effective early childhood professional development tools through which teachers receive individualized support in implementing evidence-based practices (Powell, Steed, & Diamond, 2010). Although there are mixed findings about the effectiveness of coaching, it is considered to be more promising than other traditional forms of professional development (i.e., workshops) and has improved the learning of children at risk for school failure (Gupta & Daniels, 2012; Odom, 2009). Coaching methods have been used frequently in early childhood classrooms to promote teacher effectiveness and children's learning in the areas of literacy and language (Hsieh, Hemmeter, McCollum, & Ostrosky, 2009; Powell et aI., 2010), mathematics (Rudd, Lambert, Satterwhite, & Smith, 2009), social-emotional intervention (Fox, Hemmeter, Snyder, Binder, & Clarke, 2011), and classroom management strategies (Reinke, Stormont, Webster-Stratton, Newcomer, & Herman, 2012). Coaching is used in early childhood classrooms to help teachers adopt a new curriculum or tools or to assist their use of specific teaching strategies. The structure of coaching determines how coaching is delivered and received (e.g., frequency, number, duration of coaching contacts, supplemental materials); whereas the process of coaching includes what coaches do to promote change in teachers' practices. Coaches model or demonstrate specific strategies, observe teacher behavior and classroom interactions, share thoughts and comments about the interactions, and encourage teachers to reflect on their teaching practices. However, little is known about the mechanisms through which coaching promotes teacher knowledge and skills (Sheridan, Edwards, Marvin, & Knoche, 2009).

Coaching and mentoring with individualized and intentional support may help early childhood teachers gain science Pedagogical Content Knowledge (PCK) and self-efficacy for teaching science, which in turn may impact children's science learning. PCK is considered to be a necessary foundation for teaching and the ability to transform subject-matter content into forms that can be mastered by students (Shulman, 1986). PCK is a construct that contains five components: (a) knowledge of curriculum, (b) knowledge of student understanding, (c) knowledge of assessment in science, (d) knowledge of instructional strategies, and (e) orientation to teaching science (Falk, 2012; Magnusson, Krajcik, & Borko, 1999). Early childhood teachers are hesitant to teach science, not only because they lack science knowledge, but also because they lack PCK in science (Appleton, 2008). When teachers did not have proper PCK, they tended to avoid teaching science at all or only taught science content that is similar to the content taught in literacy or social studies (Harlen & Holroyd, 1997). Appleton (2008) investigated the role of mentoring in improving early elementary teachers' PCK. The mentor planned and taught activities together with each teacher to enhance his or her self-efficacy for teaching science in early elementary classrooms. This approach was based on the belief that effective professional development in science education should be transformative, which means that it causes changes in social, professional, and personal areas (Bell & Gilbert, 1996). More specifically, for science professional development to be effective, it should enable teachers to develop collaborative relationships with other teachers (social), develop ideas and actions (professional), and attend to their feelings (personal), which in turn produce lasting changes (Peers, Diezmann, & Watters, 2003). Although Appleton (2008) was a case study with four teachers with one science mentor, the one-on-one mentoring was perceived as beneficial by the elementary teachers and may have a potential to be an effective strategy for early childhood science professional development.

Early childhood science professional development should include efforts to promote teachers' knowledge, skills, and dispositions. Building teachers' motivation to teach science as well as scientific knowledge is essential for effective science teaching. Dispositions are defined as "prevailing tendencies to exhibit a pattern of behavior frequently, consciously, and voluntarily" (Sheridan et al., 2009, p. 380). Unless teachers have the motivation to use the skills and knowledge that were learned through professional development, it would be difficult to expect changes to occur in their behaviors or dispositions.

INNOVATIVE IDEAS: PROFESSIONAL DEVELOPMENT IN PRESCHOOL TO THIRD GRADE SCIENCE EDUCATION

Integration of Scientific Practices, Crosscutting Concepts, and Core Ideas

Recently, the NRC (2012) published a framework for K-12 science education. The goal was to create new sets of K-12 science education standards that are common, crosscutting, and integrated across grade levels, and the framework suggests that science education in K-12 grades be constructed around three main dimensions: "scientific and engineering practices, crosscutting concepts that unify the study of science and engineering through their common application across fields, and core ideas in four disciplinary areas: physical sciences, life sciences, earth and space sciences, and engineering, technology, and applications of science" (NRC, 2012, p. 2). As emphasized in early learning guidelines, children are expected to learn to ask questions, define problems, develop hypotheses and plan investigations, collect, analyze and interpret data, explain the results, make conclusions, and communicate the results with other people. All these scientific problem-solving processes are expected to be included in all K-12 science education. The suggested crosscutting concepts include: (a) patterns, (b) cause and effect, (c) scale, proportion, and quantity, (d) systems and system models, (e) energy and matter, (f) structure and function, and (g) stability and change. Michaels et al. (2008) also discussed the benefits of creating learning progression around science core concepts. When children get actively engaged in learning all these crosscutting concepts as well as the major scientific and engineering practices over the K to 12 years, their understanding of core ideas will be deepened considerably. This will also enable teachers to provide meaningful science experience in the classroom that are built on the students' previous learning at each grade level (Michaels et al., 2008).

Teacher professional development should use these guidelines to enhance tcacher effectiveness and student learning. Aligning state guidelines and standards with this framework can be the first step for planning a relevant professional development. For example, one of the core ideas included in the physical sciences is Matter and Its Interactions. Components under this core idea include structure and properties of matter, chemical reactions, and nuclear processes. The first component of the core concept (i.e., structure and properties of matter) appears in many states' early learning guidelines (for preschoolers) as well as most early elementary science standards. The depth of knowledge on this component shared at different grades may be considerably different, but the basic idea is the same: Different kinds of matter exist (e.g., water, wood, metal) with different forms and they have different characteristics (e.g., texture, size, weight); small pieces can build many different objects (e.g., blocks). Examining the continuity and progression in the content being taught across grades including prekindergarten would help teachers and researchers see the big picture of science education. The scientific and engineering practices can then be used to help children understand these core concepts. Children can explore the properties of matter by observing, comparing, and contrasting characteristics of objects; sorting them into different categories; measuring the size and weight of different objects; observing and making hypotheses about how matter changes by doing true scientific investigations and experiments; and sharing the learned knowledge with other teachers, classmates, and parents. These scientific investigations can enable children to develop understanding of some of the crosscutting concepts as well, such as patterns (e.g., recognizing patterns of similarities and differences by classifying objects) and cause and effect (e.g., temperature change causes changes in properties of matter, such as water).

Systems Approaches to Promoting an Integrated Understanding of Science

One of the crosscutting concepts included in NRC's framework for science education is Systems and System Models. Systems are an essential focus of science education and a unifying theme among science disciplines (Kay & Foster, 1999). A system is a set of relationships that all work together. A system can be as small as a cell or as large as an ecosystem. Important problems facing our society today are complex and require a systems approach for developing solutions. Unfortunately, most science instruction fails to promote an integrated understanding of science systems among students (Ben-Zvi-Assaraf & Orion, 2010; Liu & Hmelo-Silver, 2009). A systems thinking model is essential to understanding how organisms are connected with elements in ecosystems, for example, and for bridging life and physical sciences. Systems principles transcend compartmentalized content knowledge, enhancing generalizability. Therefore, science education with a focus on systems and the dynamic interactions among the system's components and functions has the potential to enhance students' learning in science. This approach is consistent with the systems-level view of mathematical proficiency (Kilpatrick, Swafford, & Findell, 2001) that emphasizes mathematical reasoning, processing and data interpretation, and communicating interconnected mathematical ideas within the same or between different topics (NCMST, 2000).

Educators view systems thinking as a viable pedagogical approach for teaching science (Hmelo, Holton, & Kolodner, 2000) that provides benefits not found in traditional methods of teaching science (Ben-Zvi-Assaraf & Orion, 2010). Key benefits include understanding the interconnectedness of the components within the system; recognizing the complexity within the system; and presenting the system, its components, and its processes as a whole. For example, in elementary classrooms teachers use a scope and sequence of science topics based on a set of independent (from their perspective) and unrelated goals and objectives. Kindergartners in most states study plants, senses, seasons, and sink, float, dissolve. Teachers create activities to demonstrate and engage children in each of these areas with goals specific to each topic. They grow a plant, use their senses, observe the seasons, and manipulate objects that sink, float, and dissolve, but never make connections linking this knowledge to a larger system of understanding. By including systems thinking as a key element in science professional development, teachers may learn connections between plants, senses, seasons, and sink/float/dissolve with an organism(s).

The systems approach can enable teachers to see connections among the life cycle of organisms (i.e., involving plants and animals, senses, seasons, weather, and change in earth and sky), basic concepts of living and nonliving, inheritance (i.e., involving plants and animals, patterns in nature), and the associations between an organism and its environments and survival (i.e., involving the concept of interdependence, seasons, plants and animals, etc.). Systems thinking can provide continuity across grades when conceptualizing the scope and sequence of concepts at each grade level. Each aspect of the systems-level approach assists teachers and students in understanding the complexity of a system (i.e., an organism) while still meeting curricular goals specified for curriculum scope and sequence. While knowledge and skills taught to preschool children focus on processes (science: observing, classifying, experimenting, communicating; mathematics: counting, measuring, classifying, identifying), these processes are applicable to life, physical, and earth sciences in building knowledge and abilities across grades.

The systems approach involves using constructs and language that cross science and mathematics areas, enabling better articulation of classroom instruction and student learning across grades due to shared use of language and concepts related to science and math. We believe that the use of systems thinking can enable teachers to build strong PCK (Shulman, 1986), one of the many tasks of science teaching requiring specialized knowledge (Ball, Thames, & Phelps, 2008). While early childhood teachers generally are not prepared to teach science using a systems thinking approach, it is learnable and readily applicable to the scope and sequence of science curricula across grades.

Science Laboratory Experiences to Enhance Teachers' Science Content Knowledge

Science laboratory experiences may be another innovative strategy to enhance early childhood teachers' science content knowledge. Walden and his colleagues developed a professional development program for sixth to twelfth grade science teachers that involved collaboration between science teachers and university scientists (Walden, Greene, Slater, Lubin, & Keesee, 2009). The intervention included a two-week summer professional development program where teachers experienced authentic scientific research processes and participated in professional learning communities across the state of Oklahoma. This project promoted teachers' science content knowledge and also improved teacher quality and student outcomes even in small, isolated rural schools. One of the assessment tools was concept mapping (i.e., representation of teachers' understanding about certain science topics), and the number of links on their map between concepts as well as their ability to integrate different science concepts significantly increased after the inquiry-based professional development. This intervention influenced how teachers thought about constructivist practices, and their increased endorsement of constructivist and inquiry-based practices were observed although it did not make a significant difference in their motivation and attitudes toward teaching science.

Providing early childhood teachers with authentic science lab experience as a part of professional development may enhance their science content knowledge as well as scientific problem-solving skills. The authentic processes of science and collaborative partnerships between science teachers and scientists may promote teachers' in-depth understanding of linked concepts as well as system-level relationships among those concepts.

Using Collective Participation in Schools for Collaboration and Problem-Solving to Support Science Teaching

One of the main objectives of professional development is to sustain "high-quality professional practices by enhancing systems and individuals to engage in activities that are self-sustaining and growth producing" (Sheridan et al., 2009, p. 380). In order to help teachers sustain the knowledge, skills, and dispositions gained from a professional development program, it is critical to provide them with a group of teachers who can reflect on what they have discovered from the professional development experience and help one another assess and monitor their professional growth (Fleet & Patterson, 2001; Riley & Roach, 2006; Sheridan et al., 2009). Although the initial information comes from outside, such as from coaches and consultants, the process of self-regulated ongoing growth comes from inside (i.e., teachers themselves) to achieve meaningful changes and improvements (Wesley & Buysse, 2006). Therefore, building a professional community that shares understanding of concepts, processes, and teaching methods can provide a culture that supports newly learned practices. The process of working together as a team should happen early in the process of professional development, and we suggest that teachers of preschool through early elementary grades participate in professional development opportunities together and reflect on their science teaching collaboratively.

A recent study examined the impact of standards-based science content and professional learning communities on science teaching efficacy with elementary and middle school science teachers (Lakshmanan, Heath, Perlmutter, & Elder, 2011). Throughout the three years of professional development, teachers were encouraged to work with one another to reflect on their science teaching and share information as a form of professional learning communities. Results revealed significant gains in teachers' science teaching efficacy and in inquiry-based instruction in the classroom as well as a positive association between the two. Although this particular study only included teachers from fifth to eight grades, elements of professional learning communities were recognized in other studies with teachers of lower grades. Richmond and Manokore (2010) analyzed teacher talk during professional learning community meetings using qualitative research methods and found five key elements: "teacher learning and collaboration, community formation, confidence in knowledge of content and guided inquiry, concerns about the impact of accountability measures on teaching and learning, and sustainability of reform" (p. 555). The main purpose of professional learning communities is to help teachers become motivated to learn and change (Grossman, Wineburg, & Woolworth, 2001). All teachers expressed that they gained science content knowledge, knowledge and strategies about designing and using performance-based and formative assessment, and how to teach the content knowledge more effectively (i.e., pedagogy). The interdependence and collegiality formed among the participating teachers enabled them to share challenges and struggles; the self-efficacy for teaching science was increased; and most importantly, there was an increase in students' science test scores when they were at fifth grade after their teacher participated in professional learning communities. Data are mostly qualitative, so this study does not provide clear learning trajectory of the teachers and students; however, the in-depth analysis of the conversations among teachers shows the positive changes in their knowledge, skills and practice, and dispositions. Yet, in order for a professional learning community to become successful and yield long-term changes in teacher practices, it may be critical to stage experiences by initiating it with an external facilitator (Garet, Porter, Desimone, Birman, & Yoon, 2001; Richmond & Manokore, 2010).

The membership of professional learning communities becomes an issue when teachers try to collaborate across sites or across school districts during the school year. Collaboration occurs most effectively when there are substantial opportunities for collaboration among teachers (Slavit, Homnlund-Nelson, & Kennedy, 2009). This suggests that collective participation in a professional development program with colleagues across grade levels within the same school district, within the same community, and within the same school building may be the most effective organization of professional learning communities (Michaels et aI., 2008). This will help teachers build structures and processes through which they can exchange information and knowledge related to teaching science.

CONCLUSIONS

Effective science education in early childhood must build upon children's powerful capacity for learning. It is necessary to support children's development of metacognitive skills in order for them to build the capacity to state, test, and revise their own hypotheses through scientific inquiry. Providing children with opportunities to make their implicit theories explicit through various modes of representation can enable teachers to understand children's theories and to provide experiences that challenge those theories when necessary. Ongoing assessment strategies that involve verbal as well as nonverbal opportunities for children to represent their understanding (i.e., through demonstrations or constructing models) help children to reflect on their own thinking and constitute evidence for learning. Teaching for conceptual change involves providing plentiful opportunities for deep discussions about core concepts in a classroom environment that values science processes and content and immerses children in the language and tools of science. We propose that student learning can be enhanced when the content and processes of science are made cohesive through a systems perspective because this perspective highlights the unity and interrelationships between all forms of science. A systems perspective can facilitate students' construction of knowledge and skills across grade levels, especially when connected to learning guidelines and standards.

Research evidence indicates that effective inquiry experiences include conceptual, epistemological, social, and procedural components as well as teacher guidance. Integration of science with other curricular domains can synergize learning while expanding the amount of time devoted to science without displacing other curricular domains. For example, science journals (Brenneman & Louro. 2008) and high-quality nonfiction literature (Sackes et al., 2009; Samarapungavan et al., 2008) have been effectively used in the context of science inquiry. Using mathematics in the context of science helps students to understand the relevance of mathematics to everyday life and questions of importance.

Early childhood teachers need confidence and PCK to effectively implement science activities. Enhancing PCK, focusing on the nature of science, and emphasizing the importance of social processes such as collaboration, argument, and communication can provide teachers with tools and greater confidence implementing science effectively. Professional development focusing on teaching for conceptual change should include specific guidance for teachers on how to facilitate concept development, provide effective feedback, and model language representing science concepts and processes. Research indicates that professional development is most effective when it is intensive and cohesive and includes ongoing support in the form of mentoring or coaching as teachers apply and reflect upon their learning in the classroom context. Just as students can benefit from the cohesion of a systems perspective, teachers can also benefit from understanding the interdependence of systems. Whenever possible, professional development that builds a professional community and culture that shares the values and vision of effective science education can help teachers to transform their practice.

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