Kathy Cabe Trundle · Mesut Saçkes
*Editors*

# Research in Early Childhood Science Education

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# Foreword

This comprehensive set of chapters addresses the full range of challenges involved in STEM education for young children. Together the 15 chapters offer careful and comprehensive examinations of currently available research on young children's acquisition of knowledge of the sciences. In addition, the various difficulties involved in helping young children to understand the basic explanations of the vast range of the complexities of our universe that took thousands of years for human beings to understand.

One of the themes that re-occurs in many of the chapters is that the fairly typical willingness if not eagerness of young children to grasp some of the basics of scientific knowledge rarely persists into adolescence. This frequent decline of interest and motivation to study science is regrettable for many reasons. Among them is not only the potential usefulness of scientific knowledge in future careers, but also the significance of acquiring the disposition to appreciate – throughout life – the importance of supporting the work of all scientists for all of us. Clearly more research is needed to help us address this decline of motivation to study the sciences. It is a provocative finding in that the overall goals of science education are not just to create a nation of world-renowned prize-winning scientists, but to ensure that we are a nation that grasps the basic relevance and usefulness of all the sciences for the protection of our living and non-living environments.

Many useful references throughout the chapters are made to what is known about effective teaching strategies. For example, the importance of provoking children's thinking by raising searching and speculative questions rather than interrogatory ones is discussed. For example, to probe the thinking of a young child who indicates and enthusiastically reports that she has seen some ice cubes have melted, a teacher could ask, in a casual way, something like "any ideas about how that happened?" rather than "What made the ice cubes melt?" The latter probing type of question is more likely to engage young children in trying to think of possible solution and answer to the question rather than attempting to guess the answer the adult is waiting for. Unfortunately, interrogatory questions have a very long tradition in all teaching of all ages of learners.

Research reported here indicates that only by the age of 9 years can most children begin to understand the complex relationships of clouds and wind and air in its various forms – concepts that took human beings many years to grasp.

Questions are also raised in various chapters about the extent to which teacher training should include more and deeper education in the sciences. It is made clear by much of the research referred to in several chapters that the majority of teachers of young children could substantially improve the effectiveness of their science teaching if their own training had emphasized much greater depth of understanding in their science education.

A careful and instructive reviews of the available evidence concerning the science education of young children with special needs, as well as for young children just learning a second language, are included in this volume. This volume also discusses the long tradition of emphasizing and valuing the wide variety of kinds of learning young children gain through play.

The final chapter addresses the complex issues involved in the assessment of children's understanding of science at all ages, and hopefully will provoke more members of the education profession to experiment, to devise and share their improved teaching strategies and their better methods of assessing their effectiveness. Furthermore, the fact that authors with the experience of teaching in countries other than the USA supports the view that the concepts and ideas presented are common to childhood in many places.

I see this book as a national text for early childhood and science education researchers, teacher educators, and teachers in training who will be teaching at the preschool and elementary level. It is also very rich in insights, examples, and suggestions for further research.

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# Contents

# Chapter 1
# The Inclusion of Science in Early Childhood Classrooms

**Kathy Cabe Trundle**

> A child's world is fresh and new and beautiful, full of wonder and excitement. It is our misfortune that for most of us that clear-eyed vision, that true instinct for what is beautiful and awe-inspiring, is dimmed and even lost before we reach adulthood.
>
> I sincerely believe that for the child… it is not half so important to know as to feel. If facts are the seeds that later produce knowledge and wisdom, then the emotions and the impressions of the senses are the fertile soil in which the seeds must grow. The years of early childhood are the time to prepare the soil. Once the emotions have been aroused—a sense of the beautiful, the excitement of the new and the unknown, a feeling of sympathy, pity, admiration or love—then we wish for knowledge about the subject of our emotional response. Once found, it has lasting meaning. It is more important to pave the way for the child to want to know than to put him on a diet of facts he is not ready to assimilate.
>
> *The Sense of Wonder* (Carson, 1999)

## Science and the Early Childhood Years

If you have ever watched young children at play, you know that they are innately curious about everything around them. They enjoy exploring and discovering, and they instinctively ask many questions—why, how, where, and when. They can be fearless in their experimentation because they are not afraid to "fail," to realize their ideas did not work-out the way they expected. They simply take what they learned, revise their thinking, ask new questions, and try again. Children enjoy observing and thinking about the natural world (Eshach & Fried, 2005; Ramey-Gassert, 1997), and they are highly motivated to explore their environments (French, 2004). This disposition toward exploration is important for children's development. Research

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on child development indicates that young children need external stimuli to develop to their full potential cognitively, emotionally, and socially (Hadzigeorgiou, 2002).

In short, our anecdotal observations and current research results indicate that young children are natural scientists. Thus, science should be included in early childhood curricula and classrooms. Traditional science instruction, however, tends to be didactic, textbook or text oriented, and focused on rote memorization of isolated facts. Tragically, what often happens in schools with young learners and their passion for science is that we institutionalize the wonder out of children. No one works harder than elementary and early childhood teachers, and I certainly am not criticizing teachers. Rather, I offer the observation that young children come into preschool to begin their more formalized learning full of wonder and excitement for science. However, too many standards and inappropriate pedagogies often cause teachers to forget what they know about children and how to effectively teach them. Children's dispositions can be damaged by instruction if it is too intense, too early, and too formal. Children may learn academic details at the expense of the dispositions to use them (Katz, Chard, & Kogan 2014).

Ineffectively teaching science yields consequences. Achievement gaps provide one example. Science achievement gaps have slowly narrowed over the past 30 years, but they still persist. Lee (2005) describes these gaps as "alarmingly congruent over time and across studies" (p. 435). The National Science Foundation reported that gaps in enrollment for science courses, college majors, and career choices also persist across racial and ethnic groups, socio-economic status, and gender (National Science Foundation, 2001 and 2002). Scholars have linked difficulties in science learning with students' decisions to not pursue advanced degrees or careers in science (Mbamalu, 2001).

The bad news is that, in general, we are not teaching science well or effectively for young children (Saçkes, Trundle, Bell, & O'Connell, 2011). As such, we cause them to dislike science, and early difficulties have long term implications, including later academic and career choices. Researchers have found that poor science instruction at the early childhood ages contributes to negative student attitudes and performance, and these problems persist beyond the middle and high school years (Mullis & Jenkins, 1988).

Research results also offer some good news for early childhood science education. Eshach and Fried (2005) suggest that effective early science experiences help develop positive attitudes toward science and a better foundation for scientific concepts to be studied later in their education. We must build on the foundation children bring to us as they enter preschool, and we must facilitate and nurture their curiosity and wonder through the early childhood years.

## Purpose and Rationale

Science education, an integral part of national and state standards for early childhood classrooms, encompasses content-based instruction as well as process skills, creativity, experimentation, and problem-solving. By introducing science in developmentally appropriate ways, we can support young children's sensory explorations of their world and provide foundational knowledge and skills for lifelong science learning as well as an appreciation of nature. This book emphasizes the significance of teaching science in early childhood classrooms, reviews the research on what young children are likely to know about science, and provides key points on effectively teaching young children science. We include a summary of research on children's ideas, including misconceptions, about science concepts across all domains (e.g., earth and space, life, and physical), young learners' conceptions of the nature of science, and children's process and technology skills. We provide an analysis of science instructional interventions and assessments in early childhood settings, include a critical analysis of methodologies used in science education research in early childhood contexts, and provide suggestions for future research in early childhood science education and implications for classroom instruction.

Our goal for this book was to answer the following questions:

(a) What does the research tell us about topics related to early childhood education?
(b) What overarching theoretical framework guides this body of knowledge?
(c) What do we know about the development in children's conceptual understandings of the targeted concepts in each specific area?
(d) What common research methods are used in the reviewed studies? What, if any, are the methodological concerns with the studies reviewed?
(e) Where can/should the research go from here in terms of methodological or theoretical advancements?
(f) How can/is this knowledge relevant to classroom teaching practices?

## Organization of Chapters

After identifying the key content to include in this book, we contacted top scholars in each area and invited them to contribute a chapter. In addition to our own contributions as editors, 28 authors generated robust accounts of research that focus on engaging young learners with science concepts. All chapters were peer-reviewed and thoroughly vetted.

The chapters are organized around unifying themes of: children's motivations for learning science (Chap. 2), children's ideas across the domains of science (Chaps. 3, 4, and 5), children's development of science related dispositions and skills (Chaps. 6, 7, and 8), the interface between science learning with logico-mathematical knowledge and literacy (Chaps. 9 and 10), the importance of play in science learning (Chap. 11), curriculum considerations (Chaps. 12 and 13), teaching special populations of young children (Chaps. 14 and 15), and assessment in early childhood science education (Chap. 16).

Helen Partick and Panayota Mantzicopoulos (Purdue University) begin our discussion with a focus on the important role of motivation in science learning. They contrast the difference in motivation for engaging with science during the early childhood years compared to middle and high school students, and they discuss the findings as well as limitations of the research in this area.

The next section addresses learning across the domains of Earth and Space, Physical, and Life Science. Mesut Saçkes (Balıkesir University) provides a rich review and critique of research on children's ideas about Earth and Space concepts, including meteorological phenomena (clouds, rainfall, evaporation, condensation, wind, thunder, lightning) , earth materials and processes (rocks, soils), and space science concepts (shape of Earth, day and night cycle, seasons, moon phases and their cause). He suggests directions for future research, including limitations of current studies. Yannis Hadzigeorgiou's (University of the Aegean) review of the research in the area of Physical Science includes the concepts of matter, heat and temperature, processes of the water cycle, force and motion, floating and sinking, electricity, and light. He also provides a detailed overview of the theoretical perspectives that guide the research in this area, research methodologies used, effectiveness of instructional interventions, and implications for classroom practices along with suggestions for directions of future research. Valarie Akerson (Indiana University), Ingrid Weiland (University of Louisville), and Khadija Fouad (Indiana University) review and critique the research on children's idea about the Life Science concepts of living vs. non-living , growth and development, germs and contagions, plants, and animals. These scholars provide an overview of methods used in this area, and they suggest directions for future research as well as implications for teaching.

In addition to the content areas or domains of science, scientific literacy includes the nature of science and science process skills. Randy Bell and Tyler St. Clair (Oregon State University) begin this section by providing a definition of the nature of science and a rationale for why it should be included in classroom instruction. They review the literature related to conceptions of the nature of science held by young children and their teachers, the effectiveness of instruction, and assessments in this area. Jamie Jirout (Rhodes College) and Corinne Zimmerman (Illinois State University) continue the discussion with a critique of the research on the development of science process skills, including children's natural curiosity, dealing with and investigating uncertainty, and related instructional interventions. Sedat Uçar (Çukurova University) looks at the research on using technology to teach young children science and the integration of technology into inquiry. He includes research on early childhood teachers and their use of technology in the classroom.

The next section includes discussions on the interface between science learning with logico-mathematical knowledge and literacy. Constance Kamii (University of Alabama at Birmingham), who argues that young children's knowledge is not differentiated into academic subjects, describes six physical-knowledge activities based on Piagetian theory, and she provides a review of the research on the effectiveness of these activities. Laura Smolkin (University of Virginia) and Carol Donnovan (University of Alabama) discuss the integration of science and literacy. Their review of the research in this area includes the types of science texts designed for young children (e.g., commercially produced texts and tradebooks), the integration of text and science inquiry, and methodological concerns in this area.

The importance of play in young children's development and learning has long been recognized by early childhood researchers and experts. Berrin Akman

(Hacettepe University) and Sinem Güçhan Özgül (Balıkesir University) begin the discussion of the role of play in science learning by defining play from different theoretical perspectives, including a description of modern play theories. They also review the research on play and cognitive development, look at play as a pedagogical tool, critique the effectiveness of play and exploration in interventions, and suggest directions for future research in this area.

Ala Samarapungavan (Purdue), Deborah Tippins (University of Georgia), and Lynn Bryan (Purdue) provide a modeling-based inquiry framework for the teaching and learning of science in early childhood classrooms, and they discuss theoretical and instructional implications of the model. Deborah J. Tippins, Stacey Neuharth-Pritchett, and Debra Mitchell (University of Georgia) discuss the importance of including authentic nature experiences in early childhood programs. These scholars review research on practices that connect young children with their local environments, and they discuss the implications of these types of experiences.

The next section focuses on teaching science with special populations, including those with special needs and emergent bilinguals. Sheila Alber-Morgan, Mary R. Sawyer, and Heather Lynnine Miller (Ohio State University) review the research related to young children with special needs and their science learning. They discuss the research methodologies, including contexts for science learning, research designs, dependent and independent variables, and effects. They also suggest implications for classroom practice along with directions for future research. Leslie Moore and Mandy McCormick Smith (Ohio State University) continue the discussion with a focus on young emergent bilinguals. These scholars discuss the theoretical frameworks and methods used in this area of research and provide a review and critique of the research literature, including the areas of curriculum development, teacher perceptions and professional development, effectiveness of instructional interventions, and classroom interactions. They also provide classroom and research implications.

Daryl Greenfield (University of Miami) concludes our discussion with a critique of assessment in early childhood science education. He provides a conceptual framework to guide assessment in early childhood science, a discussion of what science competence means during the early years, and a review and critique of research on science assessments.

## Closure

This volume documents and suggests that young children are capable of benefiting from early science learning experiences. Developmentally appropriate science learning experiences offer opportunities for children to develop foundational attitudes, skills, and concepts that promote and sustain their motivation to pursue the learning of more advanced science concepts.

No single book can cover every facet of any given topic. Likewise, our efforts, while comprehensive and rigorous, undoubtedly omitted some aspect of science education at the early childhood level that you, as the reader, believe should have been included. However, we are certain that the main message of this volume will be embraced and endorsed by members of the early childhood and science education communities: young children are natural explorers, and we, as early childhood educators and researchers, have a responsibility to sustain and capitalize on the innate curiosity children entrust to us. We hope this book helps spread this message, stimulates more research, and supports young children's learning of science. Together we can protect and keep the sense of wonder in science learning.

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# Chapter 2
# Young Children's Motivation for Learning Science

**Helen Patrick and Panayota Mantzicopoulos**

Young children generally epitomize motivated learners. They are interested in everything around them, are optimistic that they can learn more and improve their skills, and are usually not deterred by experiencing initial difficulties or failures (Freedman-Doan et al., 2000). However, after children begin school their initial enjoyment of learning declines, as does their view of themselves as being competent and able to master concepts and skills (Eccles, Wigfield, Harold, & Blumenfeld, 1993; Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002). This motivational decline continues throughout schooling, or at least in the case of reading and math (Archambault, Eccles, & Vida, 2010; Jacobs et al., 2002). Surprisingly little is known about children's motivation for learning science during the early school years (Mantzicopoulos & Patrick, 2013). What *is* well documented is that young children begin school with an avid interest in science (Brown, 1997; Chouinard, 2007), but by the middle and high school grades are considerably less positive about the subject (Gottfried, Marcoulides, Gottfried, & Oliver, 2009; Hendley, Stables, & Stables, 1996; Vedder-Weiss & Fortus, 2011). What happens between those points—the trajectories that children's science motivation typically take, reasons for those trajectories, and the practices that tend to sustain or stifle science motivation—has received very little attention by researchers.

The dearth of empirical research about young children's motivation for science is quite striking. Perhaps because of efforts to increase the number and diversity of people in STEM-related careers (e.g., National Academy of Sciences & National Academy of Engineering, and Institute of Medicine, 2010), most science motivation research involves students in high school (e.g., Aschbacher, Li, & Roth, 2010; Britner, 2008; Cleaves, 2005; Nieswandt, 2007) or college (e.g., Black & Deci, 2000; Hernandez, Schultz, Estrada, Woodcock, & Chance, 2013; Sadler, Sonnert,

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Hazari, & Tai, 2012)—the time when educational and vocational decisions predominate. Researchers have also addressed students' science motivation in the middle grades (i.e., 5th–8th; e.g., Britner & Pajares, 2006; Lee & Brophy, 1996; Swarat, Ortony, & Revelle, 2012; Vedder-Weiss & Fortus, 2011), possibly reflecting the importance of adolescence in terms of the development of personal, academic, and vocational identities (Schwartz, 2001). For the most part, motivation is not the focus of science research until science instruction is routinely included in curricula schedules and testing programs, usually in 3rd or 4th grade.

However, what if children's science motivation typically begins to decline in the early school years, like it does with reading and math, rather than being an issue primarily during adolescence? Does children's motivation diminish even if the content area is not systematically taught? What if it is most effective to nurture and sustain, during the beginning grades, the enthusiasm for science that young children enter school with? And if so, what would such science instruction look like? These are just some of the many crucial questions still to be answered about young children's motivation for learning science.

In this chapter we provide an overview of the research findings about young children's motivation to learn and understand science-related concepts and processes. We also discuss the nature of this research, in terms of both its theoretical underpinnings and methodological approaches, and provide reasons for why research into young children's motivation is so vital. Finally, we consider implications of science motivation research for teaching practices used in preschool and the early school grades. First, however, we begin by briefly noting how we and other motivation researchers conceptualize motivation.

## Conceptualizing Motivation and Theoretical Frameworks

Motivation—what people are motivated to do and where they put their efforts—is expressed by their behaviors: the choices they make, energy they expend, the extent to which they persist at something, and the care and thoughtfulness that they put into their work. People with high quality motivation, therefore, take on challenges, put forth effort, continue with a problem, topic, or issue even after making errors or incurring set-backs, and use strategies thoughtfully. It is no wonder, then, that high motivation is associated with learning and achievement (Schunk, Pintrich, & Meece, 2008)!

People who, from their behavior, appear highly motivated also hold particular beliefs about what it is they are motivated to do. They believe that the activity process or its outcome (or both!) is worthwhile, important, interesting, or enjoyable, and that they are good at the activity or will become skilled with practice (Schunk et al., 2008). It is these beliefs, therefore, that fuel the behavior we noted in the previous paragraph.

The predominant theories of motivation are social-cognitive. That is, they emphasize the primacy of individuals' perceptions and beliefs in influencing their behavior. Motivated behavior, according to these theories, depends in large part on how individuals construe: (1) the *task or subject* (e.g., how enjoyable, interesting, useful, important, or difficult is it?), (2) their own *ability or skills* (e.g., are they likely to succeed, how hard will they have to work, will they likely perform significantly better or worse than others?), (3) their *goals and desires*, (4) the *likely consequences* of their success or failure (e.g., not being accepted for a coveted position, receiving financial rewards, being ridiculed or disparaged) and (5) *reactions of people* around them (will someone be available to help if necessary, will social relationships be affected by their performance?) (for reviews see Graham & Weiner, 2012; Wigfield, Eccles, Schiefele, Roeser, & Davis-Kean, 2006).

In line with the indicators of motivation and beliefs related to them, motivation researchers investigate a range of students' behaviors and beliefs. Although all motivational theories seek to explain the same types of behavior (e.g., choices, persistence, effort), they focus on different beliefs (e.g., self-efficacy or self-competence, importance of the task or subject, current enjoyment or future desires, personal and situational interest). Therefore, findings have to be synthesized across multiple theories. In doing so, what does research tell us about young children's motivational beliefs and behavior towards learning science?

## Children's Science Motivation During Preschool and the Early Grades

Although research directly addressing young children's science motivation in early educational settings is sparse, there is a considerable body of developmental research that establishes that young children are inherently motivated to learn about science.

### *Children's Curiosity and Questions About Science*

Young children are intrinsically interested in the world around them, as reflected by the number and types of questions that they ask (Brown, 1997; Piaget, 1955). Children seem to ask questions almost incessantly. When talking with adults, young children ask between 76 and 95 information-seeking questions per hour—an average of about three questions every 2 min! (Chouinard, 2007). Some of their questions involve physical science and technology, such as, "How does the barcode in the supermarket work?" (Baram-Tsabari, Sethi, Bry, & Yarden, 2006, p. 808). Young children, however, are especially curious about the natural world.

The questions that young children ask indicate that they wonder about a diverse range of natural phenomena that cover all science content areas—life science, physical science, Earth and space science, and technology. These wonderings include: what makes flowers grow in the summer, how do clouds or rainbows form, why does rain fall, why do babies stay inside their mothers for so long, why don't animals use words, where does the sky end, and what is the difference between shooting stars and regular stars (Baram-Tsabari & Yarden, 2005; Callannan & Jipson, 2001; Mantzicopoulos & Patrick, 2008; Patrick & Mantzicopoulos, 2014; Perez-Granados & Callanan, 1997; Piaget, 1955; Przetacznik-Gierowska & Ligeza, 1990). Even before the onset of formal schooling, young children show remarkable sensitivity to the biological world and are capable of using "a variety of high-level causal and relational patterns" to reason about living things (National Research National Research Council, 2007, p. 69). This intense interest in the natural world is believed to be due to children's unique, innately controlled tendency to seek information and learn about nature in general (Chouinard, 2007; Lee, 2012; Piaget, 1955).

## *Children's Interest in Science Activities*

In addition to the wealth of research from developmental psychologists, there are some studies that document children's motivation for science within formal educational settings. The latter information, however, must sometimes be extracted from larger studies about what children do in school, rather than being presented explicitly as evidence that addresses some aspect of young children's science motivation.

**Science Books**. Young children are interested in reading informational books about science topics, and enjoy them as much as or more than fictional stories (Caswell & Duke, 1998; Donovan, Smolkin, & Lomax, 2000; Mohr, 2006; Pappas, 1993; Price, Bradley, & Smith, 2012). For example, preschool teachers judged their students as being equally attentive, and showing comparable enjoyment, while reading a novel story book about dogs, pigs, cats, or bats compared to reading a new informational science book on the same subject (Price et al., 2012). Also showing the popularity of non-fiction science, first graders preferred overwhelmingly the one non-fiction science book from a selection that included diverse genres—realistic and fantasy fiction, informational books, humor, and poetry (Mohr, 2006). Specifically, children were individually shown nine picture books spanning different topics and genres (five fiction, four non-fiction), all of which were of high quality, had full-color illustrations, and were recommended by experts in children's literature. When students were told they could keep one book, almost half (46 %) of the 190 children chose the informational book *Animals that Nobody Loves*. No information was reported about why this book was the most popular.

As part of our research on young children's use of informational books we have found that kindergarteners enjoy reading expository books about a range of science topics, in addition to being able to understand their content (Mantzicopoulos & Patrick, 2010; Patrick & Mantzicopoulos, 2014). As one example, after we read excerpts from each of four science books, individually to children, we asked them whether or not they would like to read another book on the same topic. Two of the excerpts addressed biology—*Dolphins* (about a mother and baby dolphin) and *Fins, wings, and legs* (about structures that enable animals to move); one excerpt involved physical science—*What is a lever?* (about a seesaw or teeter-totter being a simple machine); and one involved Earth and space science—*Light* (about the sun and Earth). The length and complexity of the excerpts were comparable with each other and each was accompanied by a color photo also from the book. After we read each excerpt we asked each child, *"If I had a longer book like the one we just read, would you like to read it?"* Most children expressed clear interest in each of the books. Approximately two-thirds said they would like to read a longer book similar to the texts *Dolphins*, *Fins, wings, and legs*, and *Light* (70 %, 66 %, and 68 %, respectively). More than half of them (56 %) expressed interest in reading another book like *What is a lever?* Of additional interest, girls and boys were equally keen to read more about each of the science topics. Although this study was focused on informational texts, and therefore does not provide data on how children's informational book preferences compare to fictional book preferences, the evidence clearly highlights children's early interests in informational genres.

**Science Centers.** Young children also enjoy engaging in activities that involve science. Early childhood classrooms typically include a nature table or science center as one of the areas that children can choose to play at. In analyzing how children spent their free choice time in preschool—almost one-third (29 %) of total time—Early et al. (2010) found that science activities were popular. The children spent 15 % of their free time engaged in science activities—playing with mirrors, magnets, sand, or water, or reading science books. This is comparable with their time spent on other enjoyable activities: 16 % in art (music, painting, clay, playing instruments), 16 % in gross motor activities (e.g., running, playing ball, jumping), and 17 % on fine motor activities (e.g., cutting, stringing beads). The evidence is similar in kindergarten classrooms. Spending free time in science areas (water and sand table, science and nature area) is a popular choice for children, even though teachers use science materials infrequently during structured lessons (Saçkes, Trundle, Bell, & O'Connell, 2011).

Interest in science centers may require that children find the materials attractive, can recognize the materials or equipment and know how to use them, and view the contents as appropriate for them. Familiarity with the science materials as it relates to children's interest and use was examined by Nayfield and her colleagues (Nayfeld, Brenneman, & Gelman, 2011), after evidence that the science areas of six preschool classes were empty more than three-quarters of the time. After baseline measurements, the children in three of the classes participated in two lessons during which they were introduced to the balance scale that was present in each of the centers, and discussed how it can be used and why it is useful. The center attracted enormous interest, and children's use of the science area increased dramatically compared to pre-intervention levels. The science area was also used significantly more than in comparable classrooms, where the balance scale was also present but had not been targeted as a lesson topic.

The studies referred to in this section examined children's motivated behavior, but not their beliefs surrounding their behavior, therefore we can only speculate about reasons for their choices. Other research, however, has asked children directly about their motivation-related beliefs (e.g., enjoyment, perceived competence, and expectations).

## *Children's Motivational Beliefs About Learning Science*

Children in kindergarten typically begin the year with positive, optimistic beliefs about the science they will learn during the year, and express comparable levels of confidence for learning about reading and math. Approximately 80 % of the children from different kindergarten classrooms told us that they expected to learn content pertaining to science (e.g., "In school we will learn about how living things grow," "…we will learn how to make observations")—a similar number to the approximately 90 % who expected to learn "about letters… numbers…shapes … [and] books" (Mantzicopoulos, Patrick, & Samarapungavan, 2013, p. 78).

Despite an expectation that they would learn science, kindergarteners reported at the end of the year learning very little, if any, science (we discuss this finding in a later section). This perception, though, may explain why the children reported, on average, low levels of competence in terms of knowing both science content and processes (e.g., "I know why living things camouflage," "I know how to use different tools to learn about science."). Their mean perceived competence (scored from 0 to 1) ranged from .28 to .37 across different samples (Mantzicopoulos et al., 2013; Samarapungavan, Patrick & Mantzicopoulos, 2011). At the end of kindergarten children expressed moderate enjoyment of science. Specifically, we asked different samples of kindergarteners whether or not they agree with statements such as "I have fun learning about the animals that live in the ocean," "I want to know more about living things," and "I like using different science tools." Their mean enjoyment ranged from .59 to .60 on a 0-1 scale (Mantzicopoulos et al., 2013; Samarapungavan, Patrick, & Mantzicopoulos, 2011).

Our study did not provide comparable data on children's perceived competence and enjoyment of reading and math. There is evidence, however, that children in kindergarten through 3rd grade believe, on average, that they are more competent in math than life science, and also more competent at math, reading, and life science than physical science (Andre, Whigham, Hendrickson, & Chambers, 1999). They also like life science as much as math and reading, but like physical science less than those subjects (Andre et al., 1999). Because these results were not reported separately by grade level, it is unknown whether there are differences in motivational beliefs about science between kindergarten and 3rd grade.

## Changes in Science Motivation from the Early to Later Grades

There is ample evidence that by the middle- and high-school grades children have typically lost much of the zeal for science characteristic of young children (e.g., Gottfried, Fleming, & Gottfried, 2001; Watson, McEwen, & Dawson, 1994).

Intrinsic motivation for science declined longitudinally in a linear fashion from the time children were 9 years old to subsequent testing at 10, 13, and 16 years (Gottfried et al., 2001). This finding was replicated in a cross-sectional study of science motivation. Specifically, in comparing 3rd through 12th graders' attitudes towards science, the most positive were expressed by 3rd and 4th graders, whereas 9th–12th graders were least positive; 5th–8th graders' attitudes fell between the two. The younger children (i.e., grades 3-4) also reported a significantly greater science self-concept than did the older students (Greenfield, 1996).

The relative interest in different areas of science also changes between early childhood and adolescence. For example, questions asked about physical science constitute a small proportion of the total questions submitted by students to Ask-a-Scientist web sites (Baram-Tsabari & Yarden, 2005). Interest in physical science, relative to other areas of science and technology, was greatest for young children; 7 % of the questions that children 8 years and younger submitted to Ask-a-Scientist web sites were about physics, compared to approximately 3.5 % of the questions asked by children aged 9 and older. This sizable decline is surprising. It is unlikely that upper elementary children ask fewer questions because they understand most of their physical world; it is more likely that they just wonder about it less. Given that experiences within a content area affect motivation—a point we discuss in the next section—the lower curiosity about physical science is perhaps due to the relative emphasis on life science topics in the early grades curriculum (Weiss, Pasley, Smith, Banilower, & Heck, 2003).

There is so much more to learn about young children's science motivation than it being generally high at the beginning of their school careers, and much lower 5 or 6 years later. How does their science motivation unfold from year to year? What kinds of trajectories are typical throughout? How flexible, and how resilient, is children's science motivation during the early school years? Can a dip in first grade be made up by an exceptional, or even a solidly good, second grade experience? Can some instructional practices retain or sustain children's motivation, and if so, what are they? Of all the questions, though, arguably the most important at present is: Why does young children's motivation decline?

## Experiences Shape Children's Motivation for Learning Science

Although considerably more research is needed, there is growing evidence that children's experiences with learning science are associated with their motivation in the subject, like it is in other academic areas such as reading and mathematics (Helmke & van Aken, 1995; Lerkkanen et al., 2012). Furthermore, evidence supports the argument that the typical decline in science motivation is not inevitable, but is related to the fact that young children have very few opportunities to engage in high-quality science activities. We discuss these two premises next.

The early experiences that children have with various school subjects influence the beliefs they hold about those subject areas and about themselves as learners of those subjects (Wigfield & Eccles, 2002). These beliefs, which contribute to motivation in important ways, include whether children view a subject as: being hard or easy for them, important for them to learn or not, appropriate for them to be learning (e.g., “It’s not what girls do,” “It’s not for children my age”), interesting or boring, and, something they are or can be good at.

Children develop their liking for particular subjects, and their perceptions of being good at those subjects, when they have ongoing, meaningful opportunities to engage in them. For example, instruction that focuses on developmentally appropriate, child-centered (rather than didactic, teacher-directed) approaches fosters children’s interest in reading and mathematics (e.g., Lerkkanen et al., 2012; Stipek, Feiler, Daniels, & Milburn, 1995). Also, positive early experiences with mathematics (e.g., success experiences) lead to children enjoying math and believing they are competent at it (Aunola, Leskinen, Onatsu-Arvilomni, & Nurmi, 2002; Chapman, Tunmer, & Pronchow, 2000; Helmke & van Aken, 1995).

Of interest, young children readily refer to their experiences when asked to reflect on their competence (i.e., beliefs that they are good at subjects such as reading, spelling, and writing). In their seminal study on the dimensionality of young children’s competence beliefs, Harter and Pike (1984) cited evidence that supports children’s understanding that experience is linked with motivation. Specifically, 96 % of the children’s responses to questions such as “How do you know you are good at reading (spelling, writing)” were descriptive statements about their experiences with the content area they believed they were good at (e.g., “I can write words like ‘cat’ and ‘dog’,” or “I can spell because I read a lot,” or “I read a lot at home,” or “My mom and dad helped learn how,” or “I do writing every day”, p. 1977).

Children also draw inferences that an academic area is valued when the teacher provides frequent opportunities to engage with a variety of tasks in that area (Turner, 1995). Therefore, when a subject is absent from the curriculum, children may easily infer that it is unimportant, inappropriate (e.g., too difficult), or irrelevant, at least for them. In the absence of meaningful learning experiences in academic content areas, children may not (a) develop positive beliefs about these areas (i.e., that they are interesting and worth learning about); and (b) think of themselves as having the ability to do well in subject-specific tasks.

Findings from our research show that young children’s competence beliefs and interest in science are dependent on their instructional experiences (Mantzicopoulos, Patrick, & Samarapungavan, 2008, 2013; Patrick, Mantzicopoulos, & Samarapungavan, 2009). Therefore, we have significant concerns about the effects that children’s typical science experiences in the early school years have on their motivational trajectories. Concerns include that: young children have few opportunities to engage in meaningful science; lessons are usually not identified as science; and the boundaries between science and other disciplines are typically blurred. We expand on these points next and their implications for motivation.

## *Few Opportunities to Engage in Meaningful Science*

For more than the last decade science has been virtually absent from the early grade curriculum (Blank, 2013; Marx & Harris, 2006). This is largely as a consequence of: (1) the national focus on early literacy, defined narrowly as reading competence (Marx & Harris, 2006; Rouge, Hansen, Muller, & Chien, 2008), and (2) schools' Adequate Yearly Progress being based only on English language arts (ELA) and math test scores (Judson, 2010). Other beliefs, such as that young children are concrete and unskilled thinkers who lack the readiness for engaging purposefully with science (Brown, Campione, Metz, & Ash, 1997), and that it is less important for children to learn science in the early grades than during the upper elementary grades (i.e., 4th–6th) (Andre et al., 1999), do not challenge the dominance of ELA. This situation may improve as states implement the Core Curriculum State Standards (CCSS), which integrate ELA with content areas, including science (National Governors Association [NGA] Center for Best Practices & Council of Chief State School Officers [CCSSO], 2010). However educators (e.g., International Reading Association, 2012) predict that it will take time for instructional practice to align with the CCSS.

There is substantial evidence that during preschool and the early grades, young children are afforded few opportunities for learning science. Science is taught infrequently (Fulp, 2002; National Institute of Child Health and Human Development, 2005; Saçkes et al., 2011; Tu, 2006; Weiss et al., 2003). Rather than involving practices that encourage children's rigorous and reflective science learning, instruction is usually infrequent, fragmented, and focused on decontextualized sets of skills (e.g., categorizing and classifying objects) that are thought to be foundational for science learning (Metz, 1995). However, the teaching of science as bits and pieces of discrete skills that are not integrated into a cohesive instructional framework is unlikely to promote learning about and understanding of the nature of science as a way of knowing about the world (Brown et al., 1997; Metz, 1995). Moreover, because meaningfully connected and sustained experiences with science are needed for children to develop both their knowledge and motivation in this subject (Mantziopoulos et al., 2013; Samarapungavan et al., 2011), piecemeal instructional approaches do not contribute to children developing positive motivational beliefs and behaviors about science.

Young children have the capacity to engage with science inquiry in meaningful ways (Zimmerman, 2007). Appropriate, contextualized, ongoing, and coherent science experiences promote children's science knowledge and their understanding of the process of inquiry (Samarapungavan et al., 2011); these experiences also nurture children's motivation. Rich and systematic science experiences promote the construction, organization, and maintenance of motivational belief systems about science, including science-specific self-perceptions (e.g., perceived competence, enjoyment) and perceptions about science (e.g., importance, difficulty). Therefore, when children do not have high-quality science-learning experiences their ability to maintain and develop motivation for science fades.

## *Low Disciplinary Integrity of Science Lessons*

In addition to being infrequent and presented as discrete sets of skills, when science *is* taught in the early grades it is often not recognizable as a content area separate from others (Dickinson & Young, 1998; Furtak & Alonzo, 2010). In particular, science is usually taught through art activities, or reading fiction. For example, kindergarten teachers we have worked with, when explaining what they typically did for science, told us:

> We do it [i.e., science] mainly through literature. . . like different books about animals. Talking about the weather, different books about the weather. I know we did 'Cloudy with a Chance of Meatballs.'
>
> When we did butterflies—I have a book called 'Katrina.' It's about a butterfly, and it's a song, so I would teach the kids the song and we would all make the butterfly paper.
>
> When we do fire safety, [another science theme] usually we make this HUGE cut-and-paste Sparky the Fire Dog with the rules. … And it's one of THE highlights of the whole fire safety unit. They take this dog home that's 3 feet tall.
>
> Now I would do [i.e., make] a bee, and they would too. And they could see the three body parts, and they would add the wings, and the six legs, and the antennae. So they actually do a little bee and then we hang 'em up in the classroom. So [we do] artsy kinds of things (Mantzicopoulos & Patrick, 2013).

Observational data with two different cohorts of kindergarteners also bear out the typical practice of infusing art and fiction liberally into science instruction (for different descriptions of science lessons and excerpts of discourse see Mantzicopoulos, Samarapungavan, & Patrick, 2009; Mantzicopoulos et al., 2013; Samarapungavan et al., 2011). It is important to note that the science lessons we observed were comparable with other researchers' accounts of typical science instruction in elementary school (Dickinson & Young, 1998; Furtak & Alonzo, 2010). Across the science lessons that teachers chose for us to observe, we watched, for example, children make: leaf rubbings; paper models of the pumpkin life cycle; books with pages representing each stage of the butterfly life cycle; spiders made from marshmallows, pretzels, and M&Ms (for head and body, legs, and eyes); snowflakes with crystals grown from saturated borax solutions; and a mouth of teeth by pasting mini marshmallows onto paper to represent two rows of teeth.

Throughout all of the science activities there were no instances of press for children's understanding, elaboration, or model articulation. Teachers made efforts (albeit infrequently) to prompt recall of facts that lead children to give one-word responses (e.g., "What comes after the egg?"—"Caterpillars"). Beyond these closed, low-level questions, there were neither instances of science-related discourse, nor evidence of teachers intentionally engaging children with the language and processes of science. Even when instruction included opportunities for children to represent their understandings (e.g., make a butterfly book), it simultaneously constrained them (e.g., "Your butterfly book is going to look like this") and focused their attention on neatness and appearances (e.g., "Do your very best to stay on the line," "Don't cut his antennas off," "[The caterpillar page is] going to be this bright orange page"; Mantzicopoulos et al., 2013, p. 98).

In addition to science lessons typically not emphasizing core science concepts and language, the teachers we observed did not identify science lessons to their students, as is usual with other subjects (e.g., “It’s time for math now,” “Take out your reading book,” or “When you get back from music it’ll be lunch time.”). Of the 22 science lessons that kindergarten teachers invited us to observe, the label “science” was used only by one teacher in two lessons. Instead, lessons were introduced by their topics, such as “learning about butterflies,” “germs,” “the ocean,” or “sinking and floating.”

## *Science Is Often Not Recognizable in Science Lessons*

Kindergarteners find it difficult to recognize that they are learning science at school—or at least those in our study did—quite possibly because lessons were not identified by the teacher as ‘science’ and/or the content appeared fanciful or art-based, rather than ‘scientific.’ It does not seem unreasonable to suspect that many 1st and 2nd graders may share the same position. Consider that science in the U.S. does not appear as a separate subject on report cards or require reporting by teachers until 3rd grade. When children do not recognize they are learning science, they have no opportunities, at least at school, to construct coherent notions about science as a discipline with content, norms, and processes that are distinct from other subject areas such are language arts or art.

Not recognizing science lessons when they do occur may explain why, at the end of kindergarten, children typically stated that they had learned very little science content and process (Mantzicopoulos et al., 2013; Samarapungavan et al., 2011). Only about 40 % of the children confirmed that they learned about living things or butterflies, making predictions or talking about science, or other science content and processes. In contrast, nearly 80 % of the children reported that they learned about reading and math.

Further evidence that young children generally do not appreciate the scope of topics that fall within the domain of science comes from other interviews with kindergarten children (Mantzicopoulos et al., 2009; Patrick et al., 2009). We asked young children, individually, from regular kindergarten classes whether or not they learn science at school. Of 70 children, the majority (83 %) told us they did not learn science. Twelve children (17 %) reported learning science at school, however only five mentioned science-related activities. Activities they misidentified as science include art, music, language arts, or math, as illustrated in the following quotes:

> We color. We write our names. We write stuff.
>
> Bugs. We just color them in, that’s all. (What do you learn?) About books. (What kinds of books?) “Sam I am” [i.e., a Dr. Seuss fictional book]. That’s all.
>
> Learning to make stuff. (Like what?) Dolphins, whales, the boat, alligators, sharks. (What do you do in science?) We kind of make them with paper and we paint them. We sing the alphabet. We do math (Mantzicopoulos et al., 2009, p. 359).

We were also interested in what kindergarteners understand science to be. We asked those who reported learning science what they learn about, and those who claimed to not learn science, what they would learn if they were taught science. A large proportion (43 of 70) said they didn't know what science is. Of the 27 children who described some type of science learning, only 19 actually involved an aspect of science (e.g., "Being healthy" or "Rain, sun, and clouds"). Inaccurate construals of elementary school science included:

> You have to be big to do science. If you're little, you'd get hurt. Do stuff with chemicals, like mix them up together and they'd blow up.
>
> They can make stuff. Like people who are frozen. Or make little people, or make little monsters. Or they can make little bubble gum or rocks.
>
> It's not for kindergarten. It's for big people. I really hope I can make stuff out of science, like flowers (Patrick et al., 2009, p. 181).

Our findings indicate that most children did not recognize the discipline of the lessons that were viewed by teachers as being science. This is not surprising, considering that science instruction typically comprised superficial and unconnected content that was often more art than science, as we illustrated in the previous section. Consistent with their experiences, these children had a superficial understanding of science, at best; they tended to see it as content that didn't apply to them. When we asked these children to tell us about science, they referred to conceptions that perhaps were developed from out-of-school experiences. Certainly, science is often portrayed in children's television shows, movies, and books as a dangerous venture involving unusual people (usually men, often the villain) who mix potions or create dastardly inventions.

Does it matter that children don't have accurate ideas of science? Yes! People don't hold beliefs in a vacuum. Motivational beliefs are connected integrally to the meanings that people develop for a discipline. For example, interest in a topic or subject necessarily involves an understanding of what that topic is—its inherent meaning for the individual (Renninger, 2000). Furthermore, the way that students conceptualize what they are learning relates directly to how they view themselves as learners (Patrick et al., 2009). For example, I am more likely to view science as important or useful if I believe that science is the process of asking and answering questions about the world around us, than if I believe that science is about "do[ing] stuff with chemicals, like mix them together and they'd blow up" (Mantzicopoulos et al., 2009, p. 359). The development of competence beliefs (i.e., believing that oneself has the ability to do well or will be successful at a task) is based on frames of reference that include the individual as a participant in meaningfully linked activities and events. Therefore, children are more likely to construct realistic conceptions of their competence from participating in authentic activities (i.e., they can consider themselves as competent observers following a nature walk during which they observed and recorded different living things) than from viewing fantastical stories about scientists making frozen people. We expect that children's interest in biological growth would develop more within the process of systematically observing, recording, and learning about the transformation of a caterpillar to butterfly or of a tadpole to frog, than from a story about making potions that transform rabbits into people, or children to grown-ups, or vice versa.

## *Declines in Science Motivation and Misunderstanding the Nature of Science Are Not Inevitable*

Our overview thus far of the course that children's trajectories of science motivation usually take is rather bleak. However, the good news is that this developmental course is not inevitable. Going back to the points at the beginning of this section, the development of motivation is contextually-situated (Mantzicopoulos & Patrick, 2013; Patrick & Mantzicopoulos, 2015), and therefore different approaches to science instruction are likely associated with different motivational patterns (see Vedder-Weiss & Fortus, 2011, for evidence from middle grades).

From our research we have shown that a year-long conceptually rich, personally meaningful, inquiry-based, and literacy-infused science program (i.e., Scientific Literacy Project, [SLP], 2009) results in significantly greater science motivation for kindergarteners, compared to the motivation of children not receiving this program of activities (Mantzicopoulos et al., 2009, 2013; Patrick et al., 2009; Samarapungavan et al., 2011). Furthermore, and relatedly, children develop a significantly more accurate understanding of what science involves, and recognize that they can and do learn science (Mantzicopoulos et al., 2009; Patrick et al., 2009). For example, after engaging in SLP for a year, 88 % of the SLP children gave an explanation of science that included content or processes relevant to the discipline (compared with 27 % of comparable students without SLP lessons). Examples of the SLP children's description of science include the following:

> People do science stuff to help them to know about things that lives [sic]—live in shells, like snails, crabs, and turtles (Patrick et al., 2009, p. 181).
>
> (What do you do in science?) Well, we see what's in our fish tank. We saw snails, anemone, rocks, and the temperature thing, I think it's called a thermometer. (What happens in science?) You learn all kinds of things. You learn more about things. Read science books and learn more. You can figure things out, like what goes faster and slower and see if something can go higher than another one (Mantzicopoulos et al., 2009, p. 251, 353).
>
> We learn how to predict and be a scientist. We predict what's going to happen, and if it happens, our prediction is right (Mantzicopoulos et al., 2009, p. 352).

Although the results from our SLP project are strong and have been replicated across different samples, it would be preferable to have concurring evidence from other researchers. However, we are not aware of other research that examines the effects that particular science instructional approaches have on young children's science motivation in the early grades.

Most science programs developed for children in preschool or the early elementary grades have investigated some aspects of children's learning (e.g., French, 2004; Gelman & Brenneman, 2004; Klein, Hammrich, Bloom, & Ragins, 2000;

Peterson & French, 2008; Shymansky, Yore, & Anderson, 2004; Varelas & Pappas, 2006; Vitale & Romance, 2012). We argue, though, that *children's motivation is every bit as important as their learning*. In fact, the present situation in the U.S. of too few people with sufficient ability choosing science careers fundamentally reflects a motivational problem! Therefore, we see an urgent need for more empirical research on motivational outcomes of young children's science instruction, and for evidence that new curricula benefit children's motivation as well as learning. We turn next to consider how researchers have measured young children's motivation to learn about science, and note methodological and analytic concerns we have about this line of research in general.

## Measuring Young Children's Science Motivation

### *Methodological Approaches*

Motivation to learn science is usually measured with self-report surveys for children in the upper elementary grades and beyond (e.g., Beghetto & Baxter, 2012; Denissen, Zarrett, & Eccles, 2007; Lamb, Annetta, Meldrum, & Vallett, 2012; Vedder-Weiss & Fortus, 2011; Wenner, 2003), however this method is rare during the early grades. More often, researchers infer motivation from children's behavior—whether observed live or deduced from physical records—or they ask teachers or parents to rate children's motivation. We describe and provide examples of each method next.

**Observation.** A prominent method for investigating young children's motivation for science involves using observational measures to document behavior, particularly the behavioral indicators of motivation we outlined at the beginning of this chapter. Motivation is inferred from children's *choice* of activities when they have different options available. For example, during live classroom observations Nayfield and her colleagues (2011) used time-sampling to record every 60 s how many children and teachers were at the science center and what they were doing. These data were used to calculate the proportion of available minutes that teachers and children spent in the science area, in addition to the "child minutes", or "the number of students present there during each minute that the area was occupied" (p. 980). Minutes per activity may be recorded separately for individual children, aggregated across groups (e.g., sex), or be a composite of the entire class, depending on the unit of interest. Similarly, *persistence*, or the amount of time children stay at any activity rather than moving on to another, can be calculated from observations. Although we did not find studies about young children's science motivation that used this method, it would involve differentiating among children and noting the time that each arrived at and left a science area generally, or began and stopped engaging in a specific activity.

Another way to measure young children's motivation is by observing their facial and verbal expressions during activities, in order to infer their motivation-related affect (e.g., interest, pride, shame). Examples, albeit not in the science domain, come from investigations of preschoolers' and kindergarteners' motivation and behavior while engaging in challenging puzzle and trivia tasks (Berhenke, Miller, Brown, Seifer, & Dickstein, 2011; Stipek et al., 1995). We are not aware of studies where this method was used to examine motivation for science. However, this method has the potential to provide additional, descriptive information about children's motivation and engagement during science.

**Physical Records.** Other times physical records of children's choices are collected at a later point and analyzed, such as investigating how many children choose to carry out an optional science fair project (Adamson, Foster, Roark, & Reed, 1998) or accessing library records to identify the most popular types of books. When all options involve science, researchers can differentiate among various specialties. Examples include noting whether a science project addresses a question relating to the biological or physical sciences (Adamson et al., 1998), or whether a question submitted to an Ask-A-Scientist website represents Biology, Physics, Chemistry, Earth sciences, Astrophysics, Nature of Science, or Technology (Baram-Tsabari & Yarden, 2005).

**Teacher or Parent Reports.** Researchers sometimes ask adults to rate young children's interest or motivation, based on the assumption that adults gain this knowledge from regular interactions with children. Additionally, secondary data analysis may be conducted using large, existing data sets, such as the Early Childhood Longitudinal Study (ECLS-K). Although this approach provides large and usually representative samples, with limited cost, a downside is that items may not match the construct of interest closely or be specific to science. For example, using the ECLS-K dataset, Saçkes et al (2011) created a measure of "children's motivation to benefit from instruction" (p. 223) using four content-independent items referring to children's "attentiveness, persistence, eagerness to learn, learning independence, flexibility, and organization" (p. 223).

We have developed the Teacher Rating Scale of Children's Motivation for Science (TRMS; Patrick & Mantzicopoulos, 2008) that, as indicated by factor analysis, consists of two sub-scales (Mantzicopoulos et al., 2013). The Interest in Learning Science subscale has seven items that assess teacher perceptions of how interested children are in science (e.g., "How excited or enthusiastic is he/she during science?" "How hard does he/she try in science?"). The Need for Support vs. Independence for Learning Science subscale, also with seven items, reflects teacher perceptions of children's independence versus their need for support during science learning (e.g., "How much support does he/she need from you in science?" "How much encouragement does he/she need from you in science?"). Teacher reports of kindergarteners have been internally consistent (alphas >.90) for both subscales.

Another group of adults sometimes asked to evaluate children's motivation for science are the children's parents. To measure children's interest in science Alexander and her colleagues documented parents' reports of the activities their children engaged in (Alexander, Johnson, & Kelly, 2012). This longitudinal study continued for 3 years, beginning when their children were 4 years old. Researchers contacted parents every 2 months during the first year of the project, then at 4 month intervals, and recorded parents' estimates of their children's science-related interests, preferred activities, and behaviors. These included children's favorite free-time play activities (including lists of favorite science-related TV shows), whether children had a focused interest in a science topic (e.g., dinosaurs, rocks, cars), the frequency of children's questions about science, and the apparent inspiration for those questions (e.g., book, TV program, a community activity). A less complex approach to measuring young children's science interest has been to ask parents to rate how much their child likes science (Andre et al., 1999).

Because parents' beliefs about their children's ability in different activities and subjects influence children's own perceived ability or competence (e.g., Frome & Eccles, 1998), parents may be asked to assess children's ability or about their expectations for their children. For example, Andre and his colleagues (1999) asked parents "How well do you expect your child to perform in [science]?" (p. 727).

Scales developed for teachers and parents to rate children's competence in different subject areas have been developed by Eccles, Wigfield, and their colleagues. These scales have referred to children in 1st grade onwards, and their scores exhibit good reliability (alphas >.80 across multiple samples) and validity (e.g., form independent factors). Although studies about children in early grades have asked adults to rate reading, sports, music, and arts competence (e.g., Fredricks & Eccles, 2002; Wigfield et al., 1997), the items could be easily used to address science. Items include "How good is your/this child in [domain]?" and "How well do you think your/this child will do in [domain] next year?" (Wigfield et al., 1997, p. 454).

Although they are useful for examining behavior, methods based on researchers', teachers', or parents' observations of children are not sufficient for understanding the perceptions and meaning systems that undergird children's behaviors. Recall that *perceptions* are central to social-cognitive theories; it is the beliefs that individuals hold, rather than an objective reality, that influences their motivation most.

**Self-Reports.** In addition to knowing *what* children do, it is important to understand *how* children view themselves, their interests and abilities. What thoughts and beliefs channel particular behaviors? Why choose to read a book about marsupials rather than one about Halloween? Why choose to play with the dress-ups instead of at the science table? What roles do such factors as interest, 'real' or perceived current competence, enjoyment of challenge, fear of not doing well, construals of gender norms, or friends' choices play in what children select, persist at, and expend energy on? These questions are best answered by the children directly.

Although self-report instruments are used often from the upper elementary grades onward (e.g., Gottfried at al., 2001), few researchers have used self-report instruments to measure young children's motivation for science. Measuring young children's self-beliefs is particularly difficult, given their limited verbal expression skills, short attention spans, and their need to have items read aloud to them. Consequently, self-report measures are necessarily administered to young children individually—not an efficient process. Despite this difficulty, some researchers have used single items to assess children's self-beliefs (e.g., self-competence) or views about science content or topics (we discuss concerns with single items in the next section). In measuring both types of perceptions Andre and his colleagues (1999) asked children in grades K-3 to identify "how good you feel you are" (p. 724) at physical science and at life science, using a 3-point scale of "good" (with a smiley face), "OK" (with a neutral face), and "not very good" (with a frowny face). Another two of their items asked "how much do you like" physical science and life science, using responses of "Yes, I like it!", "It is OK", and "No, I don't like it" paired with the same graphics. Particular science topics may be focused on explicitly, such as when children rated science programs about specific concepts (e.g., catapults and trajectories), after watching each program (e.g., Fay, 1998). Yet another approach is to ask children whether or not they would like to read a new book on the science topic they have just viewed (Fay) or read about (Mantzicopoulos & Patrick, 2010).

In contrast to using single items to measure children's motivation, we have constructed a set of items—the Puppet Interview Scales of Competence in and Enjoyment of Science (PISCES; Mantzicopoulos et al., 2008; Patrick et al., 2009). PISCES was constructed in line with developmental considerations, taking into account young children's limited verbal expression skills and evidence that young children (i.e., preschoolers and kindergarteners) are able to provide a wealth of psychological information about themselves when prompted with statements about their experiences (Eder, 1990; Harter & Pike, 1984; Measelle, Ablow, Cowan, & Cowan, 1998). Framed in expectancy-value theory (Eccles, 2005; Eccles et al., 1983), the items assess children's self-beliefs across different science content and processes.

PISCES is administered individually, with the administrator attributing two opposing statements, one positive and one negative (e.g., "I can't do science yet" vs. "I can do science") to each of two identical puppets. Children then indicate which puppet expresses what they themselves think. The puppets are the same sex as the children, who chose and name the puppet pair looking most like themselves (from five different configurations of skin, hair, and eye colors). The statements are fully counter-balanced in terms of order (which puppet speaks first), valence (which puppet makes positive or negative statements), and valence order (whether the first statement is positive or negative).

The PISCES items consistently factor into competence and liking scales. Specifically, they differentiate between children's perceptions of their knowledge of general and specific science content (e.g., I can do science, I know why living things camouflage), and science processes (e.g., I am good at making predictions, I know how to use different science tools). Other items identify children's liking of science (e.g., I want to know more about science). These scales are internally consistent with different samples of ethnically diverse kindergarteners; Cronbach's alpha were .82, .85, and .76 for competence in content, competence in process, and liking, respectively. The scales also correlate with other measures in expected ways (Mantzicopoulos et al., 2008, 2009, 2013; Patrick et al., 2009; Samarapungavan et al., 2011).

In contrast to addressing different subject areas separately, researchers sometimes ask children to make comparisons among subjects. For example, in an approach used by Freedman-Doan and her colleagues (2000), 1st, 2nd, and 4th graders were shown four pictures—of a same-sex child doing math, reading, spelling, and science—and asked which one of the activities he or she was best, and which not so good, at. The researchers then asked about the subject identified as the child's worst, in order to understand children's reasoning about their competence and improvement. Follow-up questions were (1) whether children thought they could become better at the subject, (2) if that subject could be their best, and, (3) depending on their previous answer, what it would take for them to be best at that subject or why they couldn't be best at it.

## *Methodological Concerns*

In addition to the paucity of empirical research on young children's motivation for learning science, this field of research is hampered by concerns with methodological issues. We discuss some of these next.

**Distinguishing Among Grade Levels.** Young children exhibit considerable growth and development in their physical, emotional, and cognitive abilities, including memory, reasoning and judgment, and perspective-taking—all of which have implications for their motivational beliefs and behaviors. Therefore, we assume that just as there are changes in children's motivation for academic subjects such as reading and math (e.g., Jacobs et al., 2002), there are also age- or grade-related differences—quantitative and qualitative—in children's science motivation. Unfortunately, however, researchers frequently aggregate child data across a range of grade levels or ages, which obscures valuable developmental information. We believe that a better understanding of children's science motivation trajectories would result from examining the differentiation of children's beliefs across different grade levels over time (e.g., from kindergarten to 2nd grade). For example, because data for children in the early grades are reported in combination with upper elementary students (e.g., Adamson et al., 1998; Fay, 1998) it's not possible to discern whether there are significant differences among grade levels. Also, even when the participants come from a wide range of grade levels (e.g., Lamb et al., 2012), studies often don't report reliability data (e.g., Cronbach's alphas) by grade, making it difficult to assess the psychometric rigor of the scales when used with younger and older students.

**Single Item Measures.** As we have noted already, researchers sometimes assess young children's science motivation with single items. Single-item measures are appealing, because they are fast to administer and do not tax children's short attention span. However, there are significant drawbacks to this method. Single items: (a) correlate poorly with the constructs of interest; (b) may reflect skills or beliefs in domains (e.g., achievement) that are different from the domain (e.g., interest or liking of a subject) the research is intended to measure (e.g., a child may report that she likes dinosaurs because she just learned how to spell *dinosaurs* correctly); and (c) are notoriously unreliable (Nunnally & Bernstein, 1994). Because young children can sometimes be capricious in their responses, researchers need to be particularly attuned to the consistency of data collected from them.

**Ecological Validity.** As we noted earlier, young children—even by the end of kindergarten—may not have yet developed a coherent concept of science that can serve as an organizational scheme that accommodates their emerging knowledge and experiences with the natural world. This has implications for the ecological validity of questions that purport to measure children's liking, interest, or ability beliefs about science. Although children can supply answers to questions, researchers need to be confident that their study's participants understand the questions and constructs asked of them in the way the researcher intended. It is not always clear that this is the case in studies of young children's science motivation.

In order to interpret likert-scale data it is necessary to know what respondents understand the items they rate to mean; researchers cannot just assume that their understanding is the same as their study participants', especially when those participants are children. What do children mean by *science* when they answer questions about how much they like science, or how good they are at science? Do they know what science is? What if some think that science is "learn[ing] how to sing ABCs" (Patrick et al., 2009, p. 180), like one of the kindergarteners in our research project did? Might children's reports vary, depending on whether they view science in the same way as Arun, who told us "Sometimes we paper cut things with scissors and glue them together. We draw things and color things. And that's the only three things," or Malik, who responded to "What do you learn in science?" with "Measuring things, and water. Using a telescope, using trains to slide down ramps, using a microscope" (Mantzicopoulos et al., 2009, p. 348).

Even when researchers include differentiated questions about life science and physical science (e.g., Andre et al., 1999) we are concerned that without information about what children know about these two domains, these descriptors may not be meaningful. Therefore, given the contextualized development of science motivation, we wonder how useful it is to ask globally about "science," rather than about specific topics or activities (e.g., asking questions, observing, knowing why animals camouflage, recording data).

Asking children to report on activities they have not experienced undermines the validity of the study's findings, in our opinion. How can children know if they enjoy an activity or a subject if they are not aware of it? Nevertheless, researchers have investigated children's motivation to read science books this way. Some have asked how much children enjoy reading particular types of books in general, such as informational science or fairy tales (e.g., Fleener, Morrison, Linek, & Rasinski, 1997), and others have asked children to report how much they would like to read books representing different topics and genres, based only on fictitious titles and descriptions (e.g., Harkrader & Moore, 1997). If children have no experience reading informational books they may be unlikely to say they like this genre, even if it turns out they really would. Therefore, although children tend to say they prefer fiction (Harkrader & Moore, 1997), we argue it is because they have experienced fiction almost exclusively, not because they could not be equally (or more) interested in non-fiction. Without information about children's experiences these findings may simply be an artifact of familiarity and availability of resources rather than evidence of interest.

**Differentiating Children's Motivation for Science from Motivation for Other Subjects.** Sometimes teachers are asked to rate children on key, motivational qualities, such as interest, effort, or persistence, however there is no evidence about the validity of teachers' judgment of young children's motivation. Moreover, as used in research thus far, this type of measure is content-neutral; it does not refer to a specific content area, even though children's motivation does vary for different topics and they are aware of this (e.g., Eccles et al., 1993). For example, the measure created by Saçkes et al (2011), which came originally from a social skills rating system, is one of "children's motivation to benefit from instructional activities" (p. 223) and does not refer explicitly to science. The items do refer to indicators of motivation, but as general, rather than domain-specific, characteristics.

Although there is clear evidence that even young children identify differences in their motivation for various academic subjects, it is less certain that teachers make such differentiations when rating their students' motivation. Even when a measure refers to a specific domain, as in our teacher rating measure of children's science motivation, there is very little evidence that early elementary teachers make distinctions about children's motivation across different subjects. In our research, the correlations between PISCES child-reports and the Teacher Rating Scale of Children's Motivation for Science (TRMS) are statistically significant, however the magnitudes are nonetheless quite modest ($r$s = 0.18 between TRMS-Interest and PISCES science liking, –0.16 between TRMS-need for support and PISCES content competence, and -0.18 between TRMS-need for support and PISCES process competence) (Mantzicopoulos et al., 2013). However, although the constructs in the two measures are conceptually comparable, they are by no means identical, nor are we convinced that they should be. The items on the TRMS scale asked teachers to make more general judgments about children's science motivation whereas, as we noted earlier, for developmental reasons, the PISCES included many content-specific items. Together with frequently reported results on the modest agreement between young children's and teachers' reports (e.g., Mantzicopoulos & Neuharth-Pritchett, 2003; Measelle et al., 1998), our data also suggest that *children's reports are in no way a substitute for information contributed by teachers*.

There is evidence, nonetheless, that teachers are quite accurate in their judgments of young student's cognitive skills (Ready & Wright, 2011). Of note, the accuracy of teacher ratings increases with teacher experience and education (U.S. Department of Health and Human Services, 2002), and decreases as a function of the socioeconomic context of the school (i.e., teachers in schools that serve lower SES families under-estimate the cognitive abilities of their young students; Ready & Wright, 2011).

## Methodological and Theoretical Advancements Needed for Research of Young Children's Science Motivation

We have already noted, in the previous section, our concerns with the way that many studies of young children have measured their motivation for learning science. Clearly, there is a need for ongoing advancements in instruments used to measure science motivation. These include: (1) distinguishing between different topics or spheres within science, (2) creating scales so that internal consistency reliability can be assessed, (3) reporting data about (e.g., alphas) and from (e.g., descriptive statistics) measures separately by grade level, (4) understanding what children mean by the questions they respond to, and (5) knowing more about the contexts within which children learn science.

Another area where advancement is needed is in aligning motivation research with the increasingly accepted premises of sociocultural theories. Motivation research has tended to be based in social-cognitive theories that focus on individuals and their own construals of themselves and their experiences. However, motivational researchers have come to acknowledge that the complexity of student's motivational development is best understood in terms of sociocultural theories that represent patterns of engagement across multiple contexts (e.g., Hickey, 1997; Järvelä & Volet, 2004; Kaplan & Maehr, 2002; Mantzicopoulos & Patrick, 2013; Nolen, 2001; Pressick-Kilborn & Walker, 2002; Turner, 2001; Turner & Patrick, 2008).

Studies that are aligned with sociocultural perspectives require researchers to not only attend to the people and activities, but to the systems of meaning the activities are embedded within. Generally, data should be multimethod, multiinformant, multilevel, overlapping (i.e., not independent), and longitudinal. However, most writing that portrays motivation socioculturally is theoretical and offers little guidance for how motivation research can be conducted to ensure it is methodologically compatible with the undergirding theory. Although not simple, aligning methods with sociocultural premises will prompt researchers to collect evidence of systems of contextualized meanings about science and learning science. We believe this is an essential step in the process of gaining insight to children's motivational beliefs.

## Relevance of Science Motivation Research to Classroom Teaching Practices

At the risk of being repetitive, it is important to acknowledge that there is little research evidence about young children's science motivation on which to base suggestions for teaching. Nevertheless, we believe the following points, gleaned from that research, are relevant to teachers' practice:

- Motivation is inseparable from learning and the contexts in which they develop. Along with learning science, children learn whether they are or can be good at it, whether they enjoy it, and how important it is. Therefore, experiences doing (or not doing!) science have major implications for children's motivation.
- Young children need ongoing experience engaging in science, using the language, materials, and norms that are central to the discipline. They need to develop conceptually coherent and accurate notions of what science is and what scientists do, and lessons should be clearly identified as science (when science is being taught). Without explicit instruction, children are likely to construct their understanding of science from other sources, such as television and movies, which may undermine both the accuracy of their knowledge and their motivation.
- Although other subjects (e.g., art, writing) may be integrated with science lessons, the disciplinary boundaries of each should be clear. For example, drawing caterpillars within science lessons may involve close observation of a model and attempts to faithfully depict what is seen, using accurate colors and refraining from adding "extras" such as smiling faces or eyelashes.
- Interest increases as children develop skills and knowledge. Without competence there is just attraction, rather than an interest that sustains persistence, effort, and learning over time (Renninger, 2000). It takes some while for children to develop competencies, therefore central ideas need to be revisited and expanded on throughout a year, and across years. From both a motivational and knowledge acquisition stance there are few, if any, benefits from brief presentations of a potpourri of disconnected topics to children—an 'exposure' rather than an understanding approach to instruction.
- It is probably not helpful to ask children what they are interested in, in terms of science; they may not have the experience to know. It is preferable to assume that young children *will* enjoy learning about science concepts or reading informational books, and provide many opportunities for them to do so.
- Help children see that science is relevant, meaningful, and appropriate for *them*. If children believe that science is for other (e.g., older, smarter) people, they are unlikely to put forward effort and persistence to learn it, and possibly not choose to learn about it at all.

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# Chapter 3
# Young Children's Ideas About Earth and Space Science Concepts

**Mesut Saçkes**

The discovery of the importance of prior knowledge in subsequent learning (Ausubel, 1963, 1968) and Piaget's groundbreaking research on children (1972a, b) led researchers to take an interest in what students know before formal instruction. As a result of this interest, a large body of literature has been generated to investigate children's ideas about how the natural world works (e.g., Bar, 1989; Carey, 1985; Dove, 1998; Inbody, 1964; Moyle, 1980; Munn, 1974; Nussbaum, 1985; Osborne & Cosgrove, 1983; Russel & Watt, 1990; Russell, Bell, Longden, & McGuigan, 1993; Vosniadou & Brewer, 1992; Za'rour, 1976). These studies revealed that, children construct beliefs about and explanations of how things work in the world around them. However, children's ideas about the natural world are mostly divergent from scientific explanations possibly due to the limited cognitive capacities young children possess. Also, young children tend to perceive objects and phenomena from a self-centered point of view, their thinking is perceptually dominated, and they tend to focus on the change in their observations (Driver, Guesne, & Tiberghien, 1985; Inagaki, 1992).

This chapter aims to describe and discuss the research findings on young children's understanding of earth and space science concepts. Research studies targeting young children's understanding of earth and space concepts in developmental and cognitive psychology and science education literature are reviewed. The findings of these studies are organized under two main headings: earth science concepts and space science concepts. Recommendations for future research are provided.

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## Earth Science Concepts

Although a relatively large amount of information is now available in physical, space, and biological sciences, less attention has been given to children's understanding of concepts related to earth science and much of these available studies are rather dated. Studies on children's understanding of earth science concepts are limited to some meteorological phenomena, which has been given the attention of researchers around the world since the original work of the Piaget (1972a, b). There is a lack of research that addresses young children's conceptual understanding related to some specific earth science concepts, such as properties of rocks and soils. Studies mostly focused on the children's understanding of the formation of rain and clouds, and evaporation and water cycle phenomena. There are relatively few studies on children's understanding of wind, and thunder and lightning. This section describes and discusses the findings of the studies that targeted young children's understanding of the mechanisms of rainfall, wind, and thunder and lightning.

### *Rain and Clouds (Mechanism of Rain Fall)*

Piaget (1972a, b) conducted some of the earliest research related to children's alternative conceptions about the weather. Piaget (1972a) interviewed children from age 5 to 11 about the origin of the clouds and the formation of rain and proposed that children's understanding of the origin of clouds develops in three consecutive stages. The first stage includes children from 5 to 6 years old. In the first stage children perceive clouds as solid objects made by humans or God and believe that clouds are alive and conscious. The second stage includes children from 6 to 9 years old. During this period, children explain the formation of clouds as the smoke that comes from roofs. In other words, the makeup of clouds is explained with half artificial (human-made) and half natural substances. The final stage comprises children 9–10 years old. In this third stage children explain the formation of clouds with natural processes like condensed air, moisture, or steam.

Piaget (1972a) also classified children's understanding of the formation of rain into three stages paralleling children's understanding of the formation of clouds. During the first stage, children think that clouds and rain are independent of each other, and they believe that rain simply comes from the sky. In the second stage, children think of clouds as a sign of rain, but interestingly they still believe that rain comes from the sky and not from clouds. In this stage, some children assert that clouds move intentionally to the places in need of water and rain. The second stage seems to be a transition period from "artificialistic thinking" to "true causal thinking." Children state that clouds foretell rain but that rain does not come from the clouds. Piaget called this thinking "artificialist causality." During the third stage children perceive clouds as a cause of rain as well as a sign of it. However, some children at the third stage might still attribute intentionality to the clouds.

Oakes (1947) conducted one of the earliest research studies in the United States about children's understanding of meteorological phenomena. He interviewed children and found that older children tend to provide more scientific responses whereas kindergartners respond that supernatural forces are causes of meteorological phenomena. In a similar study, Inbody (1964) investigated 50 kindergarten children's understanding of rain and clouds. He reported that only 40 % of interviewed children understood that rain falls from clouds and over half of children described rain as falling from the sky. These findings are consistent with Piaget's earlier findings that young children made no connection between rain and clouds. Two of the 50 children in Inbody's study provided supernatural explanations indicating that rain comes from God or Jesus, and about half of the children suggested that water could evaporate into the air. Inbody reported that 20 % of children suggested the water cycle as a factor in rainfall. Nearly two-thirds failed to provide an explanation for the source of water in clouds, and over one half of the children used religious factors to explain the source of water in clouds.

In a study conducted with 74 children from kindergarten to 5th grade in the United States, Munn (1974) found that 50 % of children from kindergarten to 1st grade, 50 % of children from grades 2 to 3, and 25 % of children from grades 4 to 5 explained that the rain comes from the sky. Only 35 % of children from kindergarten to 1st grade, 50 % of children from grade 2 to 3, and 55 % of children from grade 4 to 5 identified clouds as the source of rain. Only fourth and 5th grade children included the cycle of condensation and evaporation in their verbal explanations of the mechanism of rainfall. These findings suggest that accuracy in scientific explanations of the mechanism of the rainfall tend to increase with grade levels, which is consistent with previous research.

Za'rour (1976) examined Lebanese children's understanding of some meteorological phenomena in a sample of 220 children from kindergarten to 4th grade. About 51 % of interviewed children referred to clouds or to the sky as the origin of rainfall. While older children were more likely to offer clouds as the origin of the rain, younger children were more likely to offer supernatural explanations. These findings are consistent with the results of other research studies (Oakes, 1947; Piaget, 1972a,b) which reported that scientific explanations of weather phenomena tend to increase with age. Za'rour also reported that only about one fourth of 3rd and 4th graders held understandings of the evaporation and the water cycle phenomena and younger children tend to provide supernatural explanations to describe the displacement of water. Consistent with the results of Piaget (1972a) and Inbody (1964), Za'rour reported that children age 5 or 6 years did not relate clouds to rain. Za'rour also stated that 8 and 9 year old children typically failed to include clouds in their explanation of the mechanism of rainfall.

Miner (1992) investigated preschool children's understanding of the water cycle. A total of 56 3–5 year old children from geographically different locations in the United States were interviewed. Twenty-eight children were from a mountainous region and 28 children were from a desert region. Miner reported that 43 % of the children did not have an understanding of the water cycle. Eighteen percent of the children partially understood the water cycle, and 37 % of the children completely understood the water cycle. Children from a mountainous region were more likely to notice a difference in the clouds, mentioning a darker color in the clouds before rainfall and knowing that rain drops are made of water. Only the children from a mountainous region commented that snow was made from raindrops. Many of the children in the desert region believed that clouds were made of snow, cotton, rock or by humans. Results indicated that children from a mountainous location had a better understanding of the water cycle than children from a desert location. Children from a mountain area understood concepts of precipitation and condensation significantly better than their peers who lived in a desert.

Donaldson (1973) examined young children's understanding of the rainfall phenomenon in a sample of 64 boys and girls, 32 African-American and 32 European-American children, ranging from 4 through 7 years of age. Children were shown a series of picture cards depicting rainfall. Most children were able to explain what was happening in each card. Children mostly used the term raining and storming to describe the scenes, and clouds and rainbows also were recognized by the children. Several children explained that the water "went into the ground" or it "ran away" when they were asked to explain what happened to the water in a puddle. The most frequent explanation about what made puddles dry involved the sun as a factor affecting evaporation. Results demonstrated significant age, gender, and SES differences. Six year old children had a better understanding than the 5 year old children and boys demonstrated a better understanding than girls. Children from higher SES families demonstrated a better understanding than the children from lower SES families. There was no significant difference between African-American and the European-American children. The concept of evaporation was the least known phenomenon among all children.

In a recent study Saçkes, Flevares, and Trundle (2010) examined 4–6 year old Turkish children's conceptions of the mechanism of rainfall. Twenty-two children (14 boys and 8 girls) participated in the study. Half of the children stated that rain is water and about one fourth of the children indicated that clouds consist of water droplets or containers of rainwater. Almost 60 % of the children explained the makeup of clouds using substances other than water, such as cotton. Again almost 60 % of the children demonstrated an initial awareness of the water cycle, indicating that rainwater does not cease to exist when it falls to the ground, while 14 % asserted that rain ceases to exist after falling. The majority of the children (91 %) demonstrated an awareness of the change in the appearance of the clouds before the rain. Most children (64 %) were aware that dark clouds foretell rain. Some children, however, indicated other changes in the clouds, such as size, shape, texture, and movement as indicators of forthcoming rain. More than half of the children (59 %) indicated that rain comes from the clouds while about one third of the children asserted that rain comes from the sky. Results demonstrated that children use three non-scientific causal models for the mechanism of rainfall: collision model, natural agents model, and supernatural agents model. Children who held the collision model explained the mechanism of rainfall by the physical actions of the clouds. Children who held the natural agents model credited the mechanism of rainfall to a natural outside agent, while the children who held the supernatural agents model asserted that supernatural beings cause rainfall. Results demonstrated that older children's explanations of the mechanism of rainfall were more likely to include scientific elements. Although the gender difference was not tested due to unbalanced gender distribution, researchers reported that girls were more open to share their experience with rainfall than the boys and the parents were more likely to talk about rainfall with their daughters.

Children's alternative conceptions about clouds and rain were also identified by Bar (1989) in a study conducted with 300 Israeli children aged 5–15 years. Bar stated that children's verbal explanations of the source of clouds could be classified into two stages. The first stage included explanations typical to young children and the second stage was characteristic of the older children. Bar reported that, children of ages 5–10 typically offer four explanations for the source of clouds: (1) supernatural beings send clouds, (2) clouds are made of water vapor coming from kettles or bodies of water, (3) clouds are replenished by bodies of water, and (4) the make up of clouds includes cold or heat. Older children, ages 9–15, begin to offer two alternative explanations: (1) clouds are formed by water vapor coming from many water sources; and (2) clouds are formed by water evaporated from the sea. Likewise, Bar (1989) recorded two main explanations for the mechanism of rainfall: (1) colliding clouds produce rainfall and (2) clouds or rain drops getting cold or heavy produce rainfall. Younger children are more likely to believe that rain comes from colliding clouds, but about 20–30 % of the children between the ages of 7–14 years continue to entertain this conception. Around age 7, children begin to offer the second explanation, and this explanation becomes the most frequently held idea starting from the age of 10 years. During the same period, some children begin to believe that clouds melt, sweat, or they are shaken by the wind to cause rainfall. Some children think clouds descend from the sky in one piece when it rains. Bar proposed three levels paralleling the three stages proposed by Piaget. In the first level, ages 5–7, children's understanding is influenced by cultural beliefs. In the second level, ages 7–9, children's perceptions of the water cycle become pseudo-scientific in nature. In the third level, ages 9–15, children tend to provide scientific explanations for cloud formation and rainfall.

Russell and colleagues investigated 4–14 year old children's (n = 58) understanding of the weather phenomena in England (Russell et al., 1993). The results demonstrated that while many children were able to explain that rain comes from clouds, children's explanations of the relationship between the clouds and rain varied. Both PreK and early elementary children tended to report that rain occurs as the clouds become heavy. PreK children tended to suggest that the rain comes from particular clouds that hold the rain until the clouds burst. Explanations including water changing location from the ground into the clouds were infrequent in the PreK children reports, but more common in the explanations of late elementary school children. The children in this study described the change in location of the water in a number of ways. Most children considered that the water originated in the sea. Some children suggested that the water was sucked up by the clouds or that the wind gathered it up. A few children included references to fluctuations in weather temperature in explaining how rain occurred. Although some children demonstrated an awareness of the water cycle, there were few references to water changing state. Younger children often described the clouds as containers of water.

Several researchers have examined young children's understanding of evaporation and condensation, which are strongly related phenomena with the mechanisms of rainfall and formation of clouds. For example, Russel and Watt (1990) explored 5–11 year old children's ideas about evaporation. Children were interviewed using three different tasks: evaporation of pure water from a tank, clothes drying, and condensation of breath in the air. Results showed that the most common action verbs children used to describe the departure of water were disappeared/vanished, and gone up/gone down. Evaporated/vaporized were mostly used by older children (70 %) and around 10 % of PreK and early elementary children. Assumed location of the missing water was mostly the ground (24 %) and the sun (24 %) for PreK children, air/sky (34 %) and cloud (17 %) for early elementary children, and air/sky (30 %) and clouds (48 %) for older elementary children. Children mostly see heat and air as agents of change affecting the water level. A small number of children referred to clouds, humans and animals as agents, which removed the water. Russel and Watt (1990) suggested that an understanding of the process of water cycle may not develop until children have reached the age of 10 or 11.

In another study, Bar and Galili (1994) investigated 6–12 year old children's understanding of evaporation. In this study, researchers recorded four conceptions regarding the children's understanding of the evaporation with each conception peaking at a different age level. The first conception, water disappears, was popular among the younger groups, 60 % in the 5-year-old group, and declining as age increased. While children tended to hold this conception mainly up to age 7, this conception did not disappear completely at older ages. This conception began to change around age 7 when children started to practice the conservation principle. The second conception, water is absorbed into the floor or ground, was popular among 7 and 8 year old children. Some 7–8 year old children began to believe that the water evaporates, becomes unseen and is being transferred into another location. The percentage of children with this conception increased up to 60 % around the age of 12. The conception that the water changes into vapor and is transformed into air started to appear around the age of 10. Conceptual development from the second conception to the third and fourth occurred around the age of 9. Bar and Galili reported that the third and the fourth conceptions appear consecutively. By about age 13, the third conception disappeared and the scientifically accurate conception became predominant.

In a similar study Tytler (2000) explored 1st grade (ages 6–7 years) and 6th grade (ages 11–12 years) children's understanding of evaporation and condensation. Tytler reported that after an instructional intervention, about 40 % of the 1st graders used a water cycle explanation which involved movement of water into the sky. This result indicates that children understand these concepts much earlier than was previously reported (Bar, 1989; Bar & Galili, 1994; Inbody, 1964; Oakes, 1947; Piaget, 1972a, b; Za'rour, 1976). Tytler stated that around age 6–7 years children might be ready to understand the concept of the water cycle well before the transition age of 9 identified by other researchers (Bar, 1989; Bar & Galili, 1994). Tytler also found that 15 % of children age 6–7 years and 39 % of children age 11–12 years expressed a view which included water moving into the sky. This result also is higher than previously reported. According to Tytler, the previous studies underestimated young children's conceptual understandings of the evaporation phenomenon.

In a more recent study, Tytler and Peterson (2004) longitudinally examined the development of young children's understanding of evaporation. In this study, 12 children from kindergarten (age 5 years) to grade 3 (age 8 years) were followed for 4 years. Researchers organized children's conceptions of evaporation under six categories: (1) evaporation always happens, (2) associative explanations, (3) water changes position in liquid form, (4) water goes into the sky, the sun, and the clouds, (5) water mixes into the air, and (6) water transforms into another form. Tytler and Peterson reported that kindergarten and 1st grade children tend to use the first three explanations and the scientifically acceptable conceptions about evaporation emerges as children move from 1st grade to the 2nd grade. Tytler and Peterson have argued that children's learning pathways are very complex and the development of children's conceptual understandings of the evaporation phenomenon is not linear and hierarchical as previously proposed (Bar, 1989; Bar & Galili, 1994; Piaget, 1972a, b). These researchers further stated that depending on the context young children interchangeably use the first four conceptions in their explanations.

## *Wind*

Compared to the mechanism of rainfall, fewer studies focused on children's ideas about wind. Piaget (1972b) was one of the earliest scholars to investigate children's understanding of wind also. Piaget proposed that children's ideas related to the origin of wind could be grouped into three stages. In the first stage, 5–7 year old children believe that wind is produced by humans or God. Piaget described children's thinking in this stage as "artificialist." During the second stage, around the age of 8 years, children explain the wind as the result of the movement of other bodies such as clouds, trees, waves and dust. In the third stage, around the age of 10 years, children refuse to explain how the wind occurs. Children appear to see the link between the air and the wind, but they are unable to elaborate on this relationship.

Piaget (1972b) also examined children's understanding of the movement of the clouds and identified five stages. In the first stage, magical thinking, 5 year old children typically believe that the movements of humans make clouds move, and clouds obey humans' will. The second stage is both "artificialist" and "animistic". Six year old children in this stage think that clouds move because God or humans make them move. During the third stage, 7 year old children typically think that clouds move by themselves. Children cannot explain the mechanism of the movement of clouds and mostly offer moral and physical causes as responsible agents for their movement. In the fourth stage, 8 year old children think that the wind pushes the clouds. But at the same time children believe that the wind also comes out of the clouds. In the final stage, around the age of 9, children begin to understand that the wind moves the clouds and that clouds do not produce the wind.

Inbody (1964) reported similar findings from his study with kindergartners. Approximately 90 % of kindergarten children demonstrated an understanding that wind involves motion. However, children's responses were not clear enough to determine whether children understood the exact mechanism of wind. Children may believe that the wind pushes the air but that air and wind are different things. Similar alternative conceptions related to wind were also identified in older children, aged 12–18 years (Papadimitriou & Londridou, 2001). The idea that the air and wind are different things was also detected in Inbody's study (Inbody, 1964). Researchers revealed that many older children, like kindergartners, think of wind as something different from the movement of air masses. Children actually think that the wind causes air masses to move. Even older children tend to attribute intentionality to wind, similar to what Piaget (1972a,b) called "artificialism." Children believe that the wind intentionally moves air pollution from urban areas to uninhabited places (Papadimitriou & Londridou, 2001).

Oakes (1947) reported that the conception of cloud movement, trees and waves causing the wind becomes less frequent as children move into upper grades. About 32 % of kindergarten children, 14 % of children in 2nd grade, and 7 % of children in 6th grade held this idea. Oakes also investigated children's ideas about the movement of the clouds. While all children in the 6th grade provided scientific answers, only about 26 % of children from kindergarten and 67 % of children from 2nd grade understood that wind causes clouds to move. Almost 28 % of kindergartners and about 13 % of children from 2nd grade provided a simple phenomenalist answer, and they believed that clouds move when it is going to rain. About 9 % of kindergartners offered a magical answer, that humans inside clouds make them move, while about 19 % of kindergartners gave a religious answer, that Jesus makes clouds move.

Children's ideas related to wind were also investigated by Moyle (1980). Moyle reported that younger children, as Piaget (1972b) reported, think wind is from the clouds, and they believe movements of objects such as trees cause the wind. The children offered different ideas about wind speed. Only a few older children's verbal explanations included any reference to the effects of pressure. About 13 % of children made reference to temperature variation, and about 15 % of the children stated that clouds influence the speed of the wind. Some children believed that slow winds come together to produce faster winds. About 25 % of children believed that the movement of objects like clouds, cars, and rain causes the wind. Moyle also examined children's ideas about the role the moon, sun, and stars play in weather. The underlying philosophy for examining children's ideas about the relationship between the celestial objects and weather can be supported with Piaget's statement "the child makes no distinction between astronomy and meteorology. The sun and the moon are of the same order as the clouds, lightning and the wind" (1972a, p. 285). Results of the Moyle's study demonstrated that over 63 % of children did not see the moon as influencing weather. On the other hand, a significant proportion of children (about 26 %) did see the moon as influencing weather in some way. About 19 % of older children thought the moon affects tides which they related to the creation of winds.

## *Thunder and Lightning*

As was the case for the topics of rain, clouds, and wind, Piaget (1972a) was one of the earliest researchers who investigated children's ideas on thunder and lightning. According to Piaget , children's ideas related to thunder and lightning can be classified into three stages. During the first stage, children assert that thunder and lightning are made just as they are in the sky or on the mountains without mentioning any causal agent. During the second stage, children explain them as being produced through natural means by the clouds or smoke. During the third stage, children explain the origin of thunder and lightning entirely as being natural. The first stage lasts to age 6 years and the second stage lasts on an average to the ages of 7–9 years. Thunder was seen as being due to an explosion of the clouds, sun, or moon. Piaget pointed out that since children believed clouds were made from the smoke from roofs, they could revert to thinking fire produces lightning. The most common explanation found in the second stage was that thunder is produced by the collision of two clouds, which set free the fire inherent in clouds. Natural explanations begin to appear during the third stage, which marks the appearance of purely natural explanations. According to Piaget, the majority of these natural explanations are due to formal learning experiences.

Similarly, Russell et al. (1993) found that older children (age 10–14 years) used their knowledge of electric storms to explain the occurrence of thunder. Some children believed that clouds contain electricity, which is the source of both thunder and lightning. As Piaget (1972a) reported, Russell and colleagues also found that children explain thunder as an impact between clouds. As children move into the upper grades, their understanding of thunder and lightning becomes more aligned with scientific explanations. However, even middle school and college students continue to have several misconceptions regarding these meteorological phenomena. For example, most students believe that lightning never strikes the same place more than once (Aron, Francek, Nelson, & Biasrd, 1994; Nelson, Aron, & Francek, 1992).

## *Summaries of Children's Understanding of Earth Science Concepts*

Research studies demonstrated that most young children perceive clouds as solid object produced by outside agents such as humans or God. Children often attribute human characteristics to clouds and rain and think that clouds are alive and conscious (Inbody, 1964; Miner, 1992; Oakes, 1947; Piaget, 1972a; Za'rour, 1976). Most young children believe that rain is water; nevertheless they tend to think that clouds and rain are independent, and rain falls from the sky or God (Inbody, 1964; Munn, 1974; Piaget; Saçkes et al., 2010; Za'rour, 1976). While some young children tend not to pay attention to differences that occur in clouds before rainfall or focus on changes other than color, most are aware that dark clouds foretell rainfall (Miner, 1992; Piaget; Saçkes et al.). During the early elementary grades, the origin of the cloud is explained as half artificial and half natural process. Children explain the origin of clouds as smoke from roofs, and they believe that if there were no houses there would be no clouds (Piaget, 1972a). Most children think that a cloud is a sign of rain, but some children continue to claim that rain comes from the sky, not from the clouds (Piaget; Saçkes et al.). In this period, some children may continue to think that the clouds move purposefully to wherever rain is necessary and transform themselves into water. During the late elementary grades, the clouds are considered as of natural origin, such as condensed air or moisture. Children begin to see clouds as a cause of rain as well as a sign of it (Bar, 1989; Piaget, 1972a).

Children use several alternative causal explanations for the mechanism of rainfall. Very young children assert that supernatural beings or some natural agents cause the rainfall (Piaget, 1972a). As children get older, supernatural agents are replaced by natural agents. Some children believe that the rain comes from colliding clouds (Bar, 1989; Saçkes et al., 2010). These children perceive clouds as containers of water and believe that collision between clouds may break them and cause the subsequent downfall of rain (Moyle, 1980; Russell et al., 1993). Some children believe that rain falls when either the clouds or the rain drops become cold or heavy (Bar, 1989). Starting about at the age of 9 years, children's conceptions of the mechanism of rainfall become more sophisticated. Children's explanations of the mechanism of rainfall begin to include process of evaporation and condensation and children understand that rainfall is a part of water cycle (Moyle, 1980; Munn, 1974; Za'rour, 1976).

The artificialist thinking seems to be dominant in young children's explanation of the wind. Five to seven years old children believe that wind is produced by humans or God (Oakes, 1947; Piaget, 1972b). Around the age of 8 years children's explains become naturalistic. The wind is considered as the result of the action of other natural bodies such as clouds and trees (Moyle, 1980; Piaget). Children of this age think that the wind pushes the clouds, but also assert that that the wind also comes out of the clouds. This idea becomes less frequent among older children (Oakes, 1947). Around the age of 9 years, children begin to understand that the wind moves the clouds but the clouds do not produce the wind (Oakes; Piaget, 1972b). About a year later children begin to appreciate the connection between the air and the wind, but they are unable to elaborate on this relationship (Piaget, 1972b).

Kindergartners are likely to be aware that the wind involves motion, but they seem to be not sure whether the air and wind are different things and it is the air which is in motion (Inbody, 1964). Children tend to think that wind is something different from the movement of air masses. Children attribute intentionality to wind and believe that the wind clear the air by purposefully moving the air pollution away from the humans (Papadimitriou & Londridou, 2001). Some children perceive the movement of the clouds and air as an indicator of rainfall (Oakes, 1947). Some children believe that slow winds come together and produce faster winds and others make connections between celestial objects and the weather (Moyle, 1980).

While very young children offer no causal explanation for the thunder and lightning, starting from the age of 7 years children explain them as being produced through natural means (Piaget, 1972a). Thunder is considered as a result of an explosion of the clouds, the sun, or the moon. Children think that thunder is produced through the collision of two clouds. Although their explanations become more sophisticated even the older elementary school children continue hold this idea (Russell et al., 1993).

## Space Science Concepts

A large number of studies have been devoted to examining young children's understanding of various space science concepts. Most studies have focused on children's understanding of the shape of the earth, day and night cycle, seasons, and lunar concepts. The findings of these studies are described and discussed in this section.

### *Shape of the Earth*

Children's understanding of the shape of the earth has been extensively studied in the literature. In their seminal work, Vosniadou and Brewer (1992) examined 6–11 year old US children's understanding of the shape of the earth using an interview protocol that included factual questions, generative questions, and a drawing task. The findings demonstrated that most children use a small number of distinct mental representations of the earth, called mental models in explaining the shape of the earth. The flat earth model, where the earth is considered as a rectangle or disc, was prevalent among the younger children. Older children tended to have the scientific model, a spherical earth model. Some children, on the other hand, held synthetic mental models, which are blends of a flat and spherical earth model. Dual earth model, hollow sphere model, and flattened sphere model are examples of synthetic models. Children with a dual earth model stated that there is a flat earth where people reside and also a round earth located in the sky. Children with the hollow sphere earth indicated that there is a flat surface at the bottom of the spherical earth and people live on that flat surface. This model appears to be a synthesis of flat earth model with the scientific model of the earth. Children with a fattened sphere model indicated that the top and bottom of the spherical earth is flattened and humans reside on these flat surfaces. A culture specific mental model of the earth was also detected in studies conducted with Indian, Samoan, and Greek children (e.g., Samarapungavan, Vosniadou, & Brewer, 1996; Vosniadou, 1994; Vosniadou, Skopeliti, & Ikospentaki, 2004, 2005).

Vosniadou and Brewer (1992, 1994) suggested that presuppositions or intuitions developed early in life constrain children's acquisition or construction of mental models of the earth. For example, presupposition of solidity, stability, up and down organization of space, and gravity influence children's interpretation of their experiences and cultural knowledge about the earth.

The findings of several studies in different cultures support Vosniadou and her colleagues' claims. For example, Kallery (2011) examined Greek PreK children's understanding of the shape of the earth. Children either held the flat earth, dual earth, or spherical earth model. Blown and Bryce (2006) longitudinally examined the development of the earth concept in Chinese and New Zealander children. Over 600 children participated in the study and 17 were followed over time. Researchers identified similar intuitive and synthetic mental models of the earth including flat earth, disc-shaped earth, dual earth, and hollow sphere earth among the Chinese and New Zealander children. The findings demonstrate that children's conceptions of the shape of the earth develop gradually and children construct coherent conceptions of the earth. In another study, Bryce and Blown (2006) found no significant difference between Chinese and New Zealander children's understanding of the shape of the earth. They found children held models of the earth, such as dual earth, hollow sphere, and flat earth, similar to the models reported in Vosniadou and colleagues' studies. Novel models were also identified, for example, irregular flat earth model and bun-shaped or dome shaped-earth models. More recently, in a cross-age, cross-cultural study of 247 Chinese and New Zealander children, Blown and Bryce (2013) examined 3–18 year old children's understanding of the earth. Based on the findings of this study Blown and Bryce suggested that children's conceptual understandings of the astronomy phenomena are coherent rather than fragmented.

Findings of other studies also supported Vosniadou and Brewer's mental model theory. Hayes, Goodhew, Heit, and Gillian (2003) examined 132 6-year-old Australian children's understanding of the shape of the earth using the interview protocol developed by Vosniadou and Brewer (1992). Dual earth (33 %), hollow sphere (18 %), and flattened sphere (9 %) models of the earth were the most common alternative models held by the children. The percentage of children with the scientific model of the earth was 22 %. Tao, Oliver, and Venville (2012) examined 18 Australian and 18 Chinese 8-year-old children's understanding of the shape of the earth. Australian and Chinese children held similar understanding regarding the shape of the earth. Most children indicated that the shape of the earth is round or circular. Only two Australian children used the term spherical. Some children held a round and flat earth model suggesting people would fall from the edge of the earth (nine children). Several children held synthetic models (ten children). These children held different ideas about the place people reside on the earth. While some children insisted that people can only stand on top of the earth, others claimed that people can live only on the sides or at the bottom of the earth. Five Chinese and ten Australian children held the spherical earth model. The findings demonstrated that children's understanding of the shape of the earth is constrained by their presuppositions.

Other researchers have challenged the findings of the studies that described the children's understandings of the shape of the earth as coherent and constrained by presuppositions. Schoultz, Saljo, and Wyndhamn (2001) interviewed 6–11 year old Swedish children using a globe. Even the younger children had a scientific understanding of the shape of the earth and there was little evidence for the naive and synthetic mental models of the earth. Sharp (1999) investigated 25 7 year old

English children's conceptions of the shape of the earth. Most children held the spherical earth model. Nobes et al. (2003) examined 4–8 year old Gujarati and white British children's understanding of the shape of the earth. About 63 % of the 4–5 year old children selected the spherical shape for the earth. The number of children who selected the scientific model of the earth increased with age. The difference between Gujarati and white British children' understanding of the shape of the earth was not significant. Children's response patterns for the four forced choice questions were examined. The results demonstrated that children's understanding of the shape of the earth is fragmented. Siegal, Butterwort, and Newcombe (2004) investigated 4–9 year old Australian and English children's understanding of the shape of the earth using interview questions with or without 3D models of the earth. Australian children were more likely to hold scientific understandings than their English peers. There was also a difference between the two interview formats. The scientific shape of the earth was more prevalent among the children who interviewed with 3D models of the earth than the children who interviewed without 3D models of the earth. The findings demonstrate that by the age of 8 years most children develop a scientific understanding of the shape of the earth (Siegal et al., 2004). A similar methodology was also used in another study. Panagiotaki, Nobes, and Banerjee (2006) examined British children's understanding of the shape of the earth using open and forced-choice questions, drawings and 3D models. Fifty-nine 6 years old children participated in the study. Children were more likely to provide a scientific response to forced choice questions than open questions. No such difference was observed between the use of drawings and 3D models. Boys were more likely to hold a scientific understanding than girls. Open questions and drawings produced more flat earth model and synthetic model. Panagiotaki and colleagues argued that children's understanding of the shape of the earth does not appear to be constrained by presuppositions.

In another study, Nobes, Martin, and Panagiotaki (2005) examined 5–10 year old children's understanding of the earth using a series of cards depicting various models of the earth. Even the preschoolers demonstrated a preference for the spherical earth model. Around the age of 8 most children develop an understanding that people can live around the earth and the sky covers the earth. There was little to no evidence supporting the existence of naïve and synthetic mental models of the earth. The authors have suggested that naïve mental models identified by Vosniadou and colleagues might be methodological artifacts. Nobes and Panagiotaki (2007) found that even adults have difficulty understanding the earth drawing task used in Vosniadou and colleagues' work.

Panagiotaki, Nobes, and Potton (2009) interviewed 6–7 year old children using either the original interview protocol used by Vosniadou and Brewer or revised protocol which is designed to reduce the ambiguity of the instructions and the questions included in the original protocol. A total of 127 children participated in the study. Children who responded to the revised protocol were more likely to provide the scientific conception of the earth. Children who responded to the original protocol were more likely to provide naïve and synthetic mental models of the earth. In the revised protocol, only 7 % of the children's understanding was classified as naïve or synthetic mental models. The researcher concluded that clarifying the instructions and the questions of the Vosniadou and Brewer's interview protocol reduced the prevalence of naïve and synthetic mental models of the earth.

In a recent study, Frède et al. (2011) investigated 5–11 year old French children's understanding of the shape of the earth using multiple data collection techniques. First graders, were more likely to provide a scientific explanation in forced-choice task than the open question task. There was no task difference in the responses of the older children and they tended to hold the scientific model of the shape of the earth. Children's explanations also did not differ based on the type of earth representations (creating or selecting 2D pictures or 3D models) used in data collection (Frède et al.). In a large scale study, Straatemeier, van der Maas, and Jansen (2008) investigated 4–9 year old Dutch children's understanding of the shape of the earth using a multiple-question instrument, EARTH-2. A total of 381 children participated in the study. Children's responses were analyzed using latent class analysis. Classes corresponding to the initial and synthetic models reported by Vosniadou and colleagues were not observed.

Hannust and Kikas (2007) interviewed 113 5–7 year old Estonian children. Most children held a fragmented understanding about the shape of the earth and only 11 % held intuitive models of the earth. The results of the study suggest that children are likely to hold a fragmented understanding about the shape of the earth and the prevalence of intuitive and synthetic models of the earth among the children is very limited. In a more recent study Hannust and Kikas (2010) examined 143 2–3 year old Estonian children's understanding of the shape of the earth over the course of 4 years. Children were required to answer four open ended questions and draw a picture of the earth. Hannust and Kikas found little evidence of synthetic mental models of the earth among the Estonian children. Although the occurrence of coherent mental models among the children had increased over the course of 4 years, this increase was not higher than by chance. The children's understanding was mainly fragmented. The prevalence of the scientific understanding was also lower than previous studies (e.g., Nobes et al., 2005; Panagiotaki et al., 2009).

In response to the critiques raised by the studies described above, Vosniadou et al. (2004, 2005) examined Greek children's understanding of the shape of the earth using two modes of data collection. Seventy-two 6 to 9 year old Greek children participated in the first study (Vosniadou et al., 2004). The sample was randomly divided into two groups. Researchers used a forced choice questionnaire developed by Siegal et al. (2004) with one group and a modified version open ended questionnaire, which only included the questions in the forced-choice questionnaire and required children to construct play-dough model the earth, with the second group. The two methods of data collection generated different response patterns. While children in the open-ended questionnaire group provided responses consistent with well-defined mental models of the earth identified in previous studies, children in the forced-choice questionnaire group provided more scientific responses and their responses were more likely to be internally inconsistent. In the second study, Vosniadou et al. (2005) compared 42 Greek children's understanding of the shape of the earth using two modes of data collection. Twenty first grade children, 5–7 years old, and 22 3rd grade children, 7–10 years old, participated in the study. In the first phase of the study children were asked to draw or construct play dough models of the earth and a series of questions were asked regarding their explanations. In the second phase, a globe was presented to children and the children were informed that it represents a culturally accepted model of the earth. With the presence of the globe the children were interviewed using a different set of questions. The number of scientific responses increased with age. The 3rd graders provided more scientific response than the 1st graders in both the first and the second phase of the study. In the first phase of the study, without the presence of the globe, 90 % of the first and 3rd grade children produced internally consistent responses that were aligned with a model category. In the second phase of the study, with the presence of the globe, only 45 % of the children gave internally consistent responses. Use of the globe increased the number of children who were assigned the mixed category, internally inconsistent model. About 73 % of the children changed their responses with the presence of the globe and most children were not aware that they changed their responses. The presentation of the globe increased the number of scientific responses children provided and decreased the internal consistency of the responses. Although the presence of the globe led children to change their responses, most were unaware of the changes in their explanations. Vosniadou and colleagues have argued that children interpreted the globe, a cultural artifact, based on what they already knew. While older children profited more from the presence of the globe, it did not influence the explanations of younger children. According to Vosniadou and her colleagues, discourse analysis alone is not sufficient to explore children's understanding and researchers should also pay attention to cognitive factors in studying children's conceptions.

## *Day and Night Cycle*

Interviews Piaget (1972a) conducted with young children revealed that most children see the apparent movement of the sun in the sky as the reason for the day and night cycle. Later studies with PreK children and children in early elementary grades reported similar findings (e.g., Küçüközer & Bostan, 2010; Sharp, 1996; Valanides, Gritsi, Kampeza, & Ravanis, 2000). Valanides et al. (2000) examined Greek children's understanding of the day and night cycle. The most common explanation for the day and night cycle was the movement of the sun in the sky. Kallery (2011) observed similar responses in her study with over 100 Greek children. In the study children tended to offer two different explanations for the day and night cycle. While some children attributed the day and night cycle to the sun's movement in the sky, others believed that variations in sun's strength cause the day and night cycle claiming that the sun is strong in the morning, gets stronger in the day, and loses its strength by the end of the day. In recent studies with Turkish kindergarten children the movement of the sun in the sky was the most common alternative conception held by the children (Doğru & Şeker, 2012; Küçüközer & Bostan, 2010). Küçüközer and Bostan (2010) reported that some children attributed the day and night cycle to the movement of the moon in the sky. Children asserted that when there is no moon it is daytime and when the moon is up it is nighttime. A single child provided an interesting explanation stating that when the moon shows its white side to the earth it is daytime and when the moon shows its black side to the earth it is nighttime. Some children believe that varying degrees of cloud cover over the sun causes the day and night cycle. A few children attributed supernatural forces as being responsible for the occurrence of the day and night cycle, or they provided utilitarian explanations indicating that the night is for people to sleep and day is for work or school (Küçüközer & Bostan, 2010).

Alternative conceptions of the day and night cycle seem to be persistent beyond the early childhood period. For example, Baxter (1989) surveyed 9–16 year old children about their ideas regarding the day and night cycle in England. The results indicated that even older elementary school children believe that cloud cover causes the day and night cycle. The findings of Baxter's study indicated that the movement of the sun in the sky continues to be a popular explanation among older elementary children. Baxter identified another alternative conception: the earth orbits the sun in one day and the movement of the earth around the sun causes the day and night cycle. This conception appears to be a synthesis of scientific information provided in school with intuitive ideas. This alternative conception was also very common among 5th and 9th grade Estonian children (Kikas, 1998) and 6th grade Turkish children (Küçüközer, Korkusuz, Küçüközer, & Yürümezoğlu, 2009). The simultaneous movement of the earth around on its axis and while it orbits the sun appears to be confusing for many children. Valanides et al. (2000) reported that some young children also tend to construct a similar alternative conception when the movement of the earth around on its axis while it orbits the sun when these concepts are introduced to them. In their study, about 12 % of the 5–6 year old children constructed this alternative conception after instruction on the day and night cycle.

Vosniadou and Brewer (1994) demonstrated that young children construct mental models of the day and night cycle under the constraints of the framework theory, which is also influenced by their everyday experiences to some extent. In their study with 6–11 year old US children Vosniadou and Brewer identified eight mental models of the day and night cycle: three initial, four synthetic and one scientific model. Initial or naive mental models were most likely held by younger children. Children who hold these initial models tend to think that the sun moves away from the earth or the sun is blocked by either going down behind the mountains or the clouds causing night. Older children construct several synthetic mental models combining the elements of scientific information with their intuitive mental models. Some of these synthetic models are similar to ones identified earlier in the literature (Baxter, 1989; Kikas, 1998; Küçüközer et al., 2009). Children with synthetic mental models of the day and night cycle offer either one of the following explanations: the sun and the moon orbit the stationary earth in a day, the earth and the moon orbit the sun in a day, the sun and the moon move in an up and down direction relative to earth and both are positioned in different sides of the earth, and the earth rotates in either an up and down or east to west directions and the sun and the moon are stationary and positioned on opposite sides of the earth (Vosniadou & Brewer, 1994).

Studies conducted with children from different cultures provided similar findings. Vosniadou et al. (2004) examined 5–9 year old Greek children's understanding of the day and night cycle. The movement of the earth around the sun was the most common alternative idea held by older children while the occlusion of the sun by the clouds or the mountains was prevalent among younger children (Vosniadou et al.). Dunlop (2000) surveyed Australian children's understanding of the day and night cycle during their visit to a planetarium. Dunlop reported that most children explained the day and night cycle with the earth's daily orbit of the sun or moon's blocking of the sun.

A study with American-Indian children demonstrated that these children hold ideas similar to European-American children, but some exhibit ideas that are culture specific reflecting Lakota Myth (Diakidoy, Vosniadou, & Hawks, 1997). Culture specific mental models of the day and night cycle were also detected in studies conducted with Indian children (Samarapungavan et al., 1996). Indian children were reported to hold mental models of the day and night cycle similar to European-American children. Younger children were more likely to hold intuitive mental models of the day and night cycle whereas older children were more likely to hold synthetic and scientific mental models. Indian mythology appeared to influence the construction of intuitive mental models. For example, young Indian children stated that the earth floats on a body of water and the sun and the moon move down into the water beneath the earth causing night (Samarapungavan et al.).

Siegal et al. (2004) examined 4–9 year old Australian and English children's understanding of the day and night cycle using two different interview formats. Researchers conducted two studies. In the first study Australian and English children were interviewed using models of the sun, earth and the moon, called explicit questioning by the researchers. The findings demonstrated that 70 % of the Australian and 43 % of English children were able to provide a scientific explanation for the day and night cycle. In the second study only 4–6 year old Australian children were interviewed using an interview format similar to Vosniadou and Brewer (1994) used. In this case, about 31 % of the Australian PreK children were able to provide a scientific explanation for the cause of the day and night cycle. The movement of the sun and blocking of clouds were the most common alternative explanations among the Australian children (Siegal et al., 2004).

Trundle, Saçkes, Smith, and Miller (2012) examined 45 US preschoolers' ideas about the objects in the sky. Only 43 % of the 3 years old children and 93 % of the 4 and 5 year old children were able to identify the day sky. However, only one 3 years old child (14 %) and about 36 % of the older children were able to articulate how they knew it was day. The majority of the 3 year old children (86 %) and more than half of the older children (64 %) did not relate the sun with the day sky or the stars with the night sky (71 % and 50 % respectively). While older children tended to know that the moon is observable during day and night, most children associated the moon only with the night (Trundle et al., 2012).

In another recent study, Tao et al. (2012) investigated 36 Chinese and Australian 8 year old children's day and night cycle. Most Chinese children explained the cause of the day and night cycle providing a description of their observations (31 %). Children associated the appearance of the sun with the day sky and the moon and the stars with the night sky. Teleological explanations were more common among Australian children. A few Australian (11 %) and Chinese (8 %) children provided the rotation of the earth as an explanation for the day and night cycle. The movement of the sun around the earth or behind the moon were other common explanations for the day and night cycle (Tao et al.).

## *Seasons*

Children's conceptual understanding of the cause of the seasons is another widely studied phenomenon by the researchers. Most studies on this phenomenon, however, targeted older children's and adults' ideas about the reasons for the seasons (Schoon, 1989; Spiropoulou, Kostopoulos, & Jacovides, 1999). The findings of these studies demonstrated that the distance model is the most common alternative conception held by children and adults (Atwood & Atwood, 1995, 1996; Kikas, 1998). Learners who hold the distance model believe that during cold seasons the earth gets further away from the sun and during the warm seasons the earth gets closer to the sun. The distance model is so pervasive that even after instruction that target the cause of the seasons children and adults tend to revert to this model (Kikas, 1998).

Few studies focused on young children's understanding of the season. Küçüközer and Bostan (2010) examined Turkish kindergartners' understanding of the cause of the seasons. The most common conception (slightly over 21 %) in their sample of 52 kindergartners was the earth's movement around the sun. Children asserted that as the earth orbits the sun different seasons occur. However, the children were unable to further articulate their explanations during the interviews. The second most common conception (25 %) was the attribution of intentionality to the seasons, labeled by the researchers as a "life centric" explanation. Children with this conception asserted that seasons occur to help plants grow and support life. More than 17 % of the kindergartners offered the movement of the sun around the stationary earth as the reason for the seasons. Children who held this conception suggested that summer takes place on the side of the earth that faces the sun while the other side experiences winter. Over 13 % of the children asserted clouds cause the seasons by either blocking the sunlight from reaching to the earth or bringing cold weather. Some children believe that dark clouds are indicators of the winter while white clouds are indicators of the summer. A few children in this sample held the distance model and over 7 % provided religious explanations for the cause of the seasons.

In their study, Tao, Oliver and Venville also investigated (2012) Chinese and Australian children's understanding of the seasons. While Chinese children used "precausal thinking" in explaining the cause of the season, Australian children mostly provided teleological explanations during the interviews. In their explanation of the cause of the seasons, Chinese children described the indicators or the products of the seasons. Australian children, on the other hand, talked about human needs in explaining the cause of the seasons. The earth's rotation, its position relative to the sun, and the sun's movement around the earth were other common explanations for the cause of the seasons. In another study with 7–14 year old Australian children's (n = 64) Dunlop (2000) examined children's understanding of the earth-moon-sun system. Dunlop reported that the majority of the interviewed children declined to offer any explanation for the reasons of the seasons. While the clouds were seen as the cause of winter by 7 % of children, 9 % of children suggested that the distance from the sun was the reason of the seasons . Only a few older children's responses included the Earth's tilt and/or orbit as causing the seasons.

Baxter (1989) reported similar findings from his study with older elementary children and middle school children. The distance model was the most commonly held alternative conception and some children asserted that clouds block the sun's heat or the sun moves to a different part of the earth. Kikas (1998) reported that some children think the earth's rotation around its axis causes the season. The side of the earth facing the sun gets more light from the sun and experiences the summer. These types of conceptions are reported from other studies as well (Küçüközer et al., 2009; Sharp, 1996).

## *Lunar Concepts*

The moon and the cause of moon phases have been popular concepts with researchers for many years. The latest literature reviews on students' understanding of lunar concepts revealed that most studies conducted on this topic were aimed at older elementary school children and high school and college students. A limited number of research studies on young children's understandings of lunar concepts have been generated (Bailey & Slater, 2003; Kavanagh, Agan, & Sneider, 2005; Lelliott & Rollnick, 2010).

Piaget (1972a) conducted some of the earliest research related to children's conceptions about the moon and its phases via interviews with children ages 6–11 years. Piaget proposed three stages of development concerning children's understanding of lunar concepts. In the first stage children think that the moon is made artificially. In this stage children explain phases of the moon by using the following ideas: the moon is born, the moon is cut by humans, and wind cause the phases of the moon. In the second stage the moon is perceived as partly a natural object. Children assert that the moon cuts itself causing different phases of the moon. In the final stage children's explanations become natural and they perceive the origin of the moon as completely natural. Children think that other natural objects or phenomena, such as clouds, cause the moon phases. Piaget reported that children in his study were aware of the phases of the moon.

Haupt (1950) interviewed 1st grade students' views about the structure, shape, and phases of the moon. He reported that children used a variety of analogies to explain the different shapes of the moon: ball, mouth, banana, and skinny. Haupt argued that these analogies may provide a basis for teaching scientific concepts. About 50 % of the children in Haupt's study were aware that the appearance of the moon changes in time. Children explained the cause of the change of the moon's shape by attributing causal actions to some natural and supernatural forces including wind, weather, clouds, and fairies.

Za'rour (1976) interviewed 220 Lebanese children, aged 4–9 years, from kindergarten to 4th grade to determine their ideas about the shape of the moon. Za'rour reported that overall 75 % of children were aware that the appearance of the moon changes, whereas only about 50 % of kindergartners were aware that the shape of moon appears to change. Significantly more Christian children described the moon as changing than Muslim children. About 19 % of children believed that when the appearance of the moon changes, the size of the moon also changes.

Küçüközer and Bostan (2010) investigated a sample of 52 Turkish kindergarten children's understanding of the phases of the moon. Almost 8 % of the children indicated that the moon's orbit around the earth causes the moon phases but none were able to further explain their responses. Over 15 % of the children indicated that the movement of the sun causes the moon phases. Children who held this conception stated that when the sun is closer to the moon we observe a full moon and when the sun is farther away from the moon we observe a crescent moon. About 12 % of the children's explanations included clouds. The children indicated that clouds block the moon and cause moon phases. Another 12 % indicated that there are many moons with different shapes in the sky and these moons become observable on different nights, causing the phases of the moon. Almost 14 % of the children offered religious explanations indicating Allah creates the phases of the moon. In a similar study, Doğru and Şeker (2012) investigated 48 Turkish children's, aged 5–6 years, understanding of lunar concepts. Almost 40 % of the children indicated that the moon moves. The Turkish children were more familiar with the crescent and the full moon phases (more than 50 %) and their drawings included exaggerated crescent moon shapes.

Researchers reported that children tend to perceive the moon as an indicator of nighttime (Küçüközer & Bostan, 2010; Trundle et al., 2012). While older children were more likely to know that the moon can be observed during the day and at night, most children associated the moon only with the night sky (Trundle et al., 2012). Hobson, Trundle, and Saçkes (2010) reported similar findings in a study where they examined understanding of lunar concepts of 21 children (ages 7–9 years) from a multi-aged, self-contained classroom. Results demonstrated that most children were not aware that the moon can be observed the daytime sky during some phases. Over three fourths of the children indicated that the moon can be seen only in the nighttime sky. Children's drawings included unobservable and nonscientific depictions of the moon phases. The most common phases included in children's drawings were the full moon phases followed by the third and the first quarter, new moon, and the waning crescent moon depicted with inaccuracies. Waning and waxing gibbous phases and the waxing crescent were the least common phases depicted in children's drawings. Although many children indicated that the phases of the moon appear in a predictable pattern none were able to produce the scientific sequence in their drawings and only 19 % were able to order the cards that illustrate the phases of the moon in an observable sequence. Before the instruction, none of the children provided a scientific explanation for the cause of the moon phases during the interviews where children were asked to support their verbal explanations with a 3D model of the sun-earth-moon system. More than half of the children provided alternative explanations for the cause of the moon phases. The most common explanation was the eclipse model where children asserted that objects including the earth block sunlight from reaching to the moon. About 24 % of the children's explanations included scientific elements and 19 % of the children's explanations included more than one alternative conception.

In a case study, Wilhelm (2009) investigated three 6–8 year old US children's understanding of the moon. Results demonstrated that children tended to provide "animistic" and "artificialistic" responses similar to what Piaget reported. Wilhelm noted that the children were familiar with the full moon and waning crescent moon phases. All three children believed that the moon is far away from the earth and appears much smaller than its actual size. None of the children used the eclipse model to explain the cause of the moon phases. One child explained the phases of the moon by attributing intentionality to the moon indicating that the moon desires to be half or full and it looks shiny and bigger when it is happy and smaller like a crescent moon when it is unhappy. Two children (6 and 8 years old) stated that part of the moon is covered by the sky causing the different appearances of the moon.

In a recent study case study with ten children, Venville, Wilhelm, and Louisell (2012) investigated 3–8 year old Australian and US children's conceptions of the moon. Children in this study were aware that the moon is a celestial object located in space and can be reached using special vehicles. Some children held animistic conceptions of the moon attributing intentionality to the moon. Two children indicated that the moon is stationary in the sky and the other two indicated that the moon moves in an up and down direction in the sky relative to the earth. Children also asserted that the change in the appearance of the moon is either due to cloud cover or the movement of the moon to other places. Children used the words round or circle to describe the shape of the moon.

Dunlop (2000) surveyed 67 Australian children, aged between 7 and 14, to determine their understanding of the earth-moon-sun system. Dunlop noted that the concept of moon phases was the least understood phenomenon in the study. Particularly, children have difficulty in explaining how the changing angle between the sun, earth, and moon cause particular lunar phases. The blocking or obstruction model (i.e., children indicated that something blocks the sun's light from reaching the moon) was the most popular explanation for the cause of moon phases. None of the children seemed to have a scientific understanding regarding moon phases. Dunlop (2000) argued that to understand the moon phases, children first need to comprehend the movement of celestial objects and the nature of the light.

Plummer (2009) examined first, third and 8 grade students' understanding of the movement of the celestial bodies in the sky. While all 3rd graders were able to depict at least two phases of the moon in their drawings, 1st graders' drawings included inaccuracies. Most children in the 1st grade held alternative conceptions regarding the duration of the moon phases. First graders asserted that phase of the moon changes in less than a day and some believed that the moon goes through the entire cycle of the phases in a year. More than half of the 3rd graders, on the other hand, were aware that the change in the appearance of the moon in a day would not be noticeable. While 45 % of the 1st graders were aware that the moon is observable during the daytime sky, 60 % of the 3rd graders stated that the moon is visible during the daytime sky. Most 1st graders (55 %) described the movement of the moon in the sky as up and down fashion involving a sudden rising to the zenith at night and setting down at the end. In contrast, 3rd graders (55 %) described the movement of the moon using a smooth curve across the sky. Some 3rd graders (20 %) indicated that the moon rises and sets from the same place in the sky. In another study with 24 3rd grade children, Plummer, Wasko, and Slagle (2011) reported that the majority of the 3rd graders (71 %) provided alternative explanations for the apparent movement of the moon in the sky. While 17 % of the children believed that the moon does not move, 25 % indicated that the moon moves in an up and down direction relative to the earth's horizon. Some children asserted that the moon remains in a stationary across from the sun (Plummer et al., 2011).

Baxter (1989) interviewed 20 children, aged 9–16 years, to determine their understanding of the cause of the moon phases. Baxter identified five categories, with four of the five categories being alternative to scientific explanations. The alternative ideas included: clouds cover part of the moon, the shadow of a planet causes moon phases, the shadow of the sun causes moon phases, and the shadow of the earth causes moon phases. Baxter reported that the shadow of the earth causes moon phases was the most popular explanation. Indeed, this alternative conception, which is often called the eclipse model in the literature, was reported as the most common alternative conception among children and their teachers (Barnett & Morran, 2002; Broadstock, 1992; Dunlop, 2000; Haupt, 1950; Hobson et al., 2010; Roald & Mikalsen, 2001; Saçkes, Trundle, & Krissek, 2011; Stahly, Krockover, & Shepardson, 1999; Trundle, Atwood, & Christopher, 2007; Za'rour, 1976).

## *Summaries of Children's Understanding of Space Science Concepts*

The findings of the Vosniadou and Brewer's study (1992) on children's understanding of the shape of the earth suggest that most children use a small number of well-defined mental models of the earth, such as the flat earth model, dual earth model, hollow sphere model, and flattened sphere model, in explaining the shape of the earth (Vosniadou & Brewer, 1992). Researchers argued that presuppositions or intuitions developed early in life are likely to constrain children's conceptions of the shape of the earth (Vosniadou & Brewer, 1992, 1994). The findings of the other studies with Greek, Chinese, New Zealand, and Australian children supported Vosniadou and colleagues' claims that children have intuitive and synthetic mental models of the earth and children's understanding of the shape of the earth is constrained by their presuppositions (Blown & Bryce, 2006, 2013; Hayes et al., 2003; Kallery, 2011; Tao et al., 2012). However, the findings of recent studies with Swedish, English, Australian, French, Estonian and Dutch children have challenged the Vosniadou and colleages' claims that children's understandings of the shape of the earth are coherent and constrained by presuppositions (e.g., Frède et al., 2011; Hannust & Kikas, 2007, 2010; Nobes et al., 2005; Schoultz et al., 2001; Siegal et al., 2004; Straatemeier et al., 2008). The results of these studies suggested that even the preschoolers have a scientific understanding of the shape of the earth and these studies reported that there was little evidence for the naive and synthetic mental models of the earth, and children's understanding of the earth is likely to be fragmented rather than coherent. Researchers suggested that naïve and synthetic mental models identified by Vosniadou and colleagues might be due to the way Vosniadou and colleagues' collected and analyzed their data (Nobes et al., 2005). For example, even the adults have difficulty understanding the earth drawing task used in Vosniadou and colleagues' studies (Nobes & Panagiotaki, 2007). When the instructions and the questions in the Vosniadou and Brewer's interview protocol are clarified the prevalence of naïve and synthetic mental models of the earth is substantially reduced (Panagiotaki et al., 2009). In these studies researchers used globes, pre-made clay or wooden models of the earth or forced choice questions with pictorial representations of the models of the earth along with or without interview questions. In response to the critics raised by recent studies, Vosniadou and colleagues (2004, 2005) conducted studies where they examined how different ways of data collection encourage different ways of reasoning. Vosniadou and colleagues found that while open-ended interview format encourages children to generate intuitive and synthetic models, forced choice questions and use of globe generates culturally accepted model of the earth and hinder construction of the intuitive and synthetic mental models of the earth. Vosniadou and colleagues have argued that forced-choice method of questioning and the use of globe requires recall rather than conceptual understanding and what appears to be a scientific response to the many questions might be false-positives. The use of forced choice questionnaires and a globe masks children's alternative ideas about the shape of the earth.

Studies on young children's understanding of the day and night cycle demonstrated that most preschoolers are able to recognize the day and night sky, yet they tend not to relate the sun with the day sky or the stars with the night sky not (Trundle et al., 2012). Research studies have demonstrated that most young children tend to perceive the apparent movement of the sun in the sky as the reason for the day and night cycle (e.g., Küçüközer & Bostan, 2010; Piaget, 1972a; Sharp, 1996; Siegal et al., 2004; Valanides et al., 2000; Tao et al., 2012). Some children assert that variation in the sun's strength cause the day and night cycle, and they believe that the sun is strong during the daytime and loses its strength by the end of the day (Kallery, 2011). Others related the day and night cycle to the movement of the moon in the sky and believe that when there is no moon it is daytime and when the moon is up it is nighttime (Küçüközer & Bostan, 2010). Other common misconceptions include clouds block the sunlight in certain degrees to cause the day and night cycle and the movement of the earth around the sun causes the day and night cycle (Baxter, 1989; Küçüközer & Bostan, 2010; Siegal et al., 2004). Surprisingly some children in late elementary grades held this idea (Baxter, 1989; Kikas, 1998). The simultaneous movement of the earth around its axis and the sun appears to be confusing for many young children and may contribute to the construction of this alternative idea (Valanides et al., 2000). Few children offered supernatural forces as being responsible for the occurrence of the day and night cycle, or they provided utilitarian explanations indicating that the night is for people to sleep and day is for work or school (Küçüközer & Bostan, 2010; Tao et al., 2012).

Vosniadou and Brewer (1994) reported that children have several mental models of the day and night cycle. Younger children believe that the sun moves away from the earth or the sun is blocked by either moving down behind the mountains or the clouds causing night. Older children, on the other hand, held either one of the following models: (1) the sun and the moon orbit the stationary earth in a day, (2) the earth and the moon orbit the sun in a day, (3) the sun and the moon travel in up and down direction and both are positioned in different sides of the earth, and (4) the earth rotates in either up and down or east and west directions and the sun and the moon are fixed and positioned on the opposite sides of the earth. Similar models of the day and night cycle were also identified in other studies with different cultural backgrounds (Diakidoy et al., 1997; Dunlop, 2000; Samarapungavan et al., 1996; Vosniadou et al., 2004).

The movement of the earth around the sun was the most common alternative explanation held by older Greek children while the blocking of the sun by the clouds or the mountains was prevalent among younger Greek children (Vosniadou et al., 2004). Most Australian children explained the day and night cycle with the earth's daily orbit of the sun or moon's blocking of the sun (Dunlop, 2000). American-Indian and Indian children held mental models of the day and night cycle similar to European-American children, yet they held some culture-specific mental models (Diakidoy et al., 1997; Samarapungavan et al., 1996). Some young Indian children asserted that the earth is positioned on top of water and the sun and the moon go down into the water beneath the earth causing night (Samarapungavan et al., 1996).

Research studies on children's understanding of the cause of the seasons suggest that children in the early years are inclined to explain the seasonal changes considering the position of the earth relative to the sun. Possibly based on their experiences with the heat sources, children believe that when the earth faces the sun or gets closer to the sun the summer takes place and when the earth faces away from the sun or gets away from the sun the winter takes place (Kikas, 1998; Küçüközer & Bostan, 2010; Tao et al., 2012). As with the day and night cycle, some children used clouds seems to explain the seasonal change (Dunlop, 2000). Utilitarian explanations (i.e., the occurrence of seasons is intentional and fulfills some purposes) and religious explanations also are common among children in the early childhood period, and these utilitarian explanations appear to diminish in frequency as children get older (Küçüközer & Bostan, 2010; Tao et al., 2012).

The findings of studies on children's understanding of lunar concepts have shown that the majority of the children, even at early ages, are aware that the appearance of the moon changes over time (Piaget, 1972a; Plummer, 2009; Za'rour, 1976). Most children expect the moon to be observable only in the nighttime sky and few are aware that about half of the time the moon also is observable in the daytime sky (Doğru & Şeker, 2012; Hobson et al., 2010; Küçüközer & Bostan, 2010; Plummer & Krajcik, 2010; Trundle et al., 2012). Children use a variety of analogies to describe different shapes of the moon (Haupt, 1950; Küçüközer & Bostan, 2010; Trundle et al., 2007; Za'rour, 1976), and children are more familiar with some phases (e.g., full moon, crescents, and the waning phases of the moon) than other phases (e.g., gibbous moon) (Doğru & Şeker, 2012; Hobson et al., 2010; Trundle et al., 2007). Also, children mostly use nonscientific shapes, such as an exaggerated crescent moon, to represent different phases of the moon (Doğru & Şeker, 2012; Hobson et al., 2010; Osborne, Black, Wadsworth, & Meadows, 1994; Trundle et al., 2007). Children seem to understand that lunar phases appear in a sequence, but they are unable to identify the observable scientific sequences (Hobson et al., 2010; Trundle et al., 2007). Some children believe that when the appearance of the moon changes, it actually changes in size (Roald & Mikalsen, 2001; Za'rour, 1976). The explanations children provided in regard to the change of the moon's appearance differ as they get older. While very young children see human actions and supernatural forces as being responsible for the lunar phases, as children move into the upper grades they begin to explain changes in the appearance of the moon via other natural phenomena, such as wind and clouds (Piaget, 1972a; Haupt, 1950). During the early elementary grades children begin to include blocking mechanisms in their explanations for the cause of the lunar phases. Children begin to assert that objects including the earth block sunlight from reaching to the moon (Hobson et al., 2010). This causal mechanism appears to remain popular even into adulthood (Trundle, Atwood & Christopher, 2002).

## Directions for Future Research

Children's understanding of various space science concepts including the shape of the earth, day and night cycle, and lunar concepts have been extensively studied following Piaget's earlier studies with young children. Although a relatively large amount of information is now available on what young children think about various space science concepts, less attention has been devoted to children's understanding of concepts related to earth science. Most studies in this domain targeted children's understanding of atmospheric phenomena. There is a lack of research that addressed young children's conceptual understanding related to earth science, such as properties of rocks and soils and the pattern of changes in the earth's materials over time. Future studies should target young children's understanding of earth science concepts.

Samarapungavan et al. (1996) have argued that children's understanding of the shape of the earth may impose a second-order constraint on their understanding of related astronomical phenomena. In other words, children's beliefs about the properties of the astronomical objects, such as the shape of earth, influence the type of conceptual understandings they construct about the day and night cycle. This hypothesis has not been given much attention in the literature. The findings of a recent study provided supporting evidence for the second-order constraint hypothesis. Tao et al. (2012) demonstrated that children who held the spherical earth model were more likely to hold a scientific understanding for the day and night cycle. However, the findings of another study suggest that children with a scientific understanding of the shape of the earth do not necessarily have a scientific understanding of the day and night cycle (Straatemeier et al., 2008). More research is needed to understand if and how children's understanding of one astronomy concept influences their understandings of other astronomy concepts.

Studies have demonstrated that early exposure to the scientific model appears to facilitate PreK children's understanding of the day and night cycle (Siegal et al., 2004). Likewise, well-designed instructional activities can be effective in promoting conceptual change even with early elementary school children (Hobson et al., 2010). Future studies should examine the efficacy of instructional interventions in helping young children develop an understanding of basic earth and space science concepts. Also, specific cognitive and affective characteristics, such as metaconceptual awareness and motivational beliefs about learning science that facilitate young children's understanding of earth and space science concepts remain unexplored. Therefore, future studies should examine the role factors (e.g., cognitive, metacognitive, and motivational variables) play in young children's learning of earth and space science concepts.

Several researchers have proposed and attempted to develop a learning progression for space science concepts (Plummer, 2009; Plummer & Krajcik, 2010). However, these studies have utilized pre-post test designs or collected cross-sectional data. Although these types of studies are informative, they are limited in contributing to our understanding of how children's understanding of natural phenomena develops in time and in response to instructional interventions. Therefore, longitudinal studies should be conducted to describe the developmental trajectories of conceptual understanding of earth and space science concepts in young children. Longitudinal studies can provide valuable information regarding the nature and the mechanism of the formation of alternative and scientific conceptions by revealing how different levels of understanding and types of alternative conceptions lead children to take different paths in their learning of science.

Parents help children in making sense of the natural world around them and provide relevant early science learning experiences in and outside of home contexts. These early science learning opportunities offered by parents have potential to foster children's interest in learning science and contribute their understanding and use of science concepts and skills (Alexander, Johnson, & Kelly, 2012; Callanan, Jipson, & Soennichsen, 2002; Tenenbaum, Snow, Roach, & Kurland, 2005). Future studies should also focus on children's early science learning experience at home and parent–child interactions in the context of learning and talking about earth and space science concepts.

Studies demonstrated that there is no significant difference between boys and girls in their understanding of the shape of the earth, and the boys and girls appear to follow a similar trajectory in the development of their understanding of the earth (Bryce & Blown, 2007; Diakidoy et al., 1997; Samarapungavan et al., 1996). Future studies should investigate whether this also the case for other space science concepts. Donaldson (1973) reported that boys demonstrated a better understanding of the rainfall phenomenon than girls did. In contrast, the findings of a more recent study suggest that girls might have a richer experience and understanding of the rainfall phenomenon than boys (Saçkes et al., 2010). Research studies suggest that children's interest in science concepts begins to differentiate before formal schooling possibly due to parental influences (Freeman, 2007; Simpkins, Davis-Kean, & Eccles, 2006; Tenenbaum et al., 2005; Tracy, 1987). These differentiated early science experiences might lead boys and girls to develop advanced domain-specific knowledge in different domains of science. Future studies should investigate possible gender differences in understanding earth and space science concepts and whether early gender socialization leads children to develop different levels of expertise in the domains of science.

And finally, cross-cultural studies should be conducted to describe possible constraints and contributions of culture on children's understandings of earth and space science concepts. Although children in different cultures appear to share some common intuitive and synthetic mental models of the earth, they also have some unique mental models of the earth (Bryce & Blown, 2006; Vosniadou et al., 2005). Likewise, children held some culture-specific mental models of the day and night cycle (Diakidoy et al., 1997; Samarapungavan et al., 1996). Children's conceptual understandings of the lunar concepts are likely to be influenced by their culture too. For example, the Turkish children were more familiar with the crescent moon possibly due to the crescent moon being a cultural and a national symbol represented on cultural artifacts and on the Turkish flag (Doğru & Şeker, 2012). Za'rour (1976) reported from his study with Lebanese children that significantly more Christian children perceived the moon as changing than Muslim children. His finding is very surprising if one considers the role of the moon as a cultural object in Muslim culture. Future studies may focus on how children's cultural knowledge about the moon affects their learning of lunar concepts, and how children's cultural concepts of the moon change when they encounter the scientific concept of the moon in PreK and early elementary grades.

Primary goals of early science learning experience involve developing young children's scientific thinkings skills, conceptual understanding of natural phenomena, and attitudes toward science (Saçkes, 2014; Saçkes, Trundle, Bell, & O'Connell, 2011; Trundle & Saçkes, 2012). Studies have demonstrated that young children have a strong predisposition to inquire about earth and space. Therefore, children's early exposure to earth and space science concepts through developmentally appropriate learning opportunities may promote their scientific inquiry skills, conceptual understanding of earth and space science phenomena, and attitudes toward doing and learning science (Saçkes, 2014; Saçkes et al., 2011; Tao et al., 2012).

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# Chapter 4

# Young Children's Ideas About Physical Science Concepts

**Yannis Hadzigeorgiou**

Over the past three decades researchers from the fields of science education and cognitive psychology have provided ample evidence that children's ideas in physical science, especially before formal instruction begins, differ from the scientific ones. Despite their everyday experiences with physical phenomena involving physical concepts such as those of heat, electricity, light, matter, and force, children, according to this evidence, cannot systematize these experiences into a coherent form that can allow them to build scientific knowledge. In fact, these early experiences make them entertain ideas and represent these ideas with mental models, that are markedly different form the ideas and the models of science, but which (mental models) are applied by children, sometimes consistently, in their attempt to make sense of and explain natural phenomena (Carey et al., 1989; Driver, Leach, Millar, & Scott, 1996; Pfundt & Duit, 1994; Trundle, 2010; Vosniadou, Skopeliti, & Ikospentaki, 2004). And it is for this reason that teachers should have knowledge of these ideas when designing effective instruction, especially in the context of early childhood science education (Hadzigeorgiou, 1998, 2005; Ravanis, 2003; Trundle & Sackes, 2012).

According to research, young children have a range of ideas about natural phenomena and physical science concepts. There is now a consensus that such ideas are common sense ideas, (b) develop prior to formal science instruction in school, (c) cross national boundaries (i.e., children, regardless of nationality, hold similar ideas about the same phenomenon and concept), (d) are used by children to interpret new information and experiences, both informal/spontaneous and formal/structured (e.g., children use their naïve 'motion-implies-a-force' idea, to make sense of phenomena of force and motion), (e) are influenced by the socio-cultural context (e.g., children's conception of time and space, developed through religious/cultural factors, influences their understanding of such concepts as velocity, acceleration), (f) they have historical parallels (i.e., they are very similar to the ideas that scientists

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held in ancient times and the middle ages) and (g) can resist formal instruction, in the sense that they do not change easily and require specific teaching strategies (Driver, Guesne, & Tiberghien, 1985; Hadzigeorgiou, 1998, 2001a, 2003; Pfundt & Duit, 1994). And it is for all these reasons that children's ideas in science are of great importance in the context of teaching and learning science (Akerson & Flick, 1999; Driver et al., 1994; Fleer, 1999; Fleer & Robbins, 2003a; Wee, 2012)

This chapter will provide a review of young children's ideas about physical science concepts, and subsequently will discuss the perspectives/theoretical frameworks on which the studies that researched these ideas were based, as well as the research methods that were used, and the possible limitations of these methods. The implications of these studies for classroom practices, and directions for future research will be also discussed.

## Reviewing the Research Literature

The vast majority of the studies prior to the early 1990s investigated upper elementary and high school pupils' construction of understanding in science (Driver et al., 1985; Pfundt & Duit, 1994). These studies provided an excellent source of information about pupils' ideas of specific science concepts. However, not many studies were conducted with young children, that is, children younger than 9/10 or even younger than 8 years old (Fleer & Robbins, 2003a, b; Hadzigeorgiou, 2001a). The increasing awareness of the importance of, and therefore an interest in, early childhood science education became apparent in the late 1990s' (e.g., Eshach & Fried, 2005; Hadzigeorgiou, 2001a; Trundle & Sackes, 2012), and resulted in studies with very young children. Even studies which targeted upper elementary school children also included in their sample children under the age of 8. Certainly, the number of such studies is still limited, compared with studies that targeted older children, but they can nonetheless provide useful information regarding young children's ideas in science.

What follows is a review/summary of the main findings regarding the following seven concepts and phenomena: matter, heat and temperature, evaporation and condensation (and the water cycle), force and motion, floating and sinking, and light. However, it is important to stress here that, by and large, young children, especially those between 4 and 6 years, do not provide explanations but descriptions of phenomena (e.g., Bar, 1989; Kamii & DeVries, 1993; Hadzigeorgiou, 2001a). And when they do give explanations, these could be classified as naturalistic (i.e., attributing material character to a phenomenon or event), non-naturalistic (e.g., magical, teleological, intentional, metaphysical), or synthetic (i.e., including both naturalistic and non naturalistic elements) (Carey, 1986; Christidou, Kazela, Kakana, & Valakosta, 2009; Hadzigeorgiou, 2001a; Piaget, 1929). It is also important to stress that young children's ideas can vary according to the type of the phenomenon discussed (Christidou et al., 2009; Tytler, 2000; Tytler & Peterson, 2004b).

## *Young Children' Ideas About Matter*

Our first information about children's conception of matter come from Piaget and Inhelder's (1974) studies on the development of the child's construction of concept of "quantity". According to these studies, for very young children matter has no permanence, that is, when matter disappears (e.g., when salt or sugar dissolve in water) it ceases to exist. However – and this is a quite interesting finding – despite its "disappearance," some of the properties of matter (e.g., sweetness, saltiness) can continue to exist completely independently of it. This conception of matter is very prevalent at the preoperational stage and the early concrete operations stage. At these early stages simple physical transformations (e.g., dissolution, melting, freezing) are not conceived as reversible. Also for very young children, as Piaget and Inhelder have reported, weight is a not an intrinsic property of matter (and as such weightless matter is an acceptable idea for very young children).

Important studies concerning young children's understanding of matter were undertaken in the mid 1980s and early 1990's. Their findings are quite informative. According to Stavy's (1991) study, first graders (6/7 year olds) can explain the concept of matter by means of example and by means of function. She found that explanation by means of properties (i.e., hardness, color) were given only by fifth and seventh graders. Given that Stavy (1991) used four groups of children (i.e., 1st, 3rd, 5th, and 7th graders) with 20 children in each group, it is of interest to look at the explanations of each group (see Table 4.1).

Stavy's (1990) and Bar and Travis's (1991) studies have also provided evidence that children younger than 8 cannot distinguish between matter itself and the phenomena in which it becomes involved. In regard to the relationship between matter and weight, Stavy (1990) has found that even for 9 year old children weight is not seen as an intrinsic property of matter, thus reconfirming Piaget and Inhelder's (1974) findings (Table 4.2).

Such naïve conceptions of matter had also been reported earlier by Stavy and Stachel (1985a, 1985b). More specifically, in a study with children of the age range 5–12 years, Stavy and Stachel (1985b) reported on a naïve classification of solids and liquids. For children, the easier it is to change the shape of the solid, the less likely it is to be included in their group of solids. What have also reported is that children have more difficulty classifying solids than liquids (e.g., new liquids are

**Table 4.1** Children's explanations of matter (percent in each grade)

| Explanation | Grade 1 | Grade 3 | Grade 5 | Grade 7 |
|---|---|---|---|---|
| By example | 40 | 45 | 20 | 20 |
| By function | 45 | 20 | 25 | 15 |
| By structure | 0 | 15 | 25 | 15 |
| By properties | 0 | 0 | 35 | 55 |

Source: Stavy (1991)

**Table 4.2** Descriptions of Piagetian levels of children's understanding of nature of heat

| Level | Descriptions |
|---|---|
| Early to middle concrete (9/10 years) | Heat is associated with its effects (e.g., burning, heating, melting, but is not modeled at all |
| Late concrete (11/12 years) | Heat is associated semi-quantitatively with its effects (i.e., the more the heat the more the effect, and more substance requires more the heat the more the effect, and more substance requires more the heat the more the effect, and more substance requires more heat for a given effect. No modeling of heat as an extensive property because the variables of mass and quantity are not differentiated |
| Early formal (12/13 years) | Heat is differentiated from the amount of substance and sensation of hotness. Children have an implied caloric- liquid model of heat flow, and can take mass and temperature as two independent variables in simple calculations on heat exchange |

Source: Shayer and Wylam (1981)

more easily classified than new solids). An explanation for this finding may be the fact that, in their physical appearance, solids are more varied than liquids.

In regard to the phenomenon of change in the states of matter, Stavy (1990) reported three different rules used by children of the age range 9–13 in thinking about such changes:

- Rule 1 (common among 9 year olds): gas has no weight.
- Rule 2: gas always weighs less than liquid (or solid).
- Rule 3: the weight of a gas (in a closed system) is equal to that of the liquid or solid from which it is derived.

Very similar rules have been reported by Stavy and Stachel (1985a), during the change of state of matter from solid to liquid:

- Rule 1: the liquid weighs more than the solid (most common among 5 year old children, probably because liquids fall downward).
- Rule 2: liquids have no weight since their heaviness cannot be felt.
- Rule 3: liquids weigh less than solids.
- Rule 4: the weight of a liquid is equal to that of the solid from which it was formed.

In regard to the changes in the state of mater, young children up to the age of 10 cannot understand how matter changes state (phase), because they do not have an understanding of the particulate model of matter (i.e., understanding of atoms and molecules). In fact, there is evidence that even children of the upper grades of elementary school believe that properties at the macroscopic level also hold at the microscopic level (Driver et al., 1985). The difficulty young children have to understand evaporation, as will be discussed later in this chapter, is apparently due to their difficulty to understand phase changes from liquid to gas (i.e., difficulty in understanding the nature of matter inside the bubble).

One of the reasons that young children have difficulty in approaching and understanding phase changes of various physical phenomena, may very well be attributed to the fact that they have already constructed broad categories for liquids and gases, that can be called 'prototypes'. Thus for children, two prototypes such as 'air and 'water' can be used for understanding various phenomena (Krnel, Watson, & Glazar, 1998; 2005). There is evidence, however, that when a material changes from one state to another, especially in the case of a solid turning to a liquid, children use the prototype of water, to say that the "solid becomes water". And they do not recognize that the material remains the same, despite the change of state (Hadzigeorgiou, 2001a). It is therefore quite reasonable, in the light of these two prototypes, that children, even of the upper grades of elementary school, have difficulty to understand such phenomena as change of state of acetone (evaporation), iodine (sublimation), etc. The inability on children's parts to classify matter is an idea that needs to be seriously considered when planning science activities (Stavy, 1990, 1991; Varelas et al., 2008). A more recent study reported that elementary school children used four distinct ways to think about states of matter. More specifically children used macroscopic properties, everyday functions, prototypes, and process of elimination (Varelas et al., 2008).

Our studies at the university of the Aegean provide ample evidence that for very young children the concept of matter is perception-bound, which reconfirms what the aforementioned studies have reported. More specifically, in our studies we found that children of the age range 4–6 years tend to associate matter mainly with solids, "because they can touch and hold them", although some children do make reference to water or other liquids (e.g., oil) as having or being matter. There has been agreement among researchers that for young children matter is associated with solid and inanimate objects (Hadzigeorgiou, 2001a).

In regard to the existence of air, we have found that almost all children between 4 and 6 years of age think that air exists only when it moves. This reconfirms Piaget's (1969) and Stavy's (1990) findings regarding the existence of air, and is similar with what Sere (1985), found with 11–12 year old pupils: a gas exists only when it moves (i.e., when they feel the pressure that the gas can exert).

It is interesting to note that there is evidence that young children (9 years old) believe that water itself is not matter, although they believe that all liquids are water (Stavy, 1990). However, it is also interesting to note that very young children can associate matter with "light, because they can see it", but not with air, "because they can not see it" (Hadzigeorgiou, 2001a). And we have also found evidence that children of the age range 4–6 years can have contradictory ideas concerning the relationship between states of matter and weight. Contrary to what Stavy and Stachel (1985a) have reported, some children tended to believe that liquids are lighter than solids "because, like water, liquids, can spread, when spilled, over a surface", or "because they are not thick" etc. When confronted with a bowl of water and a piece of ice floating on the water in the bowl, some children did keep on believing that ice floats because it is flat, like a boat, which is much heavier than water". Upon questioning, 5–6 year old children thought that ice is heavier than water, even in the case of water that freezes (i.e., when they themselves put in a freezer a quantity of water, which changes into ice). The heaviness of ice was explained by reference to "thickness", "hardness", even by reference to "temperature"! As a 5 year old girl said, "cold things stay up […] in the mountain everything is colder, but on the beach is much warmer" (Hadzigeorgiou, 2001a)!

The conceptual difficulties that young children have in regard to the concept of matter and, of course, the naive ideas about matter that they entertain, can be explained not only by the fact that their concept of matter is perception bound, but also by children's inability to conceptualize the idea of density (even though they may have conquered the concept of conservation). This is true even for some children of 7 years (1st graders) who are conservers (Hadzigeorgiou, 2001a). As Stavy (1990, p. 257) pointed out, "The weight of matter (and not necessarily its quantity) is grasped as a function of an undefined property related to its state, density (the specific 'heaviness' that characterizes a particular material, rather than the mass/volume relationship), and hardness or strength". Thus a dense solid whose weight can be felt by children is considered heavy by the young child, while the gas obtained from it is believed to have no weight.

The difficulties that children have understanding changes in the state of matter, and more specifically changes in the state of water, have been reported by more recent studies, which are included in the section on evaporation, condensation and the water cycle. These studies can be considered complementary to the ones cited in this section, in the sense that they help us clarify why young children have difficulty with the concept of matter, particularly with changes in the state of matter.

## *Young Children' Ideas About Heat and Temperature*

Research into young children's ideas of heat provides evidence that "heat" (like "cold") derive from a phenomenological kind of understanding. Sense experiences with heat sources make children associate heat with its effects. Contrary to a study by Shayer and Wylam (1981), we have found that some 6/7 year old children can model heat as an invisible substance. Although most children of the age range 4–6 cannot model heat, and focus just on its effect, some children around 6 years of age can offer explanations like "there is something that moves from the hot body into my hand when I touch it […] and air can make this {something) reach my hand if I do not touch it" (Hadzigeorgiou, 2001a). The ideas that "cold is radiated by a piece of ice" and that "heat is radiated from a stove", upon further questioning, revealed that "heat" and "cold" are two different "invisible substances". This idea of heat as a substance was found in five 6 year old children and three 7 year old children in a sample, which, over a period of 4 years, included 178 children. So it was not a prevalent idea among children of that age range, given that the vast majority of children had constructed an anthropomorphic and/or magical explanation for heat and cold. Yet the idea of modeling at an early stage is a possibility.

Children's early everyday experiences with heat sources (e.g., stoves, candles, sun) help develop a mental model that involves spatial relationships between the child's own body and the source of heat and also between the source of heat and the object affected by the heat. However, heat is localized in the source of heat. There is evidence that some children of the age range 6–7 years may have difficulty distinguish between heat and the source of heat (Hadzigeorgiou, 2001a). There is also evidence that idea of heat, as an independent entity, begins to be developed after the age of 8. Before that age children do not have the idea of heat as something extended in space and they never use spatial terms to describe heat. As Albert (1978) reported, when children, especially those between 4 and 6 years of age, talk about their feeling of hotness, they talk as if hot objects make them feel hot instantaneously. It is after the age of 8 that children begin to think of heat as something active and moving, that is, something they can feel and visualize in space (Albert, 1978).

The conduction of heat is also a difficult concept for very young children, as is the distinction between good and bad conductors of heat. It has been reported that many young children explain the conduction of heat from one point in a metal bar to another point by invoking the idea of the surrounding air (Ravanis, 2003).

Related to the concept of heat is the phenomenon of melting. Although this phenomenon is about a change in the state (phase) of matter, the difficulty for young children to understand it is also due to the fact that they cannot associate melting (and freezing) with heat. Although everyday experiences involving ice cubes that melt if left outside the freezer, or water that can freeze if placed in low temperatures, some very young children, more often than not, cannot predict what would happen in unfamiliar situations (e.g., an ice cube placed on top of a stove) (Ravanis, 2003) (Table 4.3).

**Table 4.3** Young children's categories and thought patterns for the concept of heat

| Category | Description |
|---|---|
| *Construction of "Hot Bodies" (4–6 years)* | (a) Directional/spatial construction of "hot bodies" |
| | (b) Spatial construction of a source of heat and the object affected |
| | (c) Heat as something suddenly created or destroyed |
| *Labile Nature of Heat (7–9 years)* | (a) Conditional nature of heat based on systems of plans. |
| | (b) Conditional nature of heat based on own body activities |
| | (c) "Becoming hot" as a process |
| *Heat as a Single Dimension (4–6 years)* | (a) Hot and warm as a single dimension |
| *Heat as an Independent Entity (8 years and older)* | (a) Heat started and maintained by a source |
| | (b) Heat as an extended entity in space |
| *Conceptualization of Temperature (9/10 years and older)* | (a) Levels of heat constructed on the basis of manipulations involving dial settings |

Source: Albert (1978)

## *Young Children' Ideas About Evaporation, Condensation and the Water Cycle*

Related to the understanding of the concept of heat are the concepts/phenomena of evaporation condensation, and the water cycle. The studies that were conducted have produced evidence of the difficulties young children have to conceptualize them. Given that young children's thinking is perception bound, the process of boiling is more readily understood than the processes of evaporation and condensation. The reason is the direct perceptual evidence available to children. Indeed, for the phenomenon of evaporation, the phase change from liquid to gas can be seen and even heard. As Bar & Travis (1991) have observed, this perceptual evidence affects mainly age levels younger than 12 years.

Although for children between 4 and 6, and especially for children between 4 and 5 years of age, the phenomenon of evaporation is something "magical", since for them the water "just disappears", without being able to explain it (Hadzigeorgiou, 2001a; Tytler and Peterson, 2004b). This is, of course, in line with the view that young children's explanations are just descriptions of phenomena (Kamii & DeVries, 1993). However, young children's ideas about matter as well as the complexity of the phenomenon of evaporation itself must also account for the difficulty they have to conceptualize it. It is after the age 7/8 that children can think that "water must go somewhere" when it evaporates. The fact that matter inside the bubbles can be described as water, water vapor, water and heat, air, heat or smoke (Bar & Travis, 1991), does provide evidence of the complexity of the phenomenon of evaporation.

As Bar (1989) and Bar and Travis (1991) have reported, the development of the views concerning the concept of evaporation, in the age range 5/6-12, follows certain attainment stages. For example, in the case of water evaporating from inside a container resting on the floor, children' ideas were as follows:

- the water disappeared,
- the water penetrated the floor,
- the water evaporated into a container,
- the water evaporated and scattered into the air.

By and large children of the age range of 7–9 years thought that that during the process of drying the water penetrated solid objects. It was around the age of 9 that children thought that water evaporates (i.e., it changes into unseen vapor). This change is related to the ability to conceive the existence of air in the room. As Bar and Travis (1991) reported, this development is brought about with the ability to conceive the conservation of the quantity of liquid and air (see Table 4.4). They point out that this finding was not reported by studies that were carried out with children older than 12. The progression, however, form the first to the fourth conception can also be attributed to the ability to conceive the existence of air and also to identify matter inside the bubbles (i.e., their views changed from water inside the bubble to air inside it).

**Table 4.4** Children's ideas about water evaporation

| Age | Ability to conserve | Ideas about evaporation |
|---|---|---|
| 5–7 | water and air not conserved | When water dries (evaporates), it disappears |
| 6–8 | water conserved, air not conserved | When water dries (evaporates), it penetrates solid objects |
| | | Clouds can open and close to store and release water |
| 6–9 | water conserved, air not conserved | Phase changes happen only when something boils |
| 7–10 | water and air conserved | Water evaporates into a container |
| 9–10 | water and air conserved | Water changes to vapor |
| 11–15 | water and air conserved | Weight is attributed to air and water vapor and small drops of water |

Source: Bar (1989), Bar and Travis (1991)

Tytler and Peterson's (2004b) study has found evidence of the following six conceptions/explanations for evaporation:

- It is just like that: Evaporation is explained on the basis that this always happens, like the puddles, dried up in the sun dried up in the sun‘ or ’the water soaks into the clothes and the heat of the sun dries the water up.’
- Associations: Evaporation is explained through associative thinking that is offered as an explanation in its own right – for example, a reference to water‘s ’dissolving’ into clothes or puddle drying up because the strength of the sun overcomes that of the cold water.
- Displacement Local: The liquid changes position, but not form, as in ‘dripping to the ground,’ going underground,“ or ‘soaking into’ surfaces.
- Water Cycle: The student mentions the water going to the sky, or the sun, or the clouds.
- Air: Water goes into or comes from the air or atmosphere. The critical difference that distinguishes this conception from the water-cycle conception is the implication that water goes ‘into’ air as a local entity, rather than ‘up to’ the air or sky.
- Change in Form: Water changes to or from another form, which could be perceptible, such as steam or fog or moisture, or imperceptible, such as vapor or gas.

As Tytler and Peterson (2004b) report, the children of the age range 6 to 8/9 can move fluidly among the different conceptions, with the first four conceptions/explanations being more prevalent. This finding provides evidence that these four conceptions "should be viewed as a set of conceptual tools that are available to children at a young age and that they apply to different contexts in a flexible way" (Tytler & Peterson, 2004b, p. 114). This means that they do not represent fixed positions, since children, even at the kindergarten level, can use all four conceptions/explanations.

Related of course, to the phenomenon of evaporation is condensation. However, although even very young children have already had experiences of the phenomenon (e.g., on a window glass and the bathroom mirror), they find it difficult to understand it due to their difficulty to conceptualize it, because of their difficulty to think that air exists in a room, and also to conceptualize changes in phases of matter (e.g., Bar & Travis, 1991; Bar & Galili, 1994). There are young children, who believe that what happens "when our breath makes a mirror look hazy/misty" is due to "the mirror itself", to the fact that "mirrors are always cold […] cold things look whiter", "cold seeps through the mirror" (but unable to explain where this cold actually comes from). Some first and second graders, and more ninth graders, have the idea that the appearance/formation of water on the mirror is possible, although they cannot explain where that water comes from. It deserves to be mentioned that 68 % of children's (5–6 years old) explanations were anthropomorphic and magical, and 32 % of them were just descriptions (Hadzigeorgiou, 2001a).

Tytler (2000), in comparing 1st and 6th graders conception of evaporation and condensation has found the same categories (see above) for both phenomena (i.e., "just like that", "associations", "displacement-local", "displacement-water cycle", "change in form"). For the 1st graders explanations through "associations" were most prevalent, but "displacement-local" and "just like that" were also found. As Tytler (2000) observes, "The difference with condensation compared to evaporation phenomena is noticeable, with the idea of water exchange with the air less prevalent, and the loss of the options of using the word, and the water cycle image. The use of associative thinking becomes more prevalent with this less familiar phenomenon" (p. 453).

What must be said about both evaporation and condensation is that both phenomena involve notions such 'air', 'gas', even 'steam', and 'vapor', and, therefore, with very young children, a confusion is something natural to occur. Evidently, the difficulty to understand these two phenomena makes the water cycle a phenomenon that poses difficulties to very young children, despite the fact that it is a common topic in early childhood education. Piaget's (1927/1969, 1974) work has provided evidence that for very young children clouds and rain are independent, which have been confirmed by a number of researchers (e.g., Bar, 1989; Christidou, 2006; Hadzigeorgiou, 2001a). Although some children can use analogies associated with water (Hadzigeorgiou, 2001a), their initial ideas do not provide evidence of a direct link between water and clouds. It takes time for them to associate clouds with water, air and heat. Their initial ideas are anthropomorphic, religious, and magical (e.g., God or people make clouds, clouds are made of smoke). As children begin to develop the concept of conservation (mass and substance) they begin to understand phase changes and therefore the water cycle (see Table 4.2).

Bar's (1989) study has suggested that understanding the water cycle is directly related to three levels they progress through in their understanding of conservation: (a) neither water nor air are conserved, (b) both water and air are conserved, and (c) water is conserved, but not air. Thus, although children can begin to focus on the liquid aspect of the water cycle (i.e., water goes up from the sea into the clouds, then water is stored in the clouds, stays there and then falls back to Earth), in order for them to understand her water cycle, they have to grasp the processes of evaporation and condensation (Bar, 1989; Bar & Travis, 1991; Tytler, 2000). In Chap. 3, which focuses on earth and space science concepts, the water cycle and related phenomena are discussed in more detail.

## *Young Children' Ideas About Forces and Motion*

Although naïve ideas about motion and forces have been investigated with adolescent and upper elementary pupils, there are few studies with very young children. The concept of force, although a ubiquitous concept in children's daily experiences, is a difficult one to conceptualize. The reason is that children's experiences with forces and motion (i.e., while walking, running, sliding, pulling, pushing) help develop a 'force-in-the-direction-of-motion' mental model that makes them believe that motion always implies a force (Hadzigeorgiou, 2001a). This is a strong mental model in the sense that it has been identified in adolescents and even in adults, as research has shown, despite years of formal instruction (Pfundt & Duit, 1994). All young children, at least from our findings, believed that objects possess a force, which can be transferred from other objects (e.g., our hand, our foot). Although this might be taken to be an intuitive idea of energy transfer, children's idea that objects have an 'internal force' that keeps them in motion is very widespread among young children (Hadzigeorgiou, 2001a). It is interesting to note that this 'internal force' idea is akin to a widespread idea in the Middle Ages, the so-called impetus theory that explained phenomena of motion (Gilbert & Zylbersztajn, 1985).

An interesting cross-age study, which explored children's meaning of the concept of force, was conducted by Ioannidis and Vosniadou (2002). This study confirmed the finding concerning children's belief in an internal force. However, this study also identified a number of meanings for the concept of force. In hypothesizing four core conceptions of force that underlie students' understanding of the concept force, that is, Internal Force (i.e., an internal property of stationary objects related to their size and/or weight), Acquired Force (i.e., an acquired property of inanimate objects that explains their motion and their potential to act on other objects), Force of Push/Pull (i.e., the interaction between an agent (usually animate) and an (usually non-animate) object), and Force of Gravity (i.e., the interaction at a distance between objects and the earth), they identified the following meanings for force. It is interesting to note that the meaning young children give to force is also shared by 4th graders (see Table 4.5).

**Table 4.5** Frequencies of the meaning of the concept of force in kindergarten and three grades

| Conception of force | Kindergarten | 4th | 6th | 9th |
|---|---|---|---|---|
| Internal | 7 | 4 | | |
| Internal/affected by movement | 2 | 2 | | |
| Internal/acquired | 4 | 10 | 9 | 1 |
| Acquired | 5 | 11 | 2 | |
| Acquired/force of pull & push | 5 | 10 | | |
| Force of pull & push | 1 | | | |
| Gravitational | 3 | 1 | 16 | |
| Mixed | 2 | 6 | 4 | |

Source: Ioannidis and Vosniadou (2002)

The idea that big objects exert a larger force than smaller objects when they collide with each other – an idea that is similar with what high school students think! – is very prevalent among 5–6 year old children (Hadzigeorgiou, 2001a). In line with older pupils, a force is not identified or associated with stationary objects (i.e., a box resting on a table). Children also cannot identify forces acting as a pair, although the "let's pull the rope" activity (involving two children, each sitting on a wooden board, under which wooden cylindrical pieces of wood have been placed, and through the pulling of a rope that children have in their hands), rolling of the two boards on the floor takes place. That is, they cannot understand, unless their attention if focused on what actually happens, that regardless of who is pulling who, motion is always taking place in both (opposite) directions (Hadzigeorgiou, 2001a). Apparently these findings have an important implication for teaching the law of action and reaction at the upper elementary grades (i.e., designing activities that help children understand that there are always two forces involved when two objects interact). Having traced some of these children's understanding of action and reaction (as two forces acting on two different bodies, in opposite direction), over a period of 4 years, during which twice a year they participated in certain sensorimotor activities, there is some evidence that sensorimotor experiences, along with guidance aiming to help children notice what actually happens as a result of their actions, can be effective in helping children apply the idea of action and reaction in some new contexts (Hadzigeorgiou, 2001a).

The idea of potential energy, as a quantity that depends on both weight and height is understood as what a body at a height has and can do if we release that body (e.g., "what is required to produce craters on sand-box if dropped from a certain height"). Many children, however, cannot combine both variables, that is, height and weight. There are cases that the same children use either height or weight. For example, it is quite interesting to note that in the case in which they were asked about how to make a water mill spin as fast as they could, some children thought that more water would make the mill spin fast, without making reference to height, while most of them considered only height. In the case that the same children were asked to make craters, by dropping objects on tray filled with sea sand, some children were consistent with their use of the same variable (as in the case of the water mill), while some others were not consistent. This inconsistency can be interpreted in a number of ways, but analogies must have played a role in children's use of the other variable. Form a group of 22 children only two 6 year olds used both variables simultaneously. Both variables were considered by several children after 2 years, that is, when they (same children) were first or second graders, although no formal instruction took place in the intervening 2 years (Hadzigeorgiou, 2001a).

The concept of mechanical stability was more difficult for many children to understand. In the case in which the children were asked to build as tall a tower as they could, by selecting cylindrical cans of various sizes (i.e., various heights and bottoms), they could not combine the two variables in order to make a stable structure. Very few children, of course, could focus on either variable, but the majority of children used a trial-and-error approach, unable to explain why they selected the can they did. However, they were able to construct the concept of mechanical stability, by combining the height of box and the base of support, when they received guidance in the form of scaffolding (Hadzigeorgiou, 2002b).

What is important to stress here is that even those children's socially constructed understanding of the concept of mechanical stability was contextual. Some children could apply (transfer) the concept to the situation in which they had to carry 4–5 boxes of various sizes (one on top of the other) on a tray, so that their box-tower would not topple, while others could not. And in the case in which they were asked to do what they did with boxes in the case of their own body, no child could think that spreading his/her legs would make him/her more stable (Hadzigeorgiou, 2001a).

Another interesting finding is that more boys aged 5–6 years, could predict the behavior of a toy-car (empty and filled with objects of different weights) released on a ramp, compared with girls of the same age. Although such evidence derives from small samples, it is important to note the difference between the two sexes. This, of course, might be attributed to the lower level of the girls' involvement with this particular activity, as was observed. Regardless, however, of the reason behind the girls' difficulty to understand the situation involving the motion of an object down an incline (i.e., the concepts of kinetic and potential energy, and their transformation), it is crucial to stress the misconceptions that some children might entertain. For example, a girl believed that "the empty car would roll faster since it is lighter (and it would come to a stop much farther", when compared with the heavier car), and some children did agree with her. Other children thought that "the heavy car would move faster because the boxes inside it slid forward thus pushing forward against the driver's back window". The extra weight did not make any difference, for several children, since the car could hold it, and it was the forward push, delivered by the boxes that were loaded on the car, that made it move faster down the ramp (Hadzigeorgiou, 2001a).

It needs to noted, that, while force-and-motion related concepts/phenomena are easier to understand than more complex phenomena (e.g., evaporation, melting, light) through activities that provide children with opportunities to act and directly observe the result of their own action, and also opportunities for varying that action, as was recommended by Kamii and DeVries (1993) – and quite right since such activities provide children with opportunities for the construction of logico-mathematical knowledge – the development of the concepts themselves requires intervention. Thus, even for seemingly simple concepts like stability, sliding and rolling friction, whose understanding requires the construction of logico-mathematical knowledge of directly observable factors/variables, intervention through socio-cognitive strategies is imperative (e.g., Hadzigeorgiou, 2002b; Ravanis, Koliopoulos, & Hadzigeorgiou, 2004; Ravanis, Koliopoulos, & Boilevin, 2008).

## *Young Children' Ideas About Floating and Sinking*

Children's explanations of why objects sink or float take into consideration the objects' properties, like weight, size, shape (i.e., straight/curved piece of wire), material (i.e., metal/wood/plastic) even texture (i.e., hard/soft). For objects of the same weight, the kind of object also plays a role (Hadzigeorgiou, 2001a; Havu-Nuutinen, 2005; Smith et al., 1985). For example, children can think that, while a pebble will always sink, a plastic bottle, whether empty or filled – no matter what material is filled with (e.g., water, sand, oil) – always floats. However, the idea that heavy objects sink and that light objects float is not given by all children. There are children, who indeed predict that “light objects will sink because the can move easier through the water, while heavy objects find it more difficult to reach the bottom [...] so they either reach the bottom, by moving slowly, or will remain on the surface of the water, if they are very heavy, because they are pushed by the water, just like big boats”. What should be stressed though is that contrary to Piaget’s (1930) findings, that most children between 5 and 6 year of age rely on dynamism in order to explain floatation (i.e., saying that heavy objects sink, by heavy meaning strong rather than felt weight), many 6 year olds did feel the weight of most objects, thus giving a causal explanation (Hadzigeorgiou, 2001a).

The concept of density, which is required for understanding how an object floats, cannot be understood by very young children, although it appears that an intuitive idea of density begins to develop after the age of 5–6 years. For example, although some 6 year old children, when asked to predict which of three plastic bottles – one empty, one containing sand, and the other containing cotton – will sink, opted for the sand-filled bottle (explaining that it is heavier, thus using weight, as was expected, as their criterion), they still opted for a smaller sand-filled bottle when they had to choose among that bottle, and two bigger ones filled with cotton and corn respectively. This finding is in line with what Kohn (1993) reported, but not with Piaget’s (1930) findings, according to which, it is about the age of 9 years that children begin to consider both weight and volume in their explanations.

There is evidence that although very young children usually use one property or characteristic of the object (e.g., weight or size or shape) to explain sinking and floating, interventions can be successful in the sense that children can combine more than one property or characteristic (Hadzigeorgiou, 2001a; Havu-Nuutinen, 2005; Rappolt-Schlichtmann et al., 2007). There is also evidence that children have mixed explanations when approaching the phenomenon of sinking and floating (Koliopoulos, Tantaros, Papandreou, & Ravanis, 2004).

It is interesting to note that some objects cause more difficulty for children to think about floating and sinking. For example, whereas most children could predict that some balls would sink and some others would float – their explanations based on the factors of weight, texture, size and material, in the case of a straight piece of wire and a ring made of the same kind wire children were unable to offer predictions based on explanations (Hadzigeorgiou, 2001a). This finding is consistent with Tytler and Peterson’s (2003) finding that some objects, like a candle, a paperclip, a plastic bead with a hole, and a plastic golf-sized ball with holes in it, posed conceptual difficulties for children. In a more recent study, which explored how children “typically perceive” situations of sinking and floating, it was found that the ‘spatial background’ (e.g., river, sea), the ‘main object’ (e.g., boat, human body), and the ‘position of the main object’ (e.g., just below the surface of the water, on the surface), are three factors that determine how children understand the phenomenon of floating and sinking (Yong, 2009).

## *Young Children' Ideas About Electricity*

Young children's ideas about electricity, compared to other concepts such as matter and its transformations, forces and motion or magnet attraction, have not been adequately researched. However, there have been some studies with children of the age range 8–12 years (Osborne, 1982; Jabin & Smith, 1994; Vickery, 1995; Parker & Heywood, 1996; Pilatou & Stavridou, 2004; Azaiza, Bar, & Galili, 2006), while with children of the age range 4–8, the studies are very few indeed (Newton & Newton, 1996; Glauert, 2009; Solomonidou & Kakana, 2010). There have been some studies whose samples included a wide range of ages, that is, both young children of 8 or 9 and students as old as 18 years (e.g., Osborne, 1983; Shipstone, 1984, 1985, 1988). These studies have investigated the concept of electric current, particularly in the context of a simple circuit (consisting of a battery, a light bulb and connecting wires) and provided evidence for five conceptions or models. It is important to stress that very young children's conceptions of electric current can be very similar to those of much older students. (Glauert, 2009; Mant & Wilson, 2007).

The first model, which is the most common among young children, is the "single-wire" model (i.e., current leaves the battery and travels through one wire to a bulb). The second model is the "clashing currents" model, (i.e., current leaves the battery from both terminals and travels towards the bulb where it is "used up". This is very common among children of the upper grades of elementary school and junior high school. The last three are "unidirectional" models, in the sense that children identify one direction of flow for the electric current, and have been found in high school students. More specifically, the third model could be called the "unidirectional without conservation" model (i.e., the current is thought to be gradually becoming weaker as it flows through the circuit and as a result of encountering a light bulb or some other component of the circuit), while the fourth one could be termed the "unidirectional with sharing" (the current is distributed to and consumed equally by all components of the circuit, for example with all bulbs achieving the same brightness). The fifth model is the scientific model, which can be called the "unidirectional with conservation" model. It is different from the fourth model because the current is considered conserved.

There is evidence that, in regard to the way electricity is carried/inside wires, very young children (of the age range 4–6 years), don't have developed any specific idea for movement/flow of electric current. "Their representation of electricity is rather static, since they confine it inside the electric appliances, sockets, and wires" (Solomonidou & Kakana, 2010, p. 105). This finding is to be expected given that electricity is a difficult concept, even for the upper elementary school grades, due to the variety of concepts that need to be understood such as voltage, current, energy, etc. (Shipstone, 1985). It is a difficult concept for children also due to lack of any perceptual evidence. Unlike, light, which is also a very difficult concept for very young children, but which can be seen, electricity is something that children only hear about (i.e., paying for electricity, electricity makes house appliances work).

It is very interesting to note that very often young children do not distinguish between appliances operating with electricity and objects not using electricity. Also some children believe that there are various kinds of electricity (i.e., that different ‘electricities’ go to different home appliances). Many children also seem to believe that home appliances store electricity, and therefore when an electric appliance is bought, electric current is bought along with it too. An interesting idea held by several children who participated in Solomonidou and Kakana’s (2010) study is that the nature the ‘out-of-the-house’ electricity is totally different from that inside the house.

## *Young Children’ Ideas About Light*

Children ideas about light have been investigated in various contexts (e.g., vision, shadows, color). What becomes very clear from these studies is that, although light is pervasive in children’s life, both consciously (e.g., noticing differences between light and darkness) and unconsciously (e.g., seeing around them, shadow formation), their difficulty to understand light as an independent entity is great (e.g., Guesne, 1985; Ravanis, 2003). By and large, many young children identify light with sources of artificial light and sunlight. Light is something that children take for granted since they live in a space that is in light.

Collins, Jones, Sprod, Watson, and Fraser (1998), in their cross-age study, have identified five conceptions of vision, most of which can be found even in 6 year old children.

- Light goes to the object and we look at the object.
- Light shines on the object and we can see it.
- Light is everywhere in a well-lit area and we can see the object.
- Light goes to the object and then bounces to our eye.
- Light comes to the eye and we look at the object.

More refined notions have also been reported by Selley (1996). The “Stimulated Emission” model is similar to Collins et al.’s (1998) “light to eye/look” conception, while the “light to object/look” conception is similar to the Cooperative Emission” model (see Table 4.6). These models can be divided into two broad categories, that is, Emission models and Reception models.

Related to the concept of light is the formation of shadows and the rainbow. In regard to the former, it should be stressed that it is a phenomenon that cannot be conceptualized by young children unless a teaching intervention is designed and implemented (e.g., Fleer, 1996b, 1997; Hadzigeorgiou, 2001a; Segal & Cosgrove, 1993; Ravanis, 2003). The difficulty for children to understand the relative position between the object, the light source and the shadow requires a teaching intervention that gives the children opportunities to focus on the three factors involved through cognitive conflict (Hadzigeorgiou, 2001a). Understanding certain ideas about shadows, like some objects cannot help with the formation of shadows, because they block light, that shadows can become smaller or larger, that there are as many shad-

**Table 4.6** Models of light held by children aged 9 and 10 years

| Models of light | Description |
|---|---|
| Sea of light | Both the object and the eye are in a space that is already filled with light (ambient light) |
| Primary reception | Light goes directly from the source to the eye (only for luminous sources) |
| Secondary reception | Light goes from the source to the object and then from the object to the eye |
| Dual illumination | The object and the eye are illuminated simultaneously |
| Simple emission model | Light goes from the eye to the object |
| Stimulated emission | Light goes first from source of light to the eye, and then is reflected from the eye to the object |
| Cooperative emission | Simultaneously light goes from the eye and the source to the object |
| Stimulated emission with reflection | Light from the source goes to the eye and then is reflected from the eye to the object, and then the object reflects the light back to the eye |

Source: Selley (1996)

ows as there are light sources, can be effective in helping children understand how shadows are formed. However, it should be pointed out that young children's understanding of shadows is more sophisticated than what Piaget had originally suggested (Chen, 2009).

Regarding the formation of rainbows, there is evidence that children, if provided with opportunities to discuss their ideas in a group setting, can relate rainbows to rain sunlight (Siry & Kremer, 2011). We have found that helping children make a connection between the colors that we can get through light's refraction through a prism and the colors of a rainbow also appears to be a good strategy to help 4–6 year-old children to start reconsidering some anthropomorphic/magical conceptions (Hadzigeorgiou, 2001a). Although a connection between rain and rainbows can be encouraged with young children, the idea that it is water drops in the air that are responsible for the formation/appearance of a rainbow is difficult for children to understand, unless a narrative is used, which has been structured around binary opposites and certain mental images, in short, through opportunities for children to use narrative thinking (Hadzigeorgiou, 2001a).

## Perspectives and Frameworks Guiding Research

Given that research into children's understanding of science concepts was inspired by Piaget's work (Driver & Easley, 1978), the theoretical framework on which such research studies were based was Piagetian constructivism. One can certainly talk of an overarching theoretical framework that has guided such studies. Studies in the 1970s and 1980's, and even in the 1990's, were inspired from that kind of constructivism (e.g., Bar, 1989; Ravanis, 1994; Stavy, 1990). Children were individually presented with tasks during which they were clinically interviewed about how they think about those tasks. For example, in order for the researcher to find out how children thought about evaporation, each child was asked what happened to water that had been spilled on the floor, which, after some time, was dry. The question the researcher asked was: “What happened to the water and where can it be found?” (Bar, 1989, p. 485). Similarly Stavy (1990), in exploring children’s ideas about conservation of matter, presented each child with two identical closed test tubes, each containing a drop of acetone, and with the acetone in one of the test tubes was heated until it completely evaporated, asked them such questions as “Is there matter in the heated test tube?” and “If we open the test tube will there be a smell of acetone?’

The idea that knowledge construction is mainly an individual affair is very evident in these studies, in which the researcher/interviewer was just a non-directive participant. This role, in fact, was adopted even by researchers who also used group interviews in order to give children opportunities to externalize their ideas with the aim to construct meaning, but by having children first provide an explanation of a phenomenon on their own in a separate room. For example, Selley (1996) who asked children to make drawings to represent their ideas concerning light and vision (i.e., ‘How do we see this flower?’), and then took part in conversation about them, was “neutral or non-authoritarian regarding the truth of the ideas expressed” (p. 716). And although children were later encouraged to explain their drawings to their peers, and “the investigator made notes of any further elaboration or clarification which emerged” (p. 716), the explanations were not the result of dialogue and argumentation among children but each child’s personal explanation of the drawing that was make by each child.

The construction of viable explanations of experiences was central to these studies (conducted in the 1970s and 1980s) and the legacy of Piaget needs to be acknowledged here. The limitations, however, of the psychological or personal constructivism became apparent in the 1990s. In fact, in the early 1990s there had been a reaction to “the universalist rational disembedded thought valued by Piagetian constructivism” that the search for a “more suitable ideology that acknowledges the highly contextualized nature of the kind of learning that leads to genuine ownership of ideas and possibilities for transformation” (O’Loughlin, 1992, p. 809), was imperative.

Thus most studies conducted after the mid 1990s and later were based upon a social/constructivist perspective. Although the elicitation of children ideas was one of the aims of those studies, their primary purpose was the study of children’s reasoning patterns and abilities during their participation in certain tasks/activities, in a social context (e.g., Fleer, 1996a; Cummings, 2003; Robbins, 2005; Tytler & Peterson, 2004a), as well as the effect of certain intervention socio-cognitive strategies (e.g., Christidou et al., 2009; Hadzigeorgiou, 2002b; Ravanis et al., 2004; Siry & Kremer, 2011). Central to this social constructivist perspective was the idea that thinking is a social activity, and not an individual affair. Thus it made sense to the researchers to have children work on tasks in a social setting (i.e., working in groups and discussing their ideas on an attempt to explain physical phenomena). For example, there was a big difference between Stavy’s (1990) study, where each student was interviewed independently while being shown the materials, and Tytler and

Peterson's (2003) study, where children worked in group and discussed their ideas in order to reach an agreement about the phenomenon under investigation.

It has been argued that the social/constructivist perspective is in line with very young children's complex, dynamic and emergent thinking (Fleer & Robbins, 2003a; Siry & Lang, 2010; Siry & Kremer, 2011), something, of course, that had not been captured by studies based on Piagetian constructivism. One, of course, can argue that, since children's construction of knowledge can be enhanced through social interactions (i.e., children can share their observations and ideas with one another), what the researcher registers or interprets is not the personal knowledge of each student. But this is precisely the point. From this perspective, thinking and knowledge do not reside in the mind but first appear in a social context (see Cobb, 1994). From this perspective, therefore, there is a question of validity of studies based on Piagetian constructivism (see next section).

However, studying children's ideas in science necessitates particular attention to the theoretical framework of the studies (regardless of the perspective on which they are to be based). This framework may refer to the concepts/factors that are involved in the study of a certain of concept (e.g., force, heat, light) and also to the various dimensions of children's reasoning. For example, in regard to the former, a study of children's ideas about light requires the development of a framework which can involve connections between three factors, and more specifically between pairs such as, light/eye (L/E), eye/object (E/O), and light/object (L/O) (Collins et al., 1998). For the case of studying children's ideas about floating and sinking a framework may be in the form of a categorization scheme, which includes non- relevant and non-scientific explanations, relevant –justifications and scientific explanations (see Havu-Nuutinen, 2005).

Given that science requires epistemological thinking, a framework for analyzing children's reasoning patterns about phenomena and concepts (e.g., sinking and floating, light) may also be useful. Such a framework can guide the analysis and interpretation of data. Driver and her colleagues (1996) developed such a framework, which consists of three distinct representations of students' epistemological reasoning:

- Phenomenon-based reasoning, in which children's explanations are not distinguished from their descriptions of phenomena, and the purpose of experimentation is just to look and see.
- Relation-based reasoning, in which children's explanations are given in terms of relations between observable or taken-for granted entities, and found by 'fair testing'. Explanations emerge from the data in an unproblematic way.
- Model-based reasoning, in which children's ideas (theories, models) are evaluated by the available evidence, and their relationship is recognized as provisional and problematic.

Tytler and Peterson (2004a), in order to study young children's epistemological reasoning, refined Driver et al.'s (1996) framework, and proposed the following three dimensions:

- Phenomenon-based reasoning: explanation and description are not distinguished, and the purpose of experimentation is to 'look and see.'

- Relation-based reasoning: explanation is seen as involving the identification of relations between observable or taken-for granted entities rather than the searching for an underlying cause, and exploratory approaches tend to be confirmatory and uncritical. Explanation emerges from the data in an uncritical way.
- Concept-based reasoning: explanation is cast in terms of conceptual entities that represent an underlying cause or deeper level interpretation, where experimentation is guided by hypotheses, where the role of disconfirming evidence is acknowledged as significant, if not sought for, and where the possibility of alternative explanations is acknowledged.

From a social constructivist perspective, a framework that focuses on various kinds of social interactions, and not just between children in a group setting, can also capture the complexity of children's thinking, which is influenced by the wider socio-cultural context (Robbins, 2005; Roth, 2005). Barbara Rogoff's (1998, 2003) work is promising in this direction since she has outlined three planes of social interactions that can been used for the design of theoretical frameworks for research studies (see last section in this chapter). Moreover her work points to the group as a unit of analysis (see Hadzigeorgiou, 2002b; Robbins, 2005; Siry & Kremer, 2011), in sharp contrast to previous studies that focused on the individual child as a unit of analysis. Therefore Rogoff's (2003) work necessitates the use of more sophisticated naturalistic research designs, which brings me to the next section regarding the research methodology that guided studies in early childhood science education. But what must be said here is that studies based upon a social constructivist perspective have provided evidence for the limitations of previous designs based on surveys and on the Piagetian constructivist perspective. For they have documented the fact that young children can indeed make considerable progress if their understanding is scaffolded by their teachers, and that their understanding is not as limited as was previously thought.

## The Research Methodologies

Most of the studies prior to the 1980s employed survey techniques for exploring children's and adolescents' ideas about physical science concepts (Gunstone, White, & Fensham, 1988). However, this method was not suitable for very young children due to their lack of literacy skills. As Fleer and Robbins (2003b) observed, children below the age of 8 years were unlikely to complete research surveys. This is an important point especially in the light of socio-cultural theory (Rogoff, 2003). And this seems to be the reason why very young children were not investigated before the 1990s. Of course, from the perspective of socio-cultural theory, the validity of research into young children's ideas can also be called into question, since the questioning techniques that are very commonly used in educational research can privilege those children who are familiar with this kind of interaction.

In regard to the methodologies used in the late 1980s and early 1990s, and especially after the 1990s, the researchers turned to observations and interviews (e.g., Fleer & Hardy, 1993; Selley, 1996; Ravanis et al., 2004; Stavy, 1990; Tytler, 2000). These were found to be more appropriate for investigating very young children's ideas. As Fleer & Robbins, (2003b) pointed out, these methods represented a significant methodological development, which provided more in-depth information to science educators and teachers. These were clinical interviews, complemented with everyday materials/activities, and/or cards, which assisted the researcher in the interview process (e.g., Bar, 1989; Bar & Travis, 1991; Hadzigeorgiou, Prevezanou, & Kabouropoulou, 2011; Krnel, Watson, & Glazar, 2005; Koliopoulos et al., 2004; Siry & Kremer, 2011; Tytler & Peterson, 2003, 2004a). In other words, the materials and cards helped the researcher to elicit children's ideas, which, through questioning alone might have remained unexplored. Materials, especially in the case of very young children, are of crucial importance (see for example Glauert, 2009, in whose study children were shown examples of circuits and asked to predict whether they would work and explain why, and then they were encouraged to play with the materials and make their own circuits). In the case of the development of the concept of matter it is through their actions that children gradually develop a more elaborated schema, which allows them to distinguish between intensive and extensive properties, and therefore between 'object' and 'matter' (Krnel et al., 2005).

Children's drawings also assisted researchers with exploring children's ideas (e.g., Brooks, 2009; Hadzigeorgiou et al., 2011; Selley, 1996; Siry & Kremer, 2011). Tthe importance of drawing in assessing very young children's understandings of electric circuits has been stressed by a recent study (Glauert, 2009). Some researchers have also used pair interviews, given that the children can be more quiet in one-on-one adult/child situations than in interactions with their peers (Siry & Lang, 2010; Siry & Kremer, 2011). Pair interviews were found to provide a more "interactive discussion", thus providing children with opportunities to share their ideas with each other (Siry & Kremer, 2011).

After the 1990s experimental and quasi-experimental (one- and two-group) designs were used, in order to assess the effectiveness of teaching interventions in terms of learning and concept development (e..g., Christidou et al., 2009; Hadzigeorgiou, 2002b; Hadzigeorgiou, Anastasiou, Konsolas, & Prevezanou, 2009; Ravanis et al. 2004, 2008). Cohort studies, and case studies of individual children over a short time sequence were also used (e.g., Tytler, 2000; Tytler & Peterson, 2003, 2004a, 2004b).

Most of the studies conducted after the 1990s used research designs that incorporated small group discussions, with or without an adult's mediation (i.e., depending on each study's individual design), after children's participation in various tasks/activities, in order for them to explain the observed phenomena These studies were case studies and included conversational interviews, as well as pre- and post-assessment of children's ideas (e.g., Christidou et al., 2009; Robbins, 2005; Tytler, 2000; Tytler & Peterson, 2004a; Siry & Kremer, 2011).

Of great interest is the use of naturalistic designs, and more specifically the adoption of an interpretive methodology (e.g., Tytler & Peterson, 2003, 2004a), and the use of critical ethnography along with ‘cogenerative dialogues’ (e.g., Siry & Lang, 2010; Siry & Kremer, 2011). While the former can assist the researcher with the generation of categories (i.e., how children conceptualize evaporation), the latter, by capitalizing on children’s lived experiences, can help children develop mutual understanding by actively involving them in shared activities and tasks.

However, some methodological concerns with the studies reviewed need to be pointed out. First and foremost, although the clinical interview, compared with survey techniques, shed-light on how children understand phenomena and concepts, there is a concern with all studies, which used the clinical interview method, especially like those in the early 1990’s that used the traditional Piagetian clinical interview (Bar, 1989; Bar & Travis, 1991; Stavy, 1991). In considering the view that such a method, in the case of young children, may “reflect uncertainty, a misinterpretation of the meaning or purpose of the question, a desire to give attention-seeking answers, or simply to wish to end the conversation” (Siegal, 1997, p. 147), children’s ideas and their reasoning patterns may very well be a limitation of the questioning method itself, and not a limitation of their capacities. This is true especially in cases in which children give an ambivalent answer to a question concerning, for example, the meaning of the concept of force (e.g., ambivalent about forces on unstable objects). In such a case the child may very well be misinterpreted.

On the other hand, with studies that attempted to elicit children’s understanding of complex phenomena/concepts like evaporation and condensation, which presuppose an understanding of the meaning of such ideas as air, gas, vapour, steam, mist, fog, there are two problems: the first concerns the meanings that young children assign to these words, and the second concerns the interpretation, even with a careful triangulation, that researchers give to what children say about these words. As Tytler (2000) pointed out, accepting children’s statements, like “the water has disappeared” at face value, without considering the fact that children may very well mean that “the water can no longer be seen”, poses a serious threat to the validity of the data.

However, in regard to the clinical interview method in the context of longitudinal studies (e.g., Selley, 1996; Tytler & Peterson, 2004a, 2004b), the issue of the validity and reliability of the data can also be raised. Just probing children’s intuitive ideas helps bring these ideas to children’s attention, and this “can result in misinterpretation of their implicit understanding, as children try to make possibly incoherent ideas coherent enough to state” (Sprod, 1997, p. 740). It has been reported that the interview procedure may have helped children to become more conscious of their own ideas and thus reflect on their thinking in the light of further evidence (Glauert, 2009).

Another issue that can be raised is the authenticity of the tasks/activities and the situations themselves children participate in. If, according to socio-cultural theory, children’s thinking has to be assessed within a socio-cultural context, then there is a question about whether children’s ideas and reasoning patterns reflect their potential, even when the tasks/activities take place in the traditional classroom setting (which is true of all studies). As Bruner (1990) had pointed out children who could not solve mathematical problems in school were really successful in authentic contexts (e.g., super-market). Although most studies were done in classroom settings, there is a concern, in view of socio-cultural theory, whether that context is really "authentic". Of course, considering the wider socio-cultural can provide a solution to this problem (e.g., Cummings, 2003; Fleer, 1996a).

## Evidence of Effectiveness of Intervention Studies

Although most science concepts cannot be developed in early childhood, and although the idea that logic of scientific reasoning (i.e., experimentation and inference) is not acquired until after children reach adolescence, based on what Piaget (1930) had reported, there is now evidence that concepts can begin to be developed early on, and that scientific reasoning (i.e., hypothesis testing and variable control) can be done by young children (e.g., Hadzigeorgiou, 2002b; Tytler 1998a, b; Tytler & Peterson, 2003, 2005).

Given that the majority of studies over the last two decades have been based upon a socio-cultural perspective, which places primacy on the interaction between children, between children and the teacher, and also considers the wider socio-cultural milieu (e.g., Cummings, 2003; Fleer, 1996a; Hadzigeorgiou, 2002b; Ravanis et al., 2004; Robbins, 2005; Siry & Kremer, 2011), the effectiveness of these studies can be attributed to the perspective itself. However, while this is true, one should also acknowledge the fact that one could not talk about the development of conceptual understanding, in the sense that such an understanding presupposes a conceptual framework which is unrealistic to be expected from young children. Experiential/phenomenological knowledge is strong and therefore concepts such as light/vision, matter, heat, force, matter cannot be conceptually grasped at a scientific level (see for example Albert, 1978; Collins et al., 1998; Ioannidis & Vosniadou, 2002; Selley, 1996; Shayer & Wylam, 1981; Stavy, 1991; Tytler, 2000; Tytler & Peterson, 2003, 2004a; Tytler, Prain, & Peterson, 2007).

Yet there is evidence that with support children can move to a higher, more complex level than the level characterizing their naïve/intuitive understanding. Havu-Nuutinen (2005) observed that preschool children, in regard to floating and sinking, for example, can show a 'piecemeal belief revision', without a strong reorganization of their conceptual structure. The same finding had been reported by Andreani Dentici et al. (1984): manipulation of appropriate materials and questions which help focus children's attention on certain aspects of the experiment/activity, stimulate children to reorganize their conceptual system, and as result they gave up the precausal explanations in favor of physical ones, though these were incomplete. A more recent study provides additional evidence that preschoolers can begin to approach density, if they are given opportunities for experimentation. As Rappolt-Schlichtmann, Tenenbaum, Koepke, and Fischer (2007) report, on average and without support, kindergartners tended to give simple answers that focused on the identity of the object (e.g., "The ball floats because it is a ball"), while second-graders tended to give answers that focused on object characteristics more relevant to the concept of buoyancy (e.g., "The ball floats because it is light"), but with support, children's answers became were more complex. Kindergartners tended to give answers that moved beyond the identity of the objects, by using an attribute (e.g., lightness), while second-graders tended to give answers that included more than one attribute (e.g., "The ball floats because it is small and light"). Even in the case of electricity, which, compared with other concepts, is a more difficult for young children to understand, intervention studies have reported very positive results with both elementary school children (Azaiza et al. 2006) and kindergarten children (Glauert, 2009)

There is ample evidence that socio-cognitive strategies are very effective in helping children construct logico-mathematical knowledge, that is, relationships between various factors – this is what Driver et al., (1996) termed relation-based reasoning (e.g., Hadzigeorgiou, 2002b; Ravanis & Bagakis, 1998; Ravanis et al., 2004). From our studies at the university of the Aegean, that were conducted from 1996 to 2001, we have evidence that the majority of children of the age range 4–6 years, use phenomenon-based reasoning in most free explorations with materials, but can move on, with guidance through scaffolding strategies, to the next level, that is, to relation-based reasoning. Concept-based reasoning, except in some isolated cases with 7–8 year children, was not identified (Hadzigeorgiou, 2001a). The evidence provided by Tytler and Peterson (2003, 2004a, 2004b) studies are in line with the evidence from our studies.

Of course, it is important to note that the nature of phenomena has played a role, given that phenomena of heat (e.g., evaporation, condensation, freezing and melting) and light (e.g., formation of shadows, rainbows, colour mixing) were approached by many children (i.e., 98 children from a sample of 176), even after intervention, through phenomenon-based reasoning, while phenomena of force and motion (i.e., ball rolling down ramps, balance and stability activities) and directly observable phenomena (e.g., shadow formation) both of which involved the child's own direct or indirect action like were approached through relation-based, and in some instances even through concept-based reasoning, after intervention (Hadzigeorgiou, 2001a).

In regard to children's reasoning about science tasks/activities, it has been found that, in addition to the development of fundamental cognitive skills (i.e.,comparing, measuring, counting, and problem posing, evidence-based conclusions), young children's thinking is characterized by morecomplex dimensions, which include explanations, highlighting discrepancies, asking questions and adopting new ideas (see Venville, Adey, Larkin, & Robertson, 2003; see also Soridan et al. for the distinction children make between 'hypohetial beliefs' and 'evidence'). Moreover, as Tytler and Peterson (2003, p. 461) pointed out, "young children in their first 2 years of schooling are capable of pursuing significant ideas and undertaking interesting and productive explorations that involve coordinating ideas and evidence". The various dimensions of scientific reasoning, that is, "approach to exploration", "dealing with competing knowledge claims", and "handling variables", according to Tytler and Peterson (2003, 2004a), can be observed in 7–8 year old children, for the first two levels of epistemological reasoning.

## Implications for Classroom Practices

What was discussed so far has three important and inter-related implications for science instruction. The first one concerns children's ideas themselves and how these can help with the design of instruction. The second one concerns importance of the teachers' careful use of language. And the third one refers to the sequence that should be followed when teaching science concepts. In order for teachers to help children move from phenomenon-based reasoning to relation-based reasoning they have to be aware of children's ideas and the language they use in relation to these ideas.

Given that children's ideas present them with difficulties and many times are an obstacle to science learning, these ideas can help with the design of activities that will children to overcome these obstacles. If children, for example, have difficulty develop a one-to-one correspondence between a light source and a shadow, activities with multiple light sources are imperative, so that children are encouraged to develop a one-to-one correspondence (Hadzigeorgiou, 2001a). Or the tendency for many young children to identify light with luminous/artificial sources, and hence the difficulty for them to view light as an independent entity, can be overcome if children participate in activities that provide them with opportunities to see intensely lighted regions, thus starting to identify light with the lighted area and not with the source (Ravanis, 2003).

In regard to the second implication, the words and the linguistic expressions that teachers use need to be clear and understood by children. Otherwise the meaning of the words describing concepts (e.g., force, stable, heat, air, vapour) may not be understood by children and the teachers may also misinterpret what and how child think. For example, it has been pointed out that there is no point in teaching the particulate nature of matter when children don't know what teachers mean by matter and don't believe that gas is something material (Stavy, 1991). Of course, this example does show that how subject matter is sequenced directly depends upon children's understanding of a particular concept. On the other hand, avoidance of certain words is also crucial. For example, in cases in which children participate in force and motion activities, expressions such as "the force of the object" should not be used since it may reinforce an 'internal force' mental model – the expression "the force acting on the object" being more preferable – (Hadzigeorgiou, 1987, 2001a), and in phenomena involving light, the use of 'dynamic' terms and expressions, to describe light, like "the light moves", "the light passes", and "the light arrives", are preferable to static ones, like "light exists", and "light is visible" (Guesne, 1985).

In regard to the sequence with which certain concepts have to be introduced, two things, in the light of research findings, need to be said. First some concepts need to be introduced first on the ground that children have an understanding of them. For example, for the concept of matter, conservation of weight, at least for the cases regarding changes in the form and/or states of matter (e.g., conservation during the crumbling of a lump of solid into powder, conservation during melting, dissolving), should be taught before the particulate model of matter. By the same token, there is no point in teaching biological concepts (e.g., photosynthesis, nutrition) when children do not think that animate/biological objects are material (Stavy, 1990). Second, since young children spontaneously provide naturalistic explanations for some phenomena (e.g., dissolution, floating) and non-naturalistic explanations for other phenomena (e.g., water cycle), some phenomena should be introduced first, on the grounds that for them (phenomena) children give naturalistic explanations. Thus, the water cycle (about which non-naturalistic explanations dominate), for example, should be discussed after children become capable of offering naturalistic explanations about more everyday familiar phenomena (Christidou, 2006).

## Directions for Future Research

Given the limitations of the Piagetian constructivist perspective, a serious consideration of the social constructivist perspective is imperative. If by now it has become clear that "a Piagetian-inspired framework as the major means for studying children ignores many important aspects of their thinking" and that such a framework "tends to trivialize and ignore the depth and complexity of their thought" (Robbins, 2005, p. 161), then more studies of children's ideas in science, that give primacy to the wider socio-cultural context, should be conducted. However, we should not pay lip service to the term "socio-cultural". What we need is a framework that considers present day contexts, cultures and artifacts. For example, a study conducted in informal settings, where children can make use of an array of present day artifacts and cultural tools such as computers, multimedia, cell-phones, etc., may very well reveal different patterns and different trajectories of understanding, even new forms of understanding. Gender issues should also be investigated within such context.

Rogoff's (1998, 2003) work on socio-cultural theory, can provide a framework, which, enriched with some other dimensions, as these can be identified in the research literature (e.g., what children think when they hear, for examples the words 'force' and 'floating', how gender influences understanding of some science concepts), can provide a better framework for studying young children's ideas in science. Given that science is a special activity, Rogoff's proposed three-plane model, that is, the personal, the interpersonal, and the community planes, can provide opportunities for an in-depth analysis of science teaching and learning as social endeavors, that take place on multiple levels. Such an analysis, apparently, is much richer than that derived from research based only the personal level of analysis, and which simply describes and categorizes children's knowledge, even when it documents the evolution of such knowledge over a period of time. A framework that combines Driver et al.'s (1996) epistemological model and Rogoff's (2003) socio-cultural theory is something that can shed new light on children's construction of scientific knowledge.

Notwithstanding, however, the importance of investigating children's science concept development in a social context, with very young children, the possibility of helping children construct mental models through sensori-motor experiences deserves attention too. There is evidence that for children in the age range 4–6 years and also for children of 9/10 years, participation in sensori-motor activities helps them understand concepts, which otherwise would have been very difficult for them to understand (Hadzigeorgiou & Savage, 2001; Hadzigeorgiou, 2002a; Hadzigeorgiou et al., 2009). The importance of these studies does not simply lie in the fact that sensorimotor intervention was effective in helping children understand certain concepts (e.g., mechanical equilibrium for 4–6 year olds, molecular motion for 9 year olds) but in their wider implications (see Hadzigeorgiou et al., 2009).

Also, given the importance of the narrative mode of thinking for young children (Bruner, 1990; Egan, 2005), the effect of narrative/storytelling on young children's understanding of natural phenomena and science concepts appears very promising, especially if the plot of the story can evoke a sense of wonder (Hadzigeorgiou, 2001b; Hadzigeorgiou et al., 2011; see also Hadzigeorgiou, 2013, for the role of wonder as a 'learning tool' in science education).

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# Chapter 5
# Children's Ideas About Life Science Concepts

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In this chapter we explore research related to young children's conceptions of life science topics. Life science itself is a broad field, and within the field researchers have explored young children's conceptions of several concepts, such as the distinction between living and non-living entities, growth and development of organisms (including human development, germs and contagions and differences between plants and animals).

As is the case with all science concepts, children come to the science classroom with previously formed ideas about topics they will explore in class (Osborne & Freyberg, 1985). These conceptions can sometimes be alternative conceptions that have formed based on their experiences within the world (Atkinson & Fleer, 1995). These ideas should be taken into account by teachers when planning experiences to improve children's conceptions during interventions. It is recommended by prior research that these interventions take place through investigations and inquiries that approximate the kinds of investigations that scientists undertake to aid young children in improving their science content knowledge (Osborne & Freyberg, 1985), conceptions of scientific inquiry (Metz, 2004) and ideas about the nature of science (Forawi, 2007).

Some would argue that young children are not capable of conceptualizing scientific inquiry due to developmental ability levels. However, Metz (1995, 2004) argues that even young children can conceptualize scientific inquiry when provided with experiences that scaffold their abilities to do science from an early age. Their lesser-developed content knowledge does not mean they are incapable of learning, just that they have not yet had experiences or practice in doing science and that the

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curriculum and instruction needs to be “ramped up” to support their learning of both content and processes of science. Metz (1997) notes that even scientists and philosophers of science have confusions and disagreements about content and processes of sciences so it should be expected that young children would also have confusions, yet these should not be attributed simply to being at a particular developmental stage. Kuhn (1997) argues the importance of considering developmental levels of children, but rather as guideposts for instruction, not constraints from teaching certain concepts. Indeed, children develop understandings through their experiences in the world, and appropriate science teaching that uses their abilities to reason, conceptions of cause and effect, abilities to understand modeling, abilities to consider ideas and beliefs, and their eagerness to learn, have much potential to help them improve their understandings of science concepts (Michaels, Shouse, & Schweingruber, 2008).

Research on young children’s ideas about life science concepts has been undertaken from the perspective of developmental psychology, as well as from the field of science education. Often through the developmental psychology lens the research has utilized interview methodology either in a clinical setting, or in an area close to the child’s preschool or elementary classroom to determine conceptions of life science topics. Within the field of science education the research has been undertaken using interview methods, but often as pre and post intervention to test the influence of a teaching strategy on young children’s conception of a life science concept. In the sections below we will describe the types of theoretical frameworks that guided the research in the two domains, discuss children’s conceptions of various life science concepts as identified through the research, examine common research methods that are used in the studies, make recommendations for future research on children’s ideas of life science concepts, and explore implications for teaching practice.

To identify the research studies for review we initially conducted a search through the Academic Search (EBSCO) database using the terms “Young children’s ideas about life science” and “Young children’s conceptions of biology.” In addition we used the search terms “preschool, elementary, kindergarten, 1st grade, 2nd grade,” and “conceptions, alternative conceptions, and misconceptions: for the second search terms. From this search we identified biology topics for search terms, such as “death,” “animal,” “plant growth,” finding general terms like “life science” and “biology” not yielding many results. From these terms we identified several studies, which then enabled us to expand our search to include the subtopics within life science on which the most research had been conducted. We also searched through EBSCO (ERIC). From the studies we reviewed we sought additional research studies that were cited in the reference lists. We reviewed all studies that we identified from 1985 and forward that examined children’s ideas and conceptions about the life science topics that arose from the search.

We believe that young children can develop strong and appropriate life science concepts when they participate in appropriate instruction. We will review the literature to determine the conceptions they hold of life science, and determine whether those ideas improve as a result of instruction.

## Theoretical Frameworks

The theoretical frameworks guiding the literature on young children's conceptions of life science differed between the fields of developmental psychology and science education and can vary within these two fields. The literature in the field of developmental psychology largely used theoretical frameworks that examined the biological versus the psychological domain of understanding, while science education research generally utilized learning theory and conceptual change as lenses with which to examine the phenomenon of study.

Studies in developmental psychology approached the research from the perspective of children's biological and psychological theories of living and non-living things. For example, Hickling and Gelman (1995) examined if and how young children held theories of seeds and plants as living things that have biological characteristics, such as growth, reproduction, illness, and death. Developmental psychology studies were therefore largely grounded in examinations of if and how biological theories differed from the psychological domain, in short, that some living things (like plants) have biological but not psychological characteristics (Backscheider, Shatz, & Gelman, 1993; Hickling & Gelman, 1995; Inagaki & Hatano, 1996; Nguyen & Gelman, 2002; Rosengren, Gelman, Kalish, & McCormick, 1991). Studies investigated the ages at which children began to realize that living things have various biological characteristics, and that biology can affect the growth and survival of living things. These understandings were assumed to be grounded in children's theories of biological characteristics and functions, and that these theories allowed children to apply their knowledge to new and unknown situations (e.g., unfamiliar living things).

Theoretical frameworks within the field of science education were largely drawn from learning theories. Most studies held an explicit or implicit assumption of constructivist learning (Endreny, 2006; Patrick, Mantzicopoulos, & Samarapungavan, 2009; Petrova, Siderova, Stefanova, & Nikolova, 2010; Shepardson, 1997). Endreny (2006) explicitly grounded her study within constructivist frameworks by examining children's understandings of habitats and adaptations within the context of prior knowledge and experiential learning. Patrick et al. (2009), on the other hand, utilized theoretical underpinnings of motivation rather than constructivism to examine differences boys or girls may have in learning these same science topics. Constructivist learning was implicit within this study as it described the use of an inquiry-based unit to foster young children's biological understandings, as well as confidence and enjoyment.

The differences in theoretical approaches of the two bodies of literature are logical. Developmental psychology seeks to understand the cognitive aspects of the human experience, while science education focuses more on pedagogical approaches and sociological understandings of children and the sense they make of life science. Therefore, studies in developmental psychology were grounded in the cognitive elements of life science learning—namely, how children understand the biological and psychological domain of living things. Science education research logically focused on learning theory and mechanisms for developing constructivist understandings of life science content. Findings from the literature in both fields are presented in the next section.

## Young Children's Ideas of Life Science Concepts

In this section we will describe what previous research has found are children's ideas of various life science concepts. Through our review of the literature we have identified themes that illustrate the focus of research on children's ideas. We have identified the following content areas as areas of foci on children's ideas of life science: (a) the distinction between living and non-living, (b) growth and development of organisms (including human development), (c) germs and contagion, and (d) plants and animals. We describe the results of research in terms of children's conceptions of these life science topics in the sections below. See Table 5.1 for an overview of all studies we reviewed.

## Children's Conceptions of the Distinction Between Living and Non-living

We have identified several major studies that explored young children's conceptions of the distinction between living and non-living entities. Backscheider et al. (1993) conducted a series of experiments within a developmental psychology study that explored 3 and 4 year old preschool students' conceptions of re-growth compared to the need for artifacts to be mended by people. The first two experiments reported in this paper explored 3 and 4 year old children's conceptions of mending humans, animals, plants, and artifacts using a series of 14 cards with parts cut or scratched off. Children were asked whether the parts would regrow or whether people needed to mend them. They found that both the 3 and 4 year olds knew that living things can heal, and that artifacts need to be fixed by people. The 3-year-old children did not know whether living things could mend other living things. The 3 year olds also focused on what does not work regarding mending artifacts rather than ways to fix them. In the third experiment the researchers included unfamiliar animals on the cards to determine whether children used memory and experience in their responses, or whether they were building a biological theory. Results of this experiment indicated that even with unfamiliar items 3 and 4 year old children do know that living things can heal, and that people can mend objects. However, their performance on this task was less successful overall than the previous two experiments that included only organisms that were familiar to the children.

Inagaki and Hatano (1996) conducted a series of four experiments within developmental psychology with children of ages 4 and 5 to determine their understandings

**Table 5.1** Summary of literature reviewed

| Study | Content category | Children's ages | Results | Methodology | Field |
|---|---|---|---|---|---|
| Backscheider et al. (1993) | Living/non-living (regrowth from injury vs. mending) | 3–4 Years old | Living things can heal; people can mend objects | Series of clinical experiments | Psychology |
| Inagaki and Hatano (1996) | Living/non living (commonalities between plants and animals) | 4–5 years old | Children understand properties of living things | Series of clinical experiments | Psychology |
| Nguyen and Rosengren (2004) | Living/non-living (biological concepts such as life, aging, reproduction, illness, death) | Preschool | Children asked questions about death. Held misunderstandings about aging, reproduction, illness. | Interviews and questionnaires of parents | Psychology |
| Hughes et al. (2005) | Living/non-living (classifications of living or non-living) | Preschool | Children's perceptual knowledge is salient; object representation is key to their understandings | Clinical experiment | Psychology |
| Rosengren et al. (1991) | Growth and development (transformations of animals) | 3–6 years old | Children recognize that animals grow and inanimate objects do not | Series of clinical experiments | Psychology |
| Strommen (1995a) | Growth and development (life processes) | First grade | Children did not identify similarities or differences in life processes, but focused on color, size and movement | Clinical interviews of first graders in rural and urban settings | Science education |
| Shepardson (1997) | Growth and development (insect life cycles) | First grade | Prior to instruction children held a one-stage model idea of insect growth. After instruction they realized insects went through metamorphosis | Qualitative intervention study | Science education |
| Johnson and Solomon (1997) | Growth and development (role of birth in relation to origin of properties) | 4–7 years old | Children hold a birth bias, believing that children will be like their mother (not father) whether or not they are adopted | Series of clinical experiments | Psychology |

(continued)

**Table 5.1** (continued)

| Study | Content category | Children’s ages | Results | Methodology | Field |
|---|---|---|---|---|---|
| Nguyen and Gelman (2002) | Growth and development (death in plants and animals) | 4 and 6 years old | Children understand that plants die, but understand better that it is final for animals rather than plants | Series of clinical experiments | Psychology |
| Siegel and Share (1990) | Germs and contagions (conceptions of illness) | 36–47 months old | Children are capable of ignoring the appearance of an item and could focus on whether it had been contaminated | Series of clinical experiments | Psychology |
| Solomon and Cassimatis (1999) | Germs and contagions (causes of illness) | 4–11 years old; adults as comparison | Children did not distinguish between germs and poisons as causes of illness | Series of clinical experiments | Psychology |
| Osborne and Freyberg (1985) | Plants and animals (classifications of plants and animals) | 6–7 years old | Most considered grass a plant; few considered a carrot a plant. Most considered a whales and cows animals, but not spiders or worms | Interview | Science education |
| Strommen (1995b) | Plants and animals (forest dwellers) | First grade | Children can identify many animals, but did not know which belonged in forests | Clinical interviews | Psychology |
| Simons and Keil (1994) | Plants and animals (what is inside animals) | 3–4 years old | Children expect that the insides of animals and machines to differ, but don’t understand how they differ | Series of clinical experiments | Psychology |
| Hickling and Gelman (1995) | Plants and animals (seeds) | 4 years old | Young children were able to understand the cyclical process of seed development | Series of clinical experiments | Psychology |
| Leach et al. (1996) | Plants and animals (interdependence of life) | 5–16 years old | Young children thought of organisms as individuals rather than part of a population | Series of interviews | Science education |
| Myers et al. (2004) | Plants and animals (conceptions of animals’ needs) | 4–14 years old | Young children noted physiological needs rather than social needs | Randomized interviews | Psychology |

| | | | | | |
|---|---|---|---|---|---|
| Ross et al. (2005) | Plants and animals (classification) | 5–7 years old | Children were able to infer classifications of animals | Series of clinical experiments | Psychology |
| Endreny (2006) | Plants and animals (animal adaptations) | Third grade | Students held preconceptions, but through instruction began making accurate conceptualizations | Action research (intervention study) | Science education |
| Petrova et al. (2010) | Plants and animals (anthropomorphism) | 3 and 6 years old | Preschool children held more anthropomorphic ideas about plants and animals than primary school children | Diagnostic interviews and observations | Science education |
| Hoisington et al. (2010) | Plants and animals (fundamental life science concepts) | Preschool | Children learned new trees, retained some confusion about root structure | Intervention (arboretum field trip) | Science education |
| | | | | Interviews and collection of student drawings | |
| Eick (2012) | Plants and animals (outdoor biology) | Third grade | Including science with literacy did not hinder literacy development, and enabled students to also learn science concepts | Intervention (interdisciplinary literacy and science teaching) | Science education |
| | | | | Observation, collection of student work, Standardized test scores | |

about living things, and commonalities between plants and animals. In the first experiment 48 5-year-olds and 48 4-year-olds were shown pictures of plants, animals, and artifacts and asked what each organism or artifact would look like at an older age. Children in this experiment were successfully able to distinguish between living plants and animals and non-living artifacts. In the second and third experiments the researchers investigated whether 52 5-year-old children had a category in their minds of what constitutes “living things” (e.g. understand that living things die, heal, are born). They provided students with examples of living and non-living things and described properties of each example, such as “humans can become ill.” Children were asked to state whether items were living or non-living. They examined frequencies of student responses and results indicate that children understood different properties of living things and did not apply those properties to non-living things. The final experiment included in this set explored 50 5-year-old children’s understandings of commonalities between plants and animals by showing pictures and interviewing the children. Children understood the commonalities among living things, especially when the interview began with feeding, watering and growth, and then moved on to other biological phenomena.

Nguyen and Rosengren (2004) conducted a study that explored preschool children’s knowledge of biological concepts such as life, aging, reproduction, illness, and death, through interviews of parents. Two hundred and seventy parents responded to a questionnaire that had questions regarding the following seven content areas: (1) children’s experiences with a particular biological concept, (2) children’s discussion about a specific biological concept, (3) parent’s comfort discussing a specific biological concept, (4) the age that children should learn a specific biological concept, (5) how children should learn a specific biological concept, (6) children’s difficulties in understanding a specific biological concept, and (7) children’s misconceptions about a specific biological concept. The parent responses were coded on several dimensions. The first dimension, content, was coded as either animals/insect, plants, selves, other humans, and living things in general. The second dimension was theme, and captured themes of biological processes of illness and death. For reproduction the codes were causes, or outcomes. For aging, the codes were causes of aging, outcomes of aging, and appearance/reality distinction in aging. For illness the codes were causes, symptoms, remedies, or outcomes of illness. For death they coded inevitably, finality, and causes of death. Two coders then examined conceptions and decided whether they were within a boundary of the domain of biology (e.g. plants) or domain of psychology, or boundary of biology and physics. There were also domain codes for science and religion as well as biology and magic.

Regarding experiences with life processes, parents reported that children had influential and important experiences related to aging, illness, death. Only 48 % of parents reported that children had experience with events related to reproduction. Parents reported that children often asked questions about death, but only occasionally about life processes such as aging and illness.

For conceptions regarding reproduction, the majority (73 %) of conceptions that parents reported children having involved a misunderstanding of causal processes.

The remaining involved the outcome. Aging misconceptions reported by parents were more likely to relate to outcome (64 %) rather than cause (10 %). For illness, parents reported that the majority of conceptions their children held were related to the cause (82 %). Regarding death, most misconceptions reported were related to finality (74 %), such as children thinking that sometimes things might come back to life.

Parents reported that one third of the conceptions their children held occurred at boundaries between domains of understanding. Twenty-one misconceptions were coded as being at the boundary between physics and biology content understanding, such as "balls rolling are alive" or "Teddy bear is alive." Fifteen misconceptions were coded as being at the boundary between biology and psychology; for example, some children thought that if you are pretending being a baby then you would actually become a baby, while other children thought that "dead people are asleep." Twenty misconceptions reported were coded at the boundary between biology and religion, such as "you get sick if you don't pray to God to prevent it."

The researchers state that their data suggest that biological misconceptions are quite common in young children, with the frequency varying by concept and age. The authors recommended future research to explore what parents do when they identify misconceptions held by their children.

Hughes, Woodcock, and Funnell (2005) examined 3 and 4 year old children's understandings of living and non-living things. They presented children with categories of living things (such as animals and fruits/vegetables) and two categories of non-living things (implements and vehicles), and asked children to state whether each were living or non-living. Responses were categorized as superordinate, perceptual, factual, functional, or action. Superordinate responses were those that were applied appropriately as a category label such as "animal" or "creature" appropriately applied. Perceptual responses were based on characteristics that could be seen, felt, heard, or tasted. Factual responses included information, and functional responses included those that were about the purpose of the object. Action responses included knowledge of what is done with the item in the process of using it.

The researchers conducted two repeated measures ANOVA analyses on the five categories of coded responses in pair-wise comparisons to determine if children gave more superordinate responses than other types of responses, and if they gave more superordinate responses with regard to living and nonliving objects. They also conducted a MANOVA analyses to determine commonality of responses of each of the five categories, and finally, they examined each response type.

When compared to research on adult's conceptions, findings suggest that young children's responses form the basis of adult understandings. Perceptual responses and functional responses can both be found in high proportions in children as young as 3 to 4 years, indicating that these children have already formed categories containing conceptual information. Superordinate responses are most commonly made to objects in the living categories and were made by some of the youngest children. Perceptual responses were most common in relation to animals, fruits/vegetables and vehicles. Functional responses were particularly salient to objects that children could manipulate. Action responses were also common to objects that could be manipulated, and to fruit and vegetables for children in the youngest age groups.

Factual responses were most numerous as applied to animals and vehicles. In sum, children's perceptual knowledge proved most salient, suggesting that object representation is key to young children's understandings of objects in categories.

## Children's Conceptions of Growth and Development

Rosengren et al. (1991) reported on a series of small experiments that explored young children's conceptions of transformations of animals and their judgments of those transformations. For example, they explored whether children believed that an animal now looked like a skunk but was a dog before, whether it was actually a dog, or had transformed into a skunk. In the first two experiments the researchers wanted to know whether children could understand that animals change in appearance by increasing in size over time. The first experiment used 22 children of a younger age range, and 19 children of an older age range, and the second experiment used the same procedure with 10 3-year-old children. In each instance the children were provided with 36 animal cards and 24 artifact cards with different size items. Half the children were tested with animal cards first, and half with the artifact cards first. Children were asked to state whether items in animal cards were the same and whether they had changed. They were asked the same thing of the artifact cards. Results of these experiments indicated that by 3 years old children realized that growth in animals entails a change in size. They do not expect animals to be unchanging over time, and also realize that artifacts do not change size over time.

In experiment 2 the researchers tested for children's perceptions of aging of artifacts. They used similar cards as in the first two related experiments. Results showed that 5 and 6 year old children as well as adults understand that inanimate objects do not change in size over time, though their appearance can change due to aging and use. Some 3 and 4 year old children have that understanding as well, but to a lesser degree. Some 3 and 4 year olds do not recognize the effects of aging and wear on artifacts and believe they are different items, not older versions of the same items.

Experiment 3 tested for children's perceptions of ways that humans and animals change as they develop that did not include size. They used cards similar to the previous experiments, but also included examples of butterflies, caterpillars, and cocoons. Older children (5–6 years old) and adults recognized that species can change appearance strikingly over time, such as through metamorphosis in insects.

Overall, children 3–4 years old recognized that animals change in size over time as animals grow up, and inanimate objects do not. Older preschoolers of age 5–6 recognized the change in size of animals, as well as sometimes striking changes in appearance that can take place as animals develop and grow.

Strommen (1995a) explored 40 first grade students' conceptions of how living things are alike or different. Children were selected from a rural area in Nebraska and a city in New Jersey. Children in both areas held similar conceptions. Most (75 %) of the children in these classrooms did not identify similarities or differences in life processes of animals. Instead they focused on color, size, and movement. They did not discuss similarities or differences among animals that were related to them actually being alive. Strommen noted that the building blocks for recognizing similarities and differences were present for the children, but there was no indication that there was a focus on processes of life for students of this age.

In his intervention study Shepardson (1997) investigated first grade students' informal ideas about the life cycle of insects and how their conceptions changed as a result of formal instruction. He focused on two randomly selected small groups of four children in one first grade classroom. His focus was on their work during a beetle and butterfly life cycle unit that comprised 15 days of instruction. Data were collected through interviews of the students, collection of their science journal entries, informal conversations with the students, and classroom observations of instruction. He employed a qualitative analysis seeking patterns in single and cross-case analytic induction. Prior to instruction he found that students held a one-stage model idea of insect growth, meaning that most children thought that larva just grew into bigger sizes. However, several did hold a two stage model, believing that the adult insect developed directly from the larva. Following instruction all the focus children developed a four-stage model of thinking about how insects develop—they conceptualized the life cycle as larva, pupa, nymph, and adult insect, and recognized that these were life stages of the same organism. He concluded that the teaching strategies used in this classroom, framed through the social construction of ideas through discourse, meaning making through discussion, science journals that enabled recording of ideas, and developing a language system for explaining and interpreting data was effective for improving children's understandings of insect life cycles.

Johnson and Solomon (1997) explored children's understandings of the role of birth in terms of biological origins through a series of experiments. In experiment 1 they examined the children's conceptions of the origins of properties. A cross-species adoption story was shared with 75 children (ages 4–7) followed by questions such as "Who gave birth to the baby?" and "Who did the baby grow up with?" The children were then asked to match physical characteristics of the baby to either the birth or the adoptive parent. Reponses were coded as *birth bias, adoptive bias, differentiated,* or *mixed.* Findings suggest that most children held a *birth bias,* and that their biological reasoning was according to species kind. In experiment 2 the researchers examined if children could use birth information to predict and justify the species kind. The researchers utilized the same adoption story as in Experiment 1. Sixty five children (ages 4–7) participated in this phase of the study. Each item was coded as either birth parent or adoptive parent judgment. Explanations under each of the two categories were further coded as either *origins, non-origins birth, adoptive* or *mixed.* Findings of this study were inconclusive, as children were inconsistently able to predict the species kind and then justify the response. In experiment 3 the researchers examined the notion of mother bias in children. Twenty 5-year-old children participated, and were again told a story that explained the birth origins of the baby organism. Results indicated that the children held a mother bias (in terms of heredity) in both physical and non-physical properties.

Overall, children of ages 4–7 have biases about birth (biological reasoning was according to species kind rather than who raised them) and mother (believing both physical and non-physical traits mostly inherited by mother, not father).

Nguyen and Gelman (2002) explored 4 and 6 year old children's conceptions of death with regard to flowers, trees, and leaves in a series of experiments. In experiment, 1 30 4-year-olds and 20 6-year-olds (as well as some adults for comparison) participated. They were shown pictures of flowers, trees and leaves and asked whether these organisms could die. The researchers probed children's thought processes in relation to the concept of death. Responses were categorized by universality, inevitability, finality and causality. A 3 (age: 4-years, 6-years, adults) × 3 (plant type: flower, weed, tree) × 3 (component: universality, inevitability, finality) ANOVA was conducted. Results indicated that 4 year-olds did not have a coherent and biological understanding of plant death related to the three characteristics of death and across the three types of plants. Therefore there was a significant difference in their understanding depending on the plant type. Six year olds, however, did have this universal (across plant type) understanding.

Experiment 2 was similar to experiment 1 but included several examples of each plant type (Experiment 1 only included one example of each). Experiment 2 also included distracters (nonliving artifacts) in the pictures of plants, and incorporated a picture-pointing task which combined the concepts of universality and inevitability. Seventeen 4-year-olds and 20 6-year-olds (and adults) participated. A 3 (age: 4-years, 6-years, adults) × 3 (plant type: flower, weed, tree) × 2 (component: universality/inevitability, finality) ANOVA was conducted. Results indicated that 4-year-olds understood the finality and causality concepts, but not the universality/inevitability concept. Six-year-olds understood all components of plant death. Both 4- and 6-year-old children understood that death applies to plants but not artifacts.

Experiment 3 was the same as Experiment 2, but incorporated animals in addition to plants and artifacts. Nineteen 4-year-olds and 20 6-year-olds (and adults) participated. A 3 (age: 4-years, 6-years, adults) × 2 (component: universality/inevitability, finality) × 3 (object: plant, artifact, animal) ANOVA was conducted. Results indicated that children understood the concept of death with regard to animals more than they did with regard to plants.

Researchers concluded that children 4 and 6 years old differ in their understandings of death with regard to plant type (flower, weed, tree). They understood that death applies to plants and not to artifacts. They understood the concept of death (finality, universality/inevitability) with regard to animals better than they did with regard to plants.

## Young Children's Conceptions of Germs and Contagions

Siegel and Share (1990) conducted a study consisting of a series of two experiments designed to explore children's conceptions of illness. In the first experiment participants included 38 preschool children aged 3 to 4. The first experiment consisted of three phases of stories. In the first story children were asked whether juice with a cockroach in it would be safe to drink. In the second story children were asked whether juice that had a cockroach in it would be okay to drink if the insect was removed. In the third story children were asked whether a child who really wanted a glass of chocolate milk should drink a glass of chocolate milk that had originally contained a cockroach, but it had been removed, or whether the child should choose a glass of water instead. Overwhelmingly the children recognized that all drinks that had contained the cockroach were contaminated and should not be consumed because it could make them sick. In the second experiment children were asked whether it would be safe to eat a slice of moldy bread. They were then asked whether it would be okay to eat the slice of moldy bread if vegemite were spread across the bread to cover the mold. The children all knew they should not eat the moldy bread, even if they could not see the mold. Researchers concluded that children were capable of ignoring the appearance of an item and to focus on the reality of whether it had originally contained a contagion to succeed in contamination tasks.

Solomon and Cassimatis (1999) conducted a study to explore young children's conceptions of germs and contagion. This study was contextualized within conceptions of biology. There were a series of experiments reported in the study. In the first study 12 children were divided into 4 age groups—preschool (4 years old), 6 year olds, 7 year olds, and 10–11 year olds. Twelve adults also participated in the study. Participants were read four stories that described a child becoming ill and being visited by a friend, and asked to speculate whether the visitor would become ill from visiting their sick friend. Two stories indicated germs were the cause of illness, and two stories indicated that poison was the cause of illness. Adults recognized germs caused illness, as did the 10–11 year olds. The younger children did not distinguish between the causes. Preschoolers who did recognize that germs caused illness held a greater appreciation of the role of germs in contagion. Most preschoolers did not differentiate the effects of symptoms caused by germs from those caused by poisons and did not demonstrate an understanding of germs as part of contagion.

In study two participants were read similar stories except symptoms caused by germs were contrasted with those caused by irritants (not poisons). Most preschoolers did not differentiate symptoms caused by germs from those caused by irritants.

In study three participants were explicitly told that germs caused a girl to get sick. As in the previous studies almost none of the preschoolers made contagion judgments for symptoms caused by germs that were different from those they made for symptoms caused by irritants.

Study four emphasized attributes of entities. In this case the attributes were people, ants, trees, rocks, germs and poisons. Almost no young children attributed animate properties to germs or poisons. Most preschool children judged poisons and germs as inanimate.

Study five explored children's conceptions of attributes of eating, growing, and dying. Most preschoolers did not recognize germs as being of the same ontological category as plants and animals. Only 17 % acknowledged that germs feed, none judged they grow, and only 33 % judged that they age and die. In general preschoolers did not consider germs to be living things, and did not relate them causally to illness.

Overall, 4-year-olds did not distinguish between germs and poison as causes of illness, even when told explicitly that germs caused a girl to get sick. Also, preschoolers did not consider germs to be living things.

## Young Children's Conceptions of Plants and Animals

Osborne and Freyberg (1985) used interview techniques to explore 140 6 and 7 year old children's conceptions of classifications of plants and animals. Seventy-five percent of these children considered grass a plant, 59 % considered a seed a plant, 40 % considered an oak tree a plant, and 38 % considered a carrot a plant. Similarly, 80 % of the 8 year old children did not consider humans animals. Only 20 % of these children considered a spider or a worm an animal, with 70 % considering a whale an animal and 80 % considering a cow an animal.

Strommen (1995b) conducted a study of 20 first-grade urban children's knowledge of forests and the types of animals and plants that are in the forest. Research methods used were interviews and children's drawings of forests. Children's drawings were scored regarding classes of animals, different types of animals, and relationships between drawn forms (e.g. bird in a tree). Finally, other elements were scored as present or absent (e.g. the presence or absence of humans, sun, or clouds).

During the interviews children's definitions of forests, the number of animals mentioned, the number and types of food, and habitats mentioned were tracked using a card sort frequency. Results showed that 37 % of the animals drawn in the photos were inappropriate to the forest environment. Trees and mammals were the most commonly drawn elements, as well as the sun and grass. Children usually portrayed only one animal in their drawings. In 24 % of the drawings animals such as birds or bugs were portrayed in trees, showing a relationship between plant and animal in the forest environment.

Children's definitions of a forest were very uniform across samples. In general, their definition was "a place with lots of trees and lots of kinds of animals." Children spontaneously mentioned between 6 and 33 different kinds of animals being in a forest. Plants were mentioned less frequently as being present in a forest. If children mentioned plants at all they mentioned the presence of trees in a forest. Children had difficulty mentioning where living things could be found in a forest. While children knew that there was food for animals in the forest, they could rarely name that food accurately.

The researcher noted that children's ideas of forests and animals can be construed as being rich in content but poor in structure. The ideas were rich in the sense that children identify many animals, but weak in structure because they did not know which animals were found in forests, or plants and food types available to specific animals in forests.

Simons and Keil (1994) explored preschool children's understandings of the insides of animals. The researchers used comparisons of children's conceptions of the insides of machines and animals, contextualized within abstract and concrete understandings. The researchers' goal was to determine what sorts of things children expect to be inside animals and complex artifacts such as machines through a series of related small studies. In the first study the researchers provided children with cards with photos of animals with either animal or machine insides. The researchers asked the children to state which card accurately portrayed the insides of animals or machines. Older children answered slightly more correctly than younger. Findings indicated that children in the study lacked a clear understanding for what can be found inside animals and machines. In the second study the researchers used real photographs of animals with animal or machine insides instead of drawings. They found that even with increased realism and detailed photographic stimuli, fewer than half of the children were consistently correct in determining what should be inside an animal or a machine. Children had more accurate responses in relation to machines than animals.

In the third study the researchers used real gears and preserved organs, as well as rocks in jars for 4-year-old children to consider as possibilities for what could be inside animals. Despite the use of real items the researchers found similar patterns of misunderstandings by children. In the fourth study the researchers again used real items, emphasizing the functional role of insides. They found that use of the real items along with a description of the function had little effect on children's understandings of what was inside animals.

The researchers concluded that young children expect the insides of animals and machines to differ, but lack expectations for what they will look like or how they differ. They picked different insides for both animals and machines, but were incorrect in their choices. For example some children picked a natural item to be present inside of an animal, but those natural items were rocks or dirt. The researchers speculated that children may have frameworks of causal expectations without detailed mental models of underlying mechanisms. They suggest that adults might have the same kinds of ideas.

Hickling and Gelman (1995) explored 4-year old children's understandings of biological and physiological mechanisms of seeds. The researchers elicited 4-year old children's understandings of plants to determine whether they held a biological understanding of plants, and understood that there is no psychological aspect to plants. They presented children with photos and asked them to describe their knowledge of the origin of seeds, and of seed growth preconditions. They found that children were able to distinguish between biological and psychological mechanisms, and that they recognized that external, natural mechanisms are responsible for seed growth. Their second study examined the ontological status of seeds. They again showed 4-year old children photos, this time asking which things came from seeds and what seeds have inside them. Results indicated that the 4-year-old children partially understood the place of seeds in the biological domain. In the third and final study, the researchers examined 4-year olds' understandings of the life cycle of a seed, utilizing a similar interview prompted with photos. They found that children four and a half to almost 5 years old were able to understand the cyclical process of seed development, while children younger than four and a half were not.

Leach, Driver, Scott, and Wood-Robinson (1996) conducted a study to explore children's ideas about interdependence of life in communities, balance, relative population size, and relationships between organisms in food webs. They wondered how students would conceptualize the relationships between populations in food webs and forms of interdependence among organisms. The researchers used three previously validated probes called "Communities," "Scene" and "Eat."

In the "Communities" probe students were asked to select six organisms to belong to one community. It was found that children selected the organisms because they were organisms found in the wild, not because of interdependence in a community. Their vision of a balanced community included animals they were familiar with.

The "Scene" probe was used as an interview to discern where students thought certain organisms belonged. Students between ages 5 and 7 were reluctant to select organisms. Others selected organisms that were likely to be found with humans, such as plants in pots, and insects in houses. Others placed animals in odd places, such as rabbits, penguins and earthworms together in one tree. Findings suggested that many young children are not familiar with natural environments and think of animals as depending on humans.

Regarding students' conception of population size, children predicted which population of organisms would be largest and provided explanations. A large variety of responses were obtained. Species suggested by children were classified as producers, primary consumers, secondary consumers, and decomposers. Many times students suggested more than one species being most numerous. Younger participants used anthropomorphism for their reasons, such as stating "animals liked being in certain places more."

In the "Eat" probe students were also asked questions to determine their ideas about a food web. Students were most likely to talk about organisms in a singular way, suggesting conceptions of a relationship between predator and prey as opposed to conceptions of organisms in populations. Children 5 to 7 years old did not show evidence of conceptualizing groups of interdependent organisms in ecosystems.

Students were interviewed to determine their conceptions of forms of interdependence of organisms. Most pupils between the ages of 5 and 16 were found to be inconsistent in the forms of explanation they used in different contexts. They explained relative population size in different ways. Older pupils who had previous instruction had better formed explanations. Students between the ages of 5 and 7 thought of organisms as individuals rather than members of a population. They believed that organisms rely on human beings to provide for their needs. Some young children thought certain animals had similar values and emotions to humans. From age 7 students understand that organisms can fulfill their own needs without human intervention, but many do not think there is a competition for resources.

Myers, Saunders, and Garrett (2004) explored young children's conceptions of animals' needs. These researchers interviewed 171 children at the Brooklyn Zoo to determine their knowledge of animal needs. Children of ages 4–14 were randomly approached during their zoo visit and asked to describe their favorite animal's needs. Children responded verbally and through drawings. Qualitative analysis was used to categorize responses by the following needs: physiological, reproductive, activity, psychological, social, ecological, and conservation. Results indicated that girls scored higher on social needs and boys scored higher on activity needs. Children who had pet care responsibilities scored higher overall than those that did not. Children aged 4–9 predominately noted physiological needs, with an increasing trend in recognizing other needs by older children. Ecological and conservation needs were rarely mentioned by any students in this group, however these factors correlated closely with an increase in age.

Ross, Gelman, and Rosengren (2005) explored young children's ideas of categories as related to classifications of animals. The researchers noted that learning of categories and making inferences are crucial aspects of cognitive development, and as such, designed a series of experiments with young children of 5 to 7 years old to determine their ideas of classification and inferences. In the first experiment they used cards with line drawings of fictitious animals. They asked children to sort them and classify them with the researcher naming the first one, and then asking the child to state whether the next card was in that same group. Seventy-seven percent of the children classified these cards correctly.

In experiment 2 28 6 year old children were given similar cards with some critical feature changes. The researchers found that inference-making influences category knowledge during the category learning. Experiment 3 explored students' abilities in distinguishing classification and inference making. First children were asked to make classifications, then they were asked to go through cards again and to make inferences for their classifications. Most children could do both tasks. In experiment 4 children were not told the classification of an animal when they were asked to make an inference. The researchers continued to find that that children's knowledge changed due to inference. The researchers concluded that making inferences during learning influences category knowledge in young children, which enables persons to classify new instances and then make new inferences.

Endreny (2006) explored third grader's conceptions of animal adaptation. Using a theoretical framework of constructivism, she examined third graders' ideas of habitats containing living and nonliving things, of organisms having basic needs, of the function of animal structures (growth, reproduction, etc.) and adaptations. She used an action research approach by collecting and analyzing clinical interviews of children (pre, during, and post instruction), observations of lessons, and collection student work from their investigations. She used open coding to analyze her data. Results indicated that children used their prior knowledge to understand adaptations, had limited understandings of habitat (indicating an understanding of temperature only). Students did not demonstrate an understanding of animal structures and behaviors as adaptations to the environment. Students were able to identify the connections between structures and behavior of animals. The researcher concluded that some topics may not be developmentally appropriate, but that with strong, inquiry-based instruction third graders could begin to make accurate conceptualizations of connections between animals and their habitats.

Petrova et al. (2010) explored 20 Kindergarten and 26 3-year-old students' conceptions of objects as literary personage or scientific character using the idea of anthropomorphism. The researchers also sought to define the dynamics with the conceptions of the children at pre-school and primary school age.

The researchers used diagnostic interviews as well as pedagogical observations. The researchers read a literary and scientific text about plants and animals twice to each child, and then asked the child "What will you tell about the birch/wolf/stork?" (The item varied depending on the version of the story). The researchers found that anthropomorphic conceptions about the birch with preschool children were more enhanced in comparison to those of animals. The anthropomorphic conceptions with the 5 to 6 year children were not within the scientific conceptions about objects, especially the wolf. This finding suggested that primary school children held less anthropomorphic ideas about plants and animals than preschool children. Primary school children's conceptions of literary personage for the birch, wolf, and stork were found to be equal. The conceptions of scientific character were dominant for the wolf, despite the fact that literary texts paint anthropomorphic characteristics in the stories. The researchers recommended that teachers balance literary personage by talking about the discordance between anthropomorphic texts and scientific texts with children. They recommended increasing the use of scientific texts for children of all ages to provide better scientific conceptions and reduce anthropomorphic ideas about plants and animals. .

Hoisington, Sableski, and DeCosta (2010) took preschool children on a field trip to the arboretum in Boston to teach them the following fundamental life science concepts: Living things have physical characteristics that can be observed and described; living things grow, change, and have life cycles; living things have needs and depend on their environments and other living and nonliving things to get these needs met. During their visit children made observations of the life forms they saw within the arboretum, while teachers focused their instruction on helping the children explore, asking them to represent their observations through drawings, and engaging the children in science talk. Feedback from teachers at the end of the field trip suggested that the children learned new vocabulary words and names of trees. Children's drawings of trees suggested they either were unaware of or were confused about roots and root structure. Also, some children thought that birds lived and flew in tree trunks. The authors provide suggestions for how to address these conceptions (i.e., pulling up a small tree to show the children the roots and root structure).

Eick (2012) explored using an outdoor classroom to support learning of science as well as literacy skills for third grade students. The teacher in Eick's study wanted to meet language arts and science goals, and designed interdisciplinary lessons to use in the outdoor classrooms that would target literacy and science objectives. The third grade teacher was a biology science major. She taught science daily, most often in the outdoor science classroom, followed by indoor follow up investigations and explorations. Twelve of the 15 students who participated in the study met Adequate Yearly Progress (AYP) goals at level IV, which is the highest AYP attainment level. This level seems high, but it was the same passing level demonstrated by other students in this particular school. Though some administrators tried to dissuade the teacher from including as much science as she did in her curriculum, student results on standardized tests indicated that including science with literacy did not hinder their literacy development, and in fact enabled her students to also learn science concepts along with literacy objectives.

## Research Methods Used to Elicit Young Children's Understandings

Methodologies used with young children must serve to elicit understandings of participants who are at various stages of development in their abilities to read and to write. The vast majority of studies reviewed therefore used qualitative methodologies that enabled researchers to use interview methods and stories to explore children's conceptions of life science. Some studies utilized surveys and questionnaires, which were completed by adults with regard to their thoughts about children's conceptions (Fleer & Hardy, 1993; Nguyen & Rosengren, 2004; Patrick et al., 2009) or administered to children through questioning and/or storytelling (Backscheider et al., 1993; Patrick et al., 2009). Most studies reviewed utilized either a qualitative or a mixed method approach. Quantitative analysis usually consisted of ANOVA or MANOVA with regard to the age of the children and their understandings of various biological phenomena. Interestingly, methods in developmental psychology and science education demonstrated patterns within their fields.

Studies in developmental psychology often utilized qualitative interviews of children through a series of experiments in a clinical setting, making modifications after each iteration to refine the interview process (Backscheider et al., 1993; Hickling & Gelman, 1995; Inagaki & Hatano, 1996; Nguyen & Gelman, 2002; Rosengren et al., 1991; Ross et al., 2005; Simons & Keil, 1994). For example, Simons and Keil (1994) first interviewed children and showed them photos of animals and machines, asking children whether what was depicted was real. They refined this process in study two, using real photographs to increase the realism of the image. In the third study, these researchers decided to show children real objects, and finally, in the fourth study, they showed children real objects and asked them explicitly what they thought was inside the object. This iterative process allowed the researchers to elicit deeper understandings after each study, tweaking the interview methods to further obtain the information needed to answer their research questions.

Studies in developmental psychology also combined interview methodology with story telling. Researchers framed the topic of study within a story that young children could understand in order to provide context to the biological phenomena. For example, Solomon and Cassimatis (1999) examined young children's understandings of germs and contagions through a series of five studies. In the first study, participants (from 4 age groups: 4 years old, 6 years old, 7 years old, and 10–11 years old) were read four stories that described a child who became ill and was visited by a friend, and asked children to speculate whether the friend would become ill. Two stories indicated germs were the cause of illness, and two stories indicated poison was the cause of illness. In the second study, participants were again read stories except symptoms caused by germs were contrasted with those caused by irritants rather than poisons, and in the third study participants were explicitly told that germs caused a girl to get sick. Study four emphasized attributes of specific objects or entities, in this case, people, ants, trees, rocks, germs and poisons. Almost no young children attributed animate properties to germs or poisons. Most judged poisons and germs as inanimate. Finally, study five emphasized attributes of eating, growing, and dying. Presumably, the researchers utilized this methodology because felt they could elicit more information from the children when framing the interview questions in the form of a story, rather than simply asking children about their ideas of germs and contagions.

While studies in developmental psychology tended to emphasize refining the data collection process within a clinical setting, studies published within science education emphasized varied views of methodologies for understandings young children's knowledge of life science in the classroom. Most studies reviewed included interviews as a method for eliciting students' understandings, although in the case of science education, these interviews were often paired with observations of classrooms (Endreny, 2006; Patrick et al., 2009; Petrova et al., 2010; Shepardson, 1997). Others examined student work (e.g., journal entries) in addition to conducting interviews and/or observations (Britsch, 2001; Endreny, 2006; Shepardson, 1997; Strommen, 1995b). Eick's (2012) investigation of the use of an outdoor classroom teach third graders integrated science and literacy, and Patrick et al.'s (2009) examination the use of sustained inquiry-based instruction on gender differences in science learning both provide good examples of how science education research focuses on pedagogical practices. This emphasis on classroom data suggests that science education research values broad and varied data sources, while developmental psychology research values in-depth probing of children's conceptions through multiple and refined interviews (although it is important to note that not all studies in developmental psychology interviewed the same children multiple times). The emphasis of research in developmental psychology on understandings children's cognition is logical. Similarly, the focus of research in science education on pedagogical interventions to foster young children's understandings of life science is also logical given that teachers are responsible for improving students' conceptions.

## Recommendations for Future Research

Research on young children's conceptions of life science has been conducted within two fields (developmental psychology and science education) that we have reviewed, each grounded in their own theoretical frameworks. The findings from each field are critical to understanding how and what young children can learn, however both fields remain relatively independent of one another. Collaborative studies that involve both developmental psychology and science education researchers could simultaneously examine how and what children learn within the same research conditions (i.e., setting and participants). The theoretical frameworks of both fields can provide a more thorough understanding of children's cognition and learning and therefore offer holistic implications to both fields. It is therefore recommended that future research consist of interdisciplinary investigations to include multiple perspectives of young children's conceptions of life science. Additionally, studies could be conducted that include researchers collaboratively working from different paradigms, such as from the conceptual change and sociocultural paradigms.

From our review we can clearly state that young children do have already formed conceptions of life science content prior to instruction. Many of these conceptions are accurate, such as their understandings that living things can heal, but inanimate objects require repair (Backscheider et al., 1993). They conceptualize properties of living things, as well as growth and development (Inagaki & Hatano, 1996). They also hold some understandings that would not be considered scientific, such as that children will be less like their fathers than their mothers (Johnson & Solomon, 1997), or the knowledge of many different kinds of animals, but not understanding which belonged in forests (Strommen, 1995b). It is not surprising that young children would hold a mixture of scientific and unscientific ideas about life science concepts. It is common for people of all ages to hold unscientific ideas in the absence of appropriate instruction. What is also clear from our review is that young children who were taught appropriate scientific ideas improved their understandings of life science concepts. This improvement in understanding highlights the importance of teaching science from a young age—children who received such instruction improved their understandings, and it did not deter from other school objectives, such as literacy goals (Eick, 2012).

Furthermore, the literature reviewed in this chapter included studies that were conducted in 1990 or after. The studies reviewed from developmental psychology were largely conducted in the 1990s (75 %) and the studies from science education were mostly conducted within the past 5 years (69 %). While the literature in science education is more current, only four studies were found that have been published since 2008. Given the recommendations of the *Framework for K-12 Science Education* (National Research Council, 2012) and the Next Generation Science Standards, future research can focus on young children's understandings of life science concepts in relation to the frameworks and standards (i.e., From Molecules to Organisms: Structure and Processes; Ecosystems: Interactions, Energy, and Dynamics; Heredity: Inheritance and Variation of Traits; and Biological Evolution: Unity and Diversity), as well as Scientific and Engineering Practices and Cross-cutting Concepts.

Indeed, research into children's conceptions of life science was limited to specific topics, and it would be informative to expand that list to include further life science topics. It would be easy to envision a study that explored young children's conceptions of species, characteristics of species, and how organisms are categorized into species. Ross et al. (2005) investigation of children's conceptions of classification of imaginary animals touched on this concept, but not their ideas regarding classification of real animals. Numerous other topics within life science could also be explored.

Research from the science education literature has also shown that through appropriate instruction young children are able to attain better understandings of life science concepts than prior to instruction (e.g. Shepardson, 1997). Further research could explore instruction that supports children's learning of life science concepts and could help shed light on whether children are developmentally constrained by their knowledge, or whether and what kind of instruction can move them beyond their early conceptions (e.g. Metz, 1997).

## Implications for Teaching

Many researchers in both developmental psychology and science education appear to agree on effective methods for teaching life science to young children. Science instruction should include inquiry and experiential learning experiences (Doris, 1991; Endreny, 2006; Eick, 2012; Hamlin & Wisneski, 2012; Metz, 1995, 2004; Patrick et al., 2009; Worth & Grollman, 2003) and incorporate science notebooks for students to draw their understandings (Britsch, 2001; Shepardson, 1997; Stevenson; 2013). Educators should use pictures to represent investigation materials and science phenomenon, because young learners' reading levels vary. Research discussed and supported the use of "science talk" to promote young children's understandings and critical thinking about life science (Hoisington et al., 2010; Shepardson, 1997; Trundle, Mollohan, & McCormick Smith; 2013; Worth & Grollman, 2003).

Petrova et al. (2010) recommend as a result of their research that an important classroom strategy would be to incorporate more non-fiction children's books into the science classroom. Teachers often read stories to young children, yet those stories often use anthropomorphic characteristics to describe both the plants and animals. These authors suggest using a variety of children's books, and when reading a fictional book to debrief with the children, comparing characteristics of animals or plants in a fiction to characteristics found in non-fiction books to aid in development of appropriate understandings.

Eick (2012) also found evidence that incorporating science goals with literacy goals did not hinder children's attainment of literacy objectives. In fact, literacy enhanced attainment of science concepts. This study provides support for the use of interdisciplinary science and literacy instruction, capitalizing on the literacy teaching strengths held by many early childhood teachers, and enabling them to make a bridge to teaching science. French (2004) shared information regarding a preschool curriculum called ScienceStart! that used similar strategies of making science the center of the curriculum and teaching literacy as part of it. The children in this program showed improvement in language skills on standardized tests, and were also able to solve problems related to science. This curriculum could be used to teach science through literacy, as was found to be successful by Eick (2012).

In a recent *Science and Children* issue (February 2013) dedicated to young children's learning of life science, Trundle et al. (2013) present the following preschool learning cycle within the context of life science instruction to engage young children in inquiry learning: Play (engage, notice, question, wonder); Explore (predict observe, record data); and Discuss (share data, reflect, construct explanations, develop new questions, draw conclusions). Assessment should occur throughout the cycle through observations and discussion, and/or through children's drawings. This learning cycle for life science concepts can be contextualized within active inquiries that will also enable the teacher to track pre and post understandings of ideas (e.g. Endreny, 2006).

Stevenson (2013) suggested the use of an "I Wonder board" in both the formal and the non-formal educational setting. The board can be used to model curiosity and to build observation and questioning skills. This kind of strategy could also serve as a pre-and post assessment for teachers who are tracking understandings over time (e.g. Hoisington et al., 2010). Stevenson (2013) noted the following connections to the *Framework*: "showing curiosity, examining details, looking for facts, asking follow-up questions to their questions, and speculating from evidence" (p. 75). She also stated the following additional benefits of I Wonder boards: recording questions that cannot be addressed in that moment (like a Parking Lot), eliminating the pressure on the teacher to provide immediate answers, potential to engage in citizen science projects (i.e., explore phenomena on their own or with their parents). Finally, the author noted that assessment occurs through discussion/questioning and/or science journals (e.g. Shepardson, 1997)

Certainly a main teaching idea from all studies is that children will come to the classroom with ideas about life science they have developed from their experiences in the world. Teachers could use strategies similar to those used in the research to determine their students' conceptions of life science concepts and use that information to aid in designing or adapting lessons to improve their students' conceptions. For example, teachers can hold class discussions prior to instruction, similar to what is recommended by Doris (1991), and use the children's statements during talk to identify conceptions that can be addressed in instruction. If the students are capable of writing, they can be asked to respond to prompts in science notebooks that can then be used by the teacher to identify conceptions and plan lessons accordingly.

In essence, we can clearly see that children do have well-developed ideas of life science concepts. Some of these understandings are scientific, and some are preconceptions. Through appropriate instruction they can improve their understandings and develop more scientific conceptions. Therefore, they are developmentally ready for understanding life science concepts.

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# Chapter 6
# Too Little, Too Late: Addressing Nature of Science in Early Childhood Education

**Randy L. Bell and Tyler L. St.Clair**

## Introduction

Children born into the twenty-first century face an amazing array of scientific discoveries and technologies, along with the unintended consequences that accompany them. Advances in science and technology are progressing faster than ever, with knowledge doubling in a manner of years, as opposed to the decades or even centuries of the not-too-distant past. Any thought of teaching a substantial portion of this knowledge to school-aged children has long past, and so too has focusing on knowing and understanding facts as principal goals of science education. That is not to say that knowledge acquisition is no longer considered a worthy goal, but with the vast array of knowledge that is available, what we teach to children must be chosen with care. In addition, it is more important than ever to teach children how this knowledge is gained (practices of science), as well as the nature of the knowledge itself (science epistemology).

Science education reform documents have placed these three critical aspects of science under the umbrella of scientific literacy (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996), while The Next Generation Science Standards (NGSS) focuses on scientific practices and modeling in science (Next Generation Science Standards [NGSS], 2013). Either way, modern standards focus on both what science is and what scientists do as key components of scientific literacy. Thus, policy makers see the nature of science as important to teach and learn in addition to the processes and products of science.

Researchers agree on the importance of teaching science epistemology and point to a variety of benefits such instruction provides. For example, Sadler, Chambers,

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and Zeidler (2004) found student understanding of the social and cultural embedded aspect of science led students to more informed perspectives on the issue of global warming. Students who understood this aspect of science were more likely to see that an individual's personal viewpoint may influence what data they select to form an argument about an issue. Additionally, Driver (1996) makes a case of the importance of a broad public understanding of science from multiple perspectives including making sense of technology encountered in day-to-day life, recognizing and appreciating science as a component of our modern culture, and supporting the learning of science content in school. Nature of science instruction has been linked to greater student interest in science (Lederman, 1999; Meyling, 1997; Tobias, 1990), and has also been found to reinforce student learning of science content (Cleminson, 1990; Songer & Linn, 1991).

Along with the acknowledgement of the importance of teaching the nature of science has come the recognition that young children have the capacity to participate in science investigations. A growing body of research, much of it described in the present volume, demonstrates that even very young children have remarkable abilities to do and understand science when guided by informed instructors. And while the research on teaching and learning the nature of the discipline to young children is not as well developed, our understanding of what is developmentally appropriate to teach and effective ways to teach it is emerging.

In this chapter, we explore what the nature of science means in early childhood education by summarizing the findings of relevant empirical research and discussing implications of these findings for the classroom. In so doing, we argue that nature of science instruction in early childhood is needed and we present a framework to guide researchers and classroom teachers in exploring this elusive, but critically important topic.

## What Is the Nature of Science, and Why Teach It?

At its most basic level, the nature of science refers to the epistemology of science, or in simpler words, science as a particular way of knowing. A wide variety of philosophical positions exist with regard to the nature of science and there is little consensus among philosophers of science about its epistemology (Abd-El-Khalick, Bell, & Lederman, 1998). Fortunately, there seems to be a consensus on the nature of science concepts deemed appropriate for teaching K-12 students among most philosophers, historians and educators. The nature of science is taught at a general level in the K-12 setting, and few would contest tenets such as scientific knowledge is based on evidence or scientific knowledge is subject to change. In fact, national reform documents and recent science education literature have emphasized the large degree of agreement in characterizations of the nature of science appropriate for K-16 students (AAAS, 1993; Lederman, 2007; NGSS, 2013; NRC, 1996). Furthermore, a Delphi study by Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) found a substantial overlap between the nature of science standards outlined in the national reform documents and those generated by an expert panel of 23 scientists, science educators, and historians, sociologists and philosophers of sciences.

Based on this consensus, the National Science Teachers Association has published a position statement delineating the basic tenets of scientific knowledge deemed appropriate for K-12 classrooms (National Science Teachers Association [NSTA], 2000):

1. Scientific knowledge is reliable, yet still tentative.
2. Science uses a variety of methods.
3. Science involves creativity.
4. Science investigates questions related to the natural world.
5. The terms “theories” and “laws” have specific meanings in science.
6. Contributions to science have been made by people all over the world.
7. Science occurs in a social and cultural context.
8. The history of science shows science can both gradually and suddenly change.
9. There is a relationship between science and technology, but basic scientific research is not concerned with practical outcomes.

While not all of these concepts are appropriate for the early childhood years, our understanding of what young children can know and do continues to expand. As such, science educators are seeing early childhood as a time for building the conceptual foundation that young people will use to construct sophisticated understandings of the nature of science.

## Developmentally Appropriate Nature of Science for Early Childhood Years

The Next Generation Science Standards present a framework for nature of science instruction across four age progressions: K-2, 3-5, Middle School and High School. Appendix H of the NGSS includes many statements about what elementary children should learn about the nature of science (NGSS, 2013). Many of the previously mentioned aspects of the nature of science are covered, but expounded in more detail, and in varying levels of complexity based on the grade level in which they are taught. These learning progressions are more conceptual than research-based, however. In fact, the few studies that address teaching and learning the nature of science in early childhood paint an incomplete picture of what is appropriate for young children. Still, this research provides a foundation that can inform the development of appropriate learning progressions.

A number of studies focusing on elementary level students show us that they are falling short of the expectations for nature of science understanding. For example, Akerson and Abd-El-Khalick (2005) evaluated fourth grade students’ understanding of specific tenets of the nature of science, including the distinction between observation and inference, the creative and imaginative aspects of science and the notion that science ideas are reliable but subject to change. Results showed that these students did not possess desired conceptions. Other studies confirm that elementary children tend to see scientific knowledge in an absolute way, have difficulty in determining and expressing how they arrive at their knowledge, and are generally unclear when asked to distinguish between direct observations and the inferences under a variety of experimental conditions (Sandoval & Çam,m, 2011; Sodian & Wimmer, 1987).

At first glance, this research seems quite discouraging about the capabilities of young children, but these studies are focused on portraying what children understand about the nature of science prior to formal instruction, rather than the understandings they may be able to achieve. A different sort of study is needed to determine whether young children are developmentally capable of understanding the nature of science. Piaget is well known for his contribution to learning theory with his idea that children progress through developmental stages as they mature (Piaget, 1972). According to Piaget, children during the elementary school years are transitioning from the preoperational to concrete operational stage, learning to see things from multiple points of views and using logical thought, but still their thinking tends not to be abstract. Understanding the nature of science requires considerable abstract thought, so some might argue that young children are not ready for it. Consider, however, that focusing narrowly on children's developmental stages may result in failure to scaffold students to higher developmental stages in the future (Metz, 1995). Also, teachers run a risk that when they have students engage in activities that are left unconnected to a larger purpose, they may reinforce students' already existing absolute views of science (Bell, 2004).

Which, if any, of the aspects of the nature of science can young students understand? Studies of elementary children across various ages and settings show that they are very capable of learning about the nature of science. One such study found that when K-2 children were taught the nature of science explicitly, they significantly improved their understandings (Quigley, Pongsanon & Akerson, 2010). Interestingly, results also demonstrated that some aspects of nature of science were learned better than others. These students improved their understanding that scientific knowledge is tentative and that it is based on observations, but had trouble distinguishing between observation and inference. Another study examining children of the same age found that they were able to make significant progress in learning that science is creative, subject to change, based on observation and inference, and empirical (Akerson, Buck, Donnelly, Nargund-Joshi, & Weiland, 2011). They struggled however with the subjective and cultural aspects of nature of science.

Akerson and Hanuscin (2007) studied the use of inquiry to teach the nature of science and looked at student understandings in classrooms of teachers who took part in professional development to teach nature of science at the elementary level. Both teacher and student understandings showed improvement. However, the researchers found a marked difference in student understanding based on grade level. Kindergartners' understandings did not change significantly, while first graders showed noticeable improvement, and fifth and sixth graders showed the most improvement. The authors interpreted these results as possibly reflecting a developmental constraint of the children, or indicating that the interview technique and the vocabulary of the assessment tool was perhaps less appropriate for younger students.

In summary, evidence seems to indicate that young children are capable of learning many, but perhaps not all aspects of the nature of science. While developmental constraints likely play some role, even young children are capable of learning about the nature of science at more advanced levels than previously assumed. More research is necessary in order to validate learning progressions for teaching the nature of science across grade levels. Some tenets of the nature of science may be more appropriate for younger ages, but it is clear that the nature of science can be integrated into science instruction as early as science instruction begins.

## Teaching the Nature of Science in Early Childhood Years

Numerous studies have demonstrated that students across all ages possess alternative conceptions about the nature of science (Lederman, 1992, 2007; Ryan & Aikenhead, 1992). Thus, teachers not only need to teach the nature of science; they have to understand and address their students' alternative conceptions. Many possible approaches for teaching the nature of science have been presented in the literature. These include teaching the nature of science through historical case studies, teaching it implicitly, and teaching it explicitly. Among these options, explicit instruction has emerged as the most effective method for producing lasting conceptual change (Abd-El-Khalick & Lederman, 2000). It is important to note that explicit instruction is not equivalent to direct instruction. With explicit instruction, nature of science is a planned objective of the lesson- it is not left to chance. In explicit instruction there must be a component of the lesson that purposefully draws students' attention to the particular aspect of the nature of science that the lesson is designed to address (Bell, 2004).

A few studies have explored nature of science pedagogies specific to elementary settings. A study by Khishfe and Abd-El-Khalick (2002) looked specifically at teaching the nature of science through inquiry-based lessons to sixth graders. An experimental group engaged in explicit reflective discussion after completing the set of lessons, while a control group was considered to be an example of implicit instruction. Both groups received pre- and post- tests related to four dimensions of the nature of science: tentative, observation/inference, empirical, and creative/imaginative. The authors reported a large positive change for the group that engaged in explicit discussion about the nature of science, but no significant change was observed for the implicit control group. A very similar study replicated these findings in an inquiry-based chemistry lab for sixth graders using essentially the same approach, but looking instead at the tentative, empirical, subjective and social dimensions of science (Yacoubian & BouJaoude, 2010). This study also found increased learning for the explicit reflective group, but no change in the implicitly instructed control group.

Inquiry lessons provide excellent opportunities to direct student attention to nature of science concepts. Lederman (2004) highlights the strong link between science inquiry and the nature of science- a position echoed by the Next Generation Science Standards with their inclusion of the nature of science with authentic science practice (NGSS, 2013).

In addition to inquiry approaches involving authentic science practice, the nature of science can be taught explicitly through science process skills, as well (Bell, Mulvey, & Maeng, 2012). Bell (2008) presents activities that are tied to science process skills as a means to teach relatively abstract nature of science concepts in a clear and direct way. These activities allow students to practice science process skills (such as observation, inference, or modifying their conclusions based on new data), and then explicitly relate these processes to nature of science tenets. This format may be especially helpful for younger children who find it difficult to make sense of some of the abstract tenets of the nature of science.

In addition to using appropriate pedagogy, other factors impact teachers' efforts to implement nature of science instruction. For example, many curricular materials include alternative conceptions about the nature of science. One of the most common alternative conceptions is that there is a step-by-step method that all scientists follow when they do their work, usually called "the scientific method," which roughly outlines the steps of doing a controlled experiment. This is a problem, because science uses many methods, including correlational, descriptive, and epidemiological studies, to name a few. Focusing narrowly on "the scientific method" paints a picture of science that is overly formulaic and devoid of creativity, which may negatively impact student interest and choice to pursue science careers. In the present environment of high-stakes testing, teachers feel great pressure to address the basics of science content, often leaving little room in the curriculum for nature of science. In addition to these challenges, many teachers possess the same misunderstandings about nature of science as students, an issue discussed at length in the next section.

## Teacher Conceptions of Nature of Science

It is important to examine findings that reveal how elementary teachers (both preservice and in-service) conceptualize the nature of science. In an early study focusing specifically on preservice elementary teachers, Abell and Smith (1994) found that there were similarities between children's conceptions about nature of science and preservice elementary teachers' conceptions. They classified these preservice teachers' views as both realist and positivist, meaning that their views of science knowledge are too absolute and neglect that science is subjective, taking place within a social and cultural context.

Another study explored elementary preservice teacher understandings of the relationships of theories and laws in science. Scientific laws are descriptions of the way the universe works, while theories offer explanations as to how nature works. It was found that preservice elementary teachers misunderstand the relationship between theories and laws and tended to view scientific theories as simple guesses (Concannon, Brown, & Brown, 2013).

At a Turkish university, researchers explored the differences between early childhood and elementary preservice teachers using the VNOS-C instrument (Kaya, 2012). At the time of the study, the elementary group had received more science instruction and had been introduced to nature of science instruction in their methods course, whereas the early childhood group had not. This nature of science instruction was lecture-based and did not take place through inquiry or the explicit reflective method, and so not surprisingly, these two groups both ended up with underdeveloped and roughly equal notions of the nature of science.

Alternative conceptions about nature of science appear also to be the norm for in-service elementary teachers. For example, a 2010 study by Shim, Young and Paolucci suggested that in-service elementary teachers hold slightly more absolutist views of science than preservice elementary teachers. Though there was not a strong difference between the two groups, the pre-service teachers more frequently acknowledged that creativity and imagination have a place in science.

Morrison, Raab, and Ingram (2009) reported a comparison between in-service elementary and in-service secondary science teachers' views of the nature of science. Prior to an inquiry-based professional development intervention, the elementary teachers had less refined views of the nature of science than secondary science teachers. Both groups improved in their nature of science views by the end of the intervention. On average, elementary teachers generally have less exposure to science courses during their pre-service years than do their secondary science teacher counterparts. This may not actually be a detriment to understandings of the nature of science. Another study (Pomeroy, 1993) found that both scientists and secondary teachers possessed more inflexible and traditional ideas about science than elementary teachers such as the importance of teaching science hierarchically, that worksheets are an effective way to teach science and that teachers should discourage children from "wild ideas." Elementary teachers on the other hand more often identified that intuition is an important part of discovery and that science can involve non-sequential thinking.

In addition to the large body of evidence about teachers' underdeveloped views relating to the nature of science, there is also evidence that these views directly affect their teaching in a negative way. Capps and Crawford (2013) examined the teaching of 26 well-qualified 5th to 9th grade teachers and found that they very rarely taught about the nature of science, and that when such instruction did occur, it was implicit. These findings point to a certain indoctrination of more absolute views that seem to come with exposure to traditional science instruction across all age levels. If absolute views of scientific knowledge are the product of traditional instruction, what are the approaches that promote more appropriate understandings? The next section explores the research on preparing both preservice and inservice science teachers to teach this elusive construct.

## Promoting Effective Nature of Science Instruction

Teachers cannot teach what they do not understand, and as we have seen, the research indicates that their understanding of the nature of science is too often inadequate. Pre-service science methods courses are uniquely situated for imparting future teachers with solid understandings of science and ways of teaching it. A substantial amount of research has focused on preservice teachers in this context. Research is converging on the conclusion that an explicit reflective approach is most efficient for teaching nature of science to both students and teachers (Bell, Matkins, & Gansneder, 2011; Kucuk, 2008). This approach is also very effective in helping preservice teachers construct meaningful connections between the various aspects of the nature of science (Ozgelen, Hanuscin, & Yılmaz-Tuzun, 2012). As previously stated, the explicit reflective approach makes the nature of science an explicit goal of the lesson, with objectives, activities, and assessments all geared toward students understanding target aspects of the nature of science. In other words, nature of science instruction is intentional. The approach contrasts with implicit nature of science instruction, where teachers expect students to learn nature of science concepts simply by "doing science." Research has demonstrated that implicit approaches are not successful (Bell, Blair, Crawford, & Lederman, 2003).

Akerson, Weiland, Bilcan, Pongsanon, and Rogers (2012) confirmed the effectiveness of the explicit reflective approach for preservice teachers, but added that the context may impact which aspects of the nature of science are learned best. This study compared the effectiveness of three different contexts of instruction: the nature of science, problem-based learning, and authentic inquiry. Results demonstrated that all groups improved their nature of science understandings regardless of context. The authors also reported minor differences in which tenets of the nature of science improved most in each context. However, the differences were small, participant assignment was not random, and the authors did not control for initial differences in participants' understandings. Therefore, it is difficult to place much confidence in these findings.

Other studies have looked at combining the explicit reflective approach with other instructional techniques. It is worth mentioning a couple of the most interesting examples. One of these studies looked at teaching preservice elementary teachers the nature of science explicitly in context of the theme of global climate change (Bell et al. 2011). This study applied different treatment conditions to four preservice elementary science methods courses. These treatments were stand alone nature of science taught implicitly, stand alone nature of science taught explicitly, embedded nature of science taught implicitly in the context of global warming, and embedded nature of science taught explicitly in the context of global warming. Results indicated that teaching the nature of science explicitly produced statistically significant changes in understandings of the nature of science, whereas implicit approaches did not. Further, it was found that teaching the nature of science in a stand alone way was just as effective as when taught in context of global climate change. Teachers who were taught nature of science explicitly in a stand alone way were able to successfully apply what they had learned to the issue of global climate change.

Another component of successfully implementing nature of science instruction in preservice elementary methods courses is having the support of cooperating mentor teachers during teaching apprenticeships. Akerson, Buzzelli, and Donnelly (2010) found that having the support of the cooperating teacher is more important than any other factor as an indicator for whether preservice teachers would teach the nature of science to their students. This is understandable, and is a legitimate concern for those who would arrange teaching placements for teaching internships, because research shows that few in-service teachers possess adequate understandings of the nature of science. Communication among the science methods instructor, cooperating teacher and preservice teacher is necessary to address expectations about trying out nature of science instruction during preservice teaching apprenticeships.

Research on effective nature of science instruction has also been conducted with in-service teachers. Akerson, Cullen, and Hanson (2009) used a summer science camp as an opportunity to foster a community of practice among in-service elementary teachers. Explicit reflective instruction was used and found to be effective, but the additional component of having a shared community of practice was effective at facilitating discussions among teachers about their understandings of the nature of science. The cooperative nature of a community of practice provided a context for teachers to become aware of and verbalize their own struggles with learning and teaching the nature of science with their peers.

A different approach used by Mulvey and Bell (2013) for in-service middle school teachers was a process skills-based professional development designed to aid teachers in the incorporation of explicit reflective nature of science instruction into their science courses. All 25 participants in the study taught the nature of science explicitly to their own students as a result of the professional development and were observed teaching a wide range of nature of science tenets, as well.

Taken together, findings for preservice and in-service teachers emphasize the need for explicit reflective instruction, but this approach has been difficult for teachers to implement in practice. Abd-El-Khalick et al. (1998) found that understanding the nature of science does not necessarily relate to actually implementing nature of science instruction in their own teaching. The group of 14 preservice teachers in this study held adequate understandings of the nature of science, but only rarely drew attention to it explicitly in their instruction.

Akerson, Morrison, and McDuffie (2006) showed that a single semester of nature of science instruction was inadequate for long-term improved understandings. While many of the preservice elementary teachers in study initially improved their understandings of the nature of science, they reverted to their prior alternative conceptions after only 5 months. On the other hand, Bell and his colleagues demonstrated that secondary preservice teachers could learn and retain nature of understandings over long periods of time when nature of science concepts were tied to process skills (Bell, Mulvey & Maeng, 2011; 2012).

A case study examined potential instructional supports an elementary teacher might require as she taught aspects of nature of science to her fourth grade students (Akerson & Abd-El-Khalick, 2003). The researchers found that although the teacher possessed an adequate understanding of the nature of science, she needed considerable support to develop and teach her ideas new understandings about science. Surprisingly, based on this single non-representative case study, the authors concluded that all teachers need such intensive support to translate their understandings into classroom practice!

Clearly teachers need more than an understanding and experience of nature of science instruction before they can implement it themselves. Intrinsically they need to know why it is important to teach and extrinsically they need exposure to appropriate models for instruction, activities and support systems. The process skill-based approach mentioned previously has shown promise at both helping teachers develop appropriate conceptions of the nature of science and putting it into practice in their instruction (Bell et al. 2012). Preservice teachers need to have support with the explicit reflective approach in their methods courses and during their teaching practicums, while in-service teachers need to have support through targeted nature of science professional development experiences.

## Assessing Nature of Science

Various assessments have been developed for assessing the nature of science over the past five decades. These include formal research-based instruments, informal summative and informal formative assessments. One of the most widely used research instruments was developed by Lederman and colleagues to assess people's views of the nature of science (VNOS) across many domains (Lederman, 2004, 2007; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). These domains are:

1. The empirical nature of science.
2. The distinction between observation and inference.
3. The tentativeness of science.
4. The distinction between theories and laws.
5. Creativity in science.
6. Subjectivity in science (regarding the nature of scientific theories).
7. The social and cultural influences on science.

Modified versions of this instrument have been developed and used specifically to test elementary student views of nature of science, including the VNOS -D, and -E (See Appendix).

A disadvantage of using these formal research instruments, however, is that they require time and training to classify responses and interpret results. These instruments are powerful research tools for understanding children's understanding of the nature of science, but they are not practical for teachers to use on a regular basis in the classroom to assess their students. Because of this, others have approached the question of nature of science assessment from the viewpoint of the classroom teacher. Bell (2008) recommends that teachers use a combination of informal, formative, and summative assessments. Informal assessments can be as simple as talking with students during or after activities about what they learned about science, while science notebooks and class projects fall into the more formal formative assessment category.

Various summative assessments have been developed over the past several decades that teachers could choose from for use in their classroom. One example is the "Draw-A-Scientist" Test (Chambers, 1983; Farland, 2006). In this test, children's drawings of scientists are analyzed against a control group where children are simply asked to draw a person. The frequency of stereotypes occurring in the drawings that are associated with scientists is totaled to reveal the extent to which children hold these stereotypes. The test has shown that at a very early age, children hold the idea that scientists are male, wear glasses, have lots of facial hair, and work in laboratories surrounded by technology. While the instrument has shown insight into young children's views of science and scientists, it is important to remember that the instrument relies to a large degree on inference. Because of this, follow-up interviews are critical to validate such conclusions, a technique that "Draw-A-Scientist" too often fail to employ.

An example of a test for teachers to gain a better understanding of their own views is the "Myths of Science" quiz developed by Chiapetta and Koballa (2004). This short quiz helps teachers get a snapshot about their views related to topics like the tentativeness of scientific knowledge, the objectivity of science, who does science, and the relationship of science and technology.

A recent study examined elementary teachers who possessed good understandings of the nature of science themselves and how these teachers assessed their students (Akerson, Cullen, & Hanson, 2010). These teachers spanned a range of diverse K-4 classroom settings. Some teachers adopted existing instruments, such as the VNOS-D, but made modifications to fit their specific students such as eliminating specific tenets that they did not deem appropriate to the grade level they were teaching. Others used pictures to ask students about nature of science while others used journaling or more structured worksheets. What was quite evident was that the teachers had a strong natural understanding of what their students were developmentally able to handle in terms of specific aspects of nature of science, and that they were comfortable creating or modifying assessments be more aligned with their nature of science teaching goals. These assessments also proved especially useful as a way for teachers to challenge their own understandings of nature of science, in addition to gaining insight into student understandings.

## Discussion

In this chapter we have outlined rationales for teaching the nature of science to young children and have explored ways to prepare teachers to teach and assess the construct. An important result of this effort is the realization that concerns have been exaggerated that the nature of science is too advanced or abstract for young children to understand. Research demonstrates that children develop and can learn about the nature of science, even at very early ages. A limited number of studies have examined whether particular aspects of the nature of science are best suited to young children, but results are not yet conclusive. Research into the nature of science conceptions of PreK children is particularly scarce. Thus, more work is necessary to determine which aspects are most appropriate for young learners. Current research hints that foundational understandings of the empirical and tentative nature of science and the roles of observation and inference are likely to be most appropriate for young children. Understanding the social and cultural influences on science or the difference between scientific theories and laws would come later, and build upon these foundational understandings. Policy documents, such as *The Next Generation Science Standards* (NGSS, 2013), recognize the need to scaffold the nature of science based on grade level. However, additional research is required to develop validated learning progressions for teaching the nature of science for students of all ages.

An important consideration in nature of science instruction is that both children and teachers commonly possess alternative views, often based on their everyday experiences. There are many possible explanations for the prevalence of these alternative conceptions, such as how science is presented in popular culture by the media, inadequate attention to teaching the nature of science in schools, or even ineffective science curricular materials that perpetuate myths about the nature of science. More appropriate understandings of the nature of science will allow teachers to evaluate curricular materials with a critical eye. It will also help teachers recognize and address the common stereotypes of science promoted in popular culture. Unfortunately, research has demonstrated that developing the understandings of science that allow for such curricular decisions does not come easily. It is important that preservice methods courses include scaffolding to help teachers recognize and address students' alternative conceptions and that similar professional development be offered to inservice teachers.

It is important to acknowledge that a few science educators have criticized the nature of science perspectives outlined in this chapter. For example, a critique by Ault and Dodick (2010) focused on potential shortcomings of process skills as a context for nature of science instruction. The authors focused particularly on the Fossil Footprints activity, which is designed to explicitly draw students' attention to the difference between observations and inferences, as well as their roles in the development of scientific knowledge. Ault and Dodick argue that learning the nature of science through process skills is inauthentic to the way real scientists conduct their work and that process skills instruction is a caricature of real science that can lead to inappropriate views. However, their argument fails to recognize the authentic aspects of the activity and addresses it as an isolated lesson, which runs contrary to the approach described by Bell (2008). Further, the more sophisticated approach they advocate would be difficult for the majority of elementary teachers to implement and would likely be inappropriate for young learners. Again, no one is advocating for the removal of authentic science from science classes. However, there is a place for analogies that present simplified versions of science practices, especially when teaching young children. No doubt, scaffolding is necessary to help young learners bridge the gaps between their personal experiences and the abstract constructs of the nature of science. Building such a stark dichotomy between authentic science and process skills may be effective rhetoric, but it does not do justice to the research on effective nature of science instruction, nor the complexities of the early childhood classroom experience.

In a more general critique, Duschl, and Grandy (2013) advocate strongly for model- and practice-based approaches situated in extended science units. Their critique is based upon an extreme position that few, if any of the researchers whose work has been reviewed in this chapter would recognize. Duschl and Grandy describe much of the current nature of science research as advocating a pedagogy that is decontextualized and relying too heavily on a consensus list of tenets. In contrast, the present review, addresses a variety of studies that feature nature of science instruction embedded within the context of larger curricular units, inquiry investigations, scientific processes and the history of science. No one that we are aware of is advocating for decontextualized nature of science instruction, nor is anyone suggesting that authentic science practice should not be a large component of science classes. Rather, it is the explicit, reflective component within the context of inquiry, process, or historical instruction that such researchers emphasize. An important consideration is that Duschl and Grandy do not back up their practice and model-based approach with data that demonstrate its effectiveness. At this point, the rationale for the approach is conceptual, rather than empirical. It may be that certain contexts are better for teaching particular tenets of the nature of science, but caution must be exercised when making such recommendations prior to building a foundation of empirical work. From our perspective, it is likely that multiple approaches are necessary to effectively teach the multifaceted aspects of the nature of science, and that over-emphasizing the division between contextualized and decontextualized camps is both unproductive and greatly exaggerated.

Conceptual articles and qualitative studies are of value to nature of science research because they can offer suggestions, provide insight into patterns and trends, and help generate hypotheses for future studies. However, making generalizable recommendations for teacher preparation and classroom instruction requires a strong research base that includes empirically based causal pathways. Much work remains in this area. Further, while the current research base supports the use of explicit-reflective and process skills-based approaches, there is a great need to delineate the developmental progressions of nature of science understandings. As this review has demonstrated, we know a lot about teaching and learning the nature of science. It is important not to forget lessons learned as we move forward to the next stage of nature of science research.

## Appendix: Questions from VNOS-D and –E

### Questions from the VNOS-D

1. What is science?
2. How is science different from other subjects you are studying?
3. Scientists produce scientific knowledge. Some of this knowledge is found in your science books. Do you think this knowledge may change in the future? Explain your answer and give an example.

4a. How do scientists know that dinosaurs really existed?
4b. How certain are scientists about the way dinosaurs looked
4c. Scientists agree that about 65 million years ago the dinosaurs became extinct (all died away). However, scientists disagree about what led to cause this to happen. Why do you think they disagree even though they all have the same information?

5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.

5a. Do you think weather persons are certain (sure) about the weather patterns?
5b. Why or why not?

6. What do you think a scientific model is?
7. Scientists try to find answers to their questions by doing investigations/experiments. Do you think that scientists use their imagination and creativity in their investigations/experiments? Yes or no?

7a. If no, explain why.
7b. If yes, in what part of their investigations (planning, experimenting, making observations, analyzing data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.

### Questions from the VNOS-E

1. What is science?

2a. What are some of the other subjects you are learning?
2b. How is science different from these other subjects?

3. Scientists are always trying to learn more about our world. Do you think what scientists know will change in the future?

4a. How do scientists know that dinosaurs once lived on the earth?
4b. How sure are scientists about the way dinosaurs looked? Why?

5. A long time ago all the dinosaurs died. Scientists have different ideas about why and how they died. If scientists all have the same facts about dinosaurs, then why do you think they disagree about this?
6. TV weather people show pictures of how they think the weather will be for the next day. They use lots of scientific facts to help them make these pictures. (Test shows picture of a weather person on TV with a weather map). How sure do you think the weather people are about these pictures? Why?

7a. Do you think scientists use their imaginations when they do their work? Yes or no?
7b. If no, explain why?
7c. If yes, then when do you think they use their imaginations?

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# Chapter 7
# Development of Science Process Skills in the Early Childhood Years

**Jamie Jirout and Corinne Zimmerman**

Science is simultaneously an individual, social, and cultural activity. At the individual level, scientific thinking shares many characteristics with other forms of problem solving and reasoning (Klahr, Matlen, & Jirout, 2013; Zimmerman & Croker, 2013), and can be further defined as a specific type of intentional information seeking (Kuhn, 2011). Although other types of information seeking also require motivation and basic reasoning mechanisms, the curiosity that drives science is satisfied only through deliberate activities such as asking questions, testing hypotheses, engaging in inquiry, and evaluating evidence (Jirout & Klahr, 2012; Morris, Croker, Masnick, & Zimmerman, 2012). An additional defining feature of scientific thinking involves metacognitive and metastrategic knowledge – the ability to reflect on the process of knowledge acquisition and change that result from scientific activities. Metacognitive abilities develop throughout childhood (Schneider, 2008), but we see the early emergence of these skills with respect to children's beginning theory-of-mind skills – such as the idea of where beliefs come from, that others may have different beliefs, that beliefs can be more or less certain, beliefs may be formed on the basis of inference or from evidence (e.g., Sodian & Wimmer, 1987).

Psychologists and educators have long been interested in the development of scientific thinking (for reviews, see Zimmerman, 2000, 2007), which includes a potentially long list of candidate skills:

> After all, given one's point of view, scientific thinking might be assumed to include any or all of the following: conceptual development, hypothesis testing, control of variables, theory change, correlation and contingency, induction, generation and interpretation of

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> evidence, visualization, design of experiments, data modeling, causality, representation tools and notations, and a grasp of related idea like uncertainty, probability, necessity, and sufficiency. A messy list, and one that is by no means exhaustive! (Schauble, 2003, p. 155)

Entire lines of investigation have focused on these individual skills, and there is a sub-discipline of psychology focused on science (e.g., see Feist & Gorman, 2013, for an edited volume).

This volume is devoted to research that informs the science education of young children. But what does it mean to do "science" in early childhood? *Early childhood* is typically defined as birth through age 8. What types of science process skills are young children capable of? What do we know about the developmental trajectory of precursors to fully developed process skills? In what ways can basic psychological research on scientific thinking inform the science education of young children?

In this chapter we will focus on *science process skills* – the set of domain-general skills that can be applied to any domain of inquiry. As evident from the other chapters in this volume, other research programs focus on how children learn about the various domains of science: earth science, space science, physical science, life science, to name a few (for example, see Chaps. 3, 4, and 5 in this volume). Fully developed scientific thinking requires a long developmental trajectory as well as educational training. Our goal is to focus on a subset of science process skills and discuss how they are manifested in young children (as counterparts to more advanced or trained skills).

This distinction between the concepts and processes of science is mirrored in the science standards used by educators. For example, the newly published science education standards (National Research Council [NRC], 2012) focus on elements within three dimensions. The first dimension, *Scientific and Engineering Practices*, includes process skills, such as asking questions (in science) or defining problems (in engineering), conducting investigations, interpreting and using evidence, constructing explanations (science) or designing solutions (engineering). The second dimension includes *Crosscutting Concepts*, such as cause and effect, systems and system models, patterns, stability and change. The third dimension specifies *Core Ideas in Four Disciplinary Areas* (i.e., physical sciences, life sciences, Earth and space science, and engineering, technology and the applications of science). For example, molecules, organisms, ecosystems, heredity, and evolution are some of the core ideas included within *Life Sciences*.

The science process skills we will focus on are motivated by the idea that young children are "naturally curious" and that *uncertainty* is one of the factors that prompts curiosity and a "key component in scientific inquiry" (French & Woodring, 2013, p. 182). As such, we will begin the discussion with what is known about children's curiosity. Second, we focus on *dealing with uncertainty* – or the process skill of asking questions. Next, we will review process skills aimed *at investigating uncertainty* – what young children understand about investigation by examining what they know about using experiments, and how they interpret patterns of data and use evidence. Finally, we will consider some educational interventions designed for preschool and young elementary children that incorporate some or all of these process skills.

## Curiosity: The Desire to Resolve Uncertainty

The idea that curiosity is important for early science instruction is a widely held and unchallenged belief. In fact, curiosity is argued to be a "crucial element" of scientific reasoning (Klahr, Matlen, & Jirout, 2013; Klahr, Zimmerman, & Jirout, 2011) and is included across science curricula and educational standards and goals (American Association for the Advancement of Science [AAAS], 1993; Brenneman, Stevenson-Boyd, & Frede, 2009; Conezio, & French, 2002; Kagan, Moore, & Bredekamp, 1995; Klahr, Matlen, & Jirout, 2013; National Education Goals Panel (NEGP), 1995; National Association for the Education of Young Children (NAEYC), 2014; NRC, 2000b). The reason curiosity is thought to be so important in science is rarely articulated, though. One explanation for this lack of explicit justification is that people find the idea of curiosity to be easily understood – that is, everybody feels they know what curiosity is. When it comes to defining or articulating what curiosity is, however, there is a lot of variability in existing definitions (Jirout & Klahr, 2012). The *measurement* of curiosity has proven just as challenging, resulting in difficulty conducting empirical research on scientific curiosity. We argue that the reason curiosity is so important for science is that uncertainty alone is not enough to lead to exploration; curiosity is the desire or motivation to explore and ask questions. Specifically, we define curiosity as the *preferred level of uncertainty* – or the amount of uncertainty that will lead to question asking or exploratory behavior (Jirout & Klahr, 2012).

Although research on curiosity as uncertainty preference is limited, there is some support for the relationship between uncertainty and exploratory behavior. For example, simply placing a science center or science-focused toys in a classroom may not lead to exploration. When such toys are introduced in an interactive investigation, however, children will become more aware of what is unknown, leading to exploratory behavior (Nayfeld, Brenneman, & Gelman, 2011). People tend to explore most when there is some uncertainty, but not too much, suggesting an "optimal level" (Jirout & Klahr, 2009; Litman, Hutchins, & Russon, 2005). In most studies of uncertainty preference, participants are presented with only three levels of uncertainty: none, some, and a lot. In adult studies, the "some" level of uncertainty is most likely to elicit feelings of curiosity (Loewenstein, 1994), and for both adults and children "some" uncertainty leads to more exploratory behavior than none or a lot. For example, when adults were presented with trivia questions and asked to report both their "feeling of knowing" and how curious they were to know the answer, greatest curiosity was reported at the middle level of knowing (called "tip of the tongue"; Loewenstein, 1994; Loewenstein, Adler, Behrens, & Gillis, 1992, as cited in Loewenstein, 1994). Litman et al. (2005) replicated this protocol, but added the opportunity to explore and find the answers. Participants again responded with the greatest curiosity for the middle level of uncertainty, and also explored to find the answer most often at this level.

In another series of studies, children were given the option to open one of two doors on a house to see what type of pet lived there, with each door showing a different amount of uncertainty (Jirout & Klahr, 2009). For example, one door might have a small window, through which the child could see what was behind the door, resulting in minimum uncertainty. Another door might have a bowl of water in front of it, indicating that either a dog or cat would be there (medium uncertainty), or a solid door, providing no information about the pet behind the door (a lot/maximum uncertainty). Children either had a chart of the ten animals that might be behind the doors, or there was no chart, so the possibilities were unknown – creating either a higher-medium level or a maximum level of uncertainty, respectively. Children preferred the medium level of uncertainty over the minimum and maximum, however when the maximum level was presented as a finite set (of ten possibilities) rather than an unknown set of possibilities, children then preferred to explore the medium and maximum levels options equally (Jirout & Klahr, 2009). When children explained their exploratory choices, responses included reference to the different uncertainty levels, for example, “I didn’t know which one it would be” about the medium level, “I like it to be easy” about the minimum level, and “I like when it’s a mystery” about the maximum level, suggesting that that they did in fact choose based on the uncertainty level. The different pattern of exploration between maximum uncertainty of ten and unknown possibilities suggests variation of an optimal preferred level of uncertainty in children.

To pursue this hypothesis of a preferred level of uncertainty, Jirout and Klahr (2012) used a similar forced-choice paradigm with several additional uncertainty levels to assess children’s uncertainty preference. In their measure, children could explore across seven levels of uncertainty, with an adaptive game that narrowed down the preferred level by presenting 18 comparisons based on children’s previous exploration choices. Although most children’s preference level still corresponded to a “middle” level of uncertainty, overall performance on the game provides a more precise assessment of curiosity. The average level of curiosity as uncertainty preference did not differ across age groups from preschool to first grade, and there was a range of preferred uncertainty within grades. This measure provides an assessment of curiosity that could be used in future studies of science education and its effect on curiosity, and the influence of curiosity on science learning.

Even though further research is necessary, these studies highlight the importance of creating some cognitive conflict or uncertainty during science lessons. This is especially true when dealing with misconceptions or attempting to change an erroneous prior belief. For children to become curious, it is important not just to create uncertainty in the environment, but for the child to cognitively perceive the uncertainty. Creating uncertainty when a child has a strongly held belief can be challenging, but a child will not become curious if he or she believes they already know something a teacher is trying to teach. Additionally, knowing the “optimal” level of uncertainty for children might help teachers to individualize instruction and scaffold children’s learning more effectively. Just the general understanding that children do prefer some (but not too much) uncertainty can help science educators to stimulate children’s curiosity for learning. For example, Howard-Jones and Demetriou (2009) found that including uncertainty in an educational computer game leads to increased motivation and engagement. Introducing “cognitive conflict,” which creates uncertainty using a contradiction with a child’s existing knowledge, leads not only to conceptual change, but also to generalization of learned concepts (Minstrell, 1992; Posner, Strike, Hewson, and Gertzog, 1982). With young children, cognitive conflict is often induced by teachers' open-ended questions which can then lead into science activities to address those questions, and modeling question-asking behavior can help children recognize uncertainty and ask questions themselves (Zimmerman & Pike, 1972). Children's question asking provides a way of addressing uncertainty, and children who have higher curiosity (measured as uncertainty preference) have been found to ask more questions and be better able to identify questions that are more effective in resolving uncertainty (Jirout & Klahr, 2015). In the section below, we discuss the development of children's question asking to deal with uncertainty.

## Dealing with Uncertainty: Asking Questions

Asking questions is considered one of the foundational process skills of scientific practice (NRC, 2012). Kuhn and Dean (2005) articulate why formulating a question is a critical component of scientific inquiry. In terms of understanding the nature of science, it is important for students to realize that they are seeking information that will address a question for which they do not already know the answer. Older students often believe that the purpose of science is to demonstrate what is already known (Kuhn, 2005), to see if something "works," or to invent things (Carey, Evans, Honda, Jay, & Unger, 1989). Asking questions for which the answer is not known is a crucial element of inquiry that students must learn – as both a process skill and as a defining feature of science (see Chap. 6, this volume, on children's understanding of the nature of science).

Once children recognize uncertainty and decide that they want to attempt to resolve that uncertainty, curiosity can then lead to *question asking* as the next step in intentional information seeking. As mentioned above, there are several factors involved in children's ability to deal with uncertainty. These include recognizing the uncertainty, desiring to resolve it, and then acting on that desire. Teasing apart these different factors is difficult. If a child asks a question or explores, we are able to say that he or she recognizes the uncertainty and is curious to resolve it so took action toward that goal; otherwise the question would not have been asked in the first place. Thus, *question asking* and *exploration* are appealing methods for studying children's response to uncertainty. By empirically investigating these behaviors, we gain some insight on the development of these skills.

Simple problem-solving tasks that require question asking are useful for investigating children's ability to recognize specific instances of uncertainty and to evaluate information. These tasks, typically called *referential tasks*, involve asking categorical questions to identify a target from a group of possibilities (e.g., an array of pictures). Research using the referential task yields a relatively consistent picture of children's ability to ask identification type questions: 4- and 5-year-old children are able to gain specific information from questions. For example, children can ask questions to determine which of two items (shown as pictures) are hidden in a box

(Choinard, Harris, & Maratsos, 2007). When children are given the opportunity to ask a question to figure out which of the objects is hidden in a box before guessing, they are correct on about five of the six trials; if they are told to guess without being allowed to ask a question, their accuracy is at chance. These results suggest that not only can children determine what question to ask to address uncertainty, but they can also use information gained to resolve it.

In studies using a similar problem-solving task, but with more complex stimuli (see Fig. 7.1), 5- and 6-year-olds have much more difficulty using questions effectively to solve simple problems, and this type of question-asking ability does not seem to develop spontaneously until elementary school (Cosgrove & Patterson, 1977). Some methods of training children in this type of specific question-asking behavior have been effective, however the results of these studies are mixed in regards to the effectiveness of training with pre-school age children. Kindergarten students are the youngest children in which training consistently shows improvement in question-asking behavior, with successful training methods including direct instruction and/or some form of modeling: the experimenter either gives instruction or demonstrates effective question-asking behavior before asking the child to produce similar questions, sometimes offering scaffolding as well (Cosgrove & Patterson; Courage, 1989; Lempers & Miletic, 1983; Zimmerman & Pike, 1972).

The following is an example of an effective training protocol instructing kindergarten students to ask informative questions rather than guessing single items:

> Whenever you ask a question, try to think of one that will tell you about more than one picture at a time. Don't just guess. Try to figure it out. For example, you could ask if the house is [grey]. If I say 'yes' then that tells you about four of the houses. You know that the house is a [grey] one. Then you could ask me if it has a door. If I say 'yes' . . . Remember, you have to figure out the one I'm thinking about by asking good questions. Go ahead and ask me a question (Courage, 1989, p. 880).

Effectiveness of training in this and similar studies is typically indicated by differences between training and control groups in the frequency of asking categorical questions. The same type of referential task used in the training is used as a pre- and post-measures, although sometimes with different objects (e.g., instead of houses, the array could include familiar animals). Preschool and kindergarten students who received this training are significantly more likely to ask a categorical question at posttest than those who only received additional practice, however almost all students in second grade, including those who only received additional

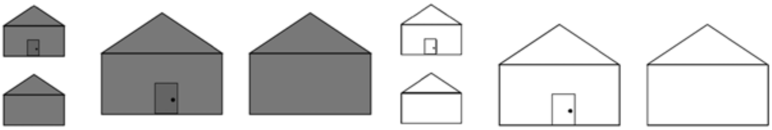

**Fig. 7.1** An example of a referential task picture array. Children are asked to identify a single target picture from the eight items in the array. Asking categorical questions, such as the color (e.g., "Is it a *grey* house or a *white* house?") size (e.g., "Is it small or large?") or if the house has a door, is a more efficient and effective strategy than guessing each picture individually

practice, asked a categorical question (Courage, 1989). In a study of 5-year-old children that did not use direct instruction, stimuli characteristics were manipulated to induce category recognition, using multiple exemplars within categories to make them more salient. For example, in the control condition, the car category included identical cars (e.g., all identical VW Beetles), whereas in the experimental condition, the car category included four different types of cars. Compared to the control group, some children did improve in asking constraint-seeking questions after experience with the experimental stimuli, but only if they approached the task initially by asking questions verbally, rather than physically gesturing to indicate their questions (Thornton, 1999). A similar study found that modeling question asking led to improvement of constraint-seeking question asking on the topic that was modeled in 4- and 5-year-old children, but the effect of the modeling does not transfer to asking similar questions on novel topics (Nelson & Earl, 1973).

In a study including both indirect and direct instruction, Johnson, Gutkin, and Plake (1991) found that children 6.5 years or younger did not improve in asking effective (i.e., "constraint seeking") questions after an intervention that included only the modeling of effective question asking. The children did show improvement, however, when the intervention included explicit explanation about how to recognize unknown information and to generate a question to address that specific unknown information. Denney (1972) also used a modeling-based training intervention with 6-, 8-, and 10-year-old children to increase constraint-seeking questions and found that, only the older children improved, and that improvement was no longer evident at a 1-week follow-up session. In a study with more extensive training across several weeks, children as young as preschool did show some improvement in question asking, from asking no constraint-seeking questions to asking an average of 17 % constraint-seeking questions in a 20 questions, referential-style assessment (Denney & Connors, 1974).

Though there has been some demonstrated success of training methods using direct instruction as well as indirect methods, these studies only consider a limited range of question-asking ability – categorical questions to address a small, specific piece of uncertainty. Science often addresses much larger, more complex and open-ended questions. Most previous studies use the same simple task as both pretest and posttest measure, and it is not clear if improvement on this type of question-asking task is related to improvement on more open-ended or naturalistic questions. However, we do know that young children ask many open-ended questions.

Observational studies of children's question asking assess the frequency and content of question asking in young children using naturalistic settings or tasks with minimal structure (Choinard et al., 2007). Chouinard and colleagues assessed children's questions asked in a naturalistic setting using recorded home observations from the CHILDES database (MacWhinney, 2000). More than 24,000 questions were asked by four children ranging in age from 1;2 to 5;2 years over several years. Of these questions, most (71 %) were considered "information seeking" – meaning that they were asked to gain some specific information in response to uncertainty (examples of non-information seeking questions would be asking a parent for permission or clarification). Not only do children ask a high proportion of information-seeking questions, but the majority of questions children ask are follow-up or “building” questions, suggesting that the children are able to evaluate information attained with the initial question, apply it to their uncertainty, reevaluate what they know and/or want to know, and ask another question. The finding that children ask more follow-up questions than initial questions is also observed in a similar but slightly more constrained approach to studying question asking (Greif, Kemler Nelson, Keil, & Gutierrez, 2006; Kemler Nelson, Egan, & Holt, 2004). Kemler Nelson and colleagues investigated children’s questions on a structured task, but one with more open-ended goals than the referential task described above. These studies assessed what characteristics children recognized and found important. Children were instructed to ask questions about unfamiliar objects and animals, which they were able to do – averaging 26 questions asked across 12 pictures. Many questions were quite general across objects and animals, such as “what is it?” Other questions, however, showed a pattern of children’s recognition and understanding of the different categories of pictures (i.e., objects and animals). Children tended to ask more function questions about the objects, while the unfamiliar animals prompted questions about category membership, food choices, and locations.

The relationship between the types of questions asked during problem solving, such as the referential task, and questions asked to learn about more open-ended topics is not yet clear. In a recent study Jirout and Klahr (2015) attempted to look at this relationship by asking young children (aged 4–7) to complete a range of question-asking tasks, including a referential task, a more open-ended generation task, and a nonverbal task to assess children’s ability to recognize good and bad questions. In the generation task, children watched a short (60 s) animated song about a science topic and then generated questions on the topic. For the nonverbal task, children had a mystery to solve. They heard several questions with answers, which they then categorized as either helpful or not helpful for solving the mystery.

Each of these tasks had similar cognitive demands: uncertainty recognition, question generation, and/or information evaluation. In the referential task, children must understand that there is a single picture that is the target, and that they do not have the information necessary to determine which picture is the target (uncertainty recognition). They must then be able to generate a question to request the necessary information for determining the target (question generation), and then apply new information and re-evaluate whether they now have enough information to identify the target (information evaluation). In the generation task, children must identify what is unknown about the topic (uncertainty recognition) and generate a question to request that information (question generation). In the nonverbal task, children are made aware of the uncertainty and given the questions, and then must determine the question effectiveness (information evaluation). Jirout and Klahr (2015) found significant correlations between tasks with common demands: the referential and generation tasks, which both involve uncertainty recognition and question generation, and the referential and nonverbal task, which both involve information evaluation. Developmental trends were seen for all three tasks, with children improving with age. Interestingly, when looking at grade levels, preschool and kindergarten students were not different from each other, but first grade students scored significantly higher than both younger groups of students on all three tasks. Questions remain about *how* these question-asking skills develop, whether there are similar developmental patterns, and whether development of each question type or skill supports the development of other science process skills.

In addition to verbal question asking, children's recognition of uncertainty can be observed through other nonverbal tasks. Klahr and colleagues (Fay & Klahr, 1996; Klahr & Chen, 2003) found that children are able to *recognize* uncertainty in simple situations, and improve in recognizing uncertainty through practice. The *desire to resolve* uncertainty through intentional knowledge seeking can also be observed in goal-oriented exploratory behavior, for example in children's hypothesis testing. Schulz and Bonawitz (2007) gave children the choice to play with a toy they had some experience with or a novel toy. Experience with the toy included a demonstration of either an ambiguous (and uncertain) or unambiguous causal relationship. The researchers found that children will choose to explore the toy with ambiguous casual functions over exploring a new toy, but will choose to explore the new toy when uncertainty is not presented. When they do explore the ambiguous relationship, they are able to resolve the uncertainty and learn the causal relationship through testing different possibilities spontaneously during play. The process of *purposeful exploration*, however, is complex, and several studies have examined the development of children's early experimentation skills.

## Investigating Uncertainty: Early Experimentation Skills

One way that science differs from other forms of intentional knowledge seeking is that in addition to recognizing that there is something to be found out (Kuhn, 2005) one can engage in active inquiry and investigation of physical or virtual systems. There is a significant body of literature on scientific thinking skills in elementary and middle school (e.g., Zimmerman, 2007). Moreover, the NRC Report, *Taking Science to School* (NRC, 2007) is devoted to the formal science education from kindergarten through eighth grade. Although many developmental studies of science process skills have been conducted, it is often the case that fourth grade (around 9 years of age) represents the lower end of the age range in cross-sectional designs.

Only recently has there been an effort to revisit our assumptions about what science education should consist of for our youngest students (i.e., those age 8 or younger). Science education was very much influenced by Piaget's theory of cognitive development (e.g., Inhelder & Piaget, 1958), which was used to justify waiting until adolescence to teach science process skills (French & Woodring, 2013; Metz, 1995). We see these assumptions being challenged with the accumulation of evidence about how learning works (e.g., NRC, 2000a), and how children learn science (e.g., NRC, 2007).

Science education for young children often focuses on simple process skills such as observing, describing, comparing, and exploring (French & Woodring, 2013; NAEYC, 2014; National Science Teachers Association [NSTA], 2007). Active manipulation of the world – experimentation – involves the coordination of a number of individual skills: identifying variables, manipulating variables, observing and measuring, drawing conclusions, and so forth. It is not until the later school years that we see evidence that children are successful at coordination with extended practice and scaffolding (e.g., Kuhn, Black, Keselman, & Kaplan, 2000). There are a number of studies that examine the precursors to later experimentation skills.

In her classic study, Tschirgi (1980) included second graders (age 7) as the youngest group in a cross-sectional design. She presented children and adults with everyday problem-solving situations that involve the manipulation of a number of variables. The situation always involved an outcome that could be described as either positive or negative, for example "John baked a cake and it turned out terrible" or "Susan made a paper airplane and it turned out great." The character would then propose a hypothesis for which variable caused the outcome (e.g., shortening type, sweetener type, or flour type in the cake story). The participant was then asked to choose which of three options to select to help the character prove the hypothesis. In the vary-one-thing-at-a-time (VOTAT) answer, the proposed variable was changed, but the others were kept the same (i.e., the logically correct answer that corresponds to a controlled experiment). The hold-one-thing-at-a-time (HOTAT) answer involved keeping the hypothesized variable the same, but the other variables should be changed. The change-all (CA) answer consisted of changing all of the variables. Each answer choice was presented with pictures to illustrate the levels of the variable that were represented. Participants were asked to pick the one *best* answer for four positive outcome stories and four negative outcome stories.

For all age groups (adults and children in grades 2, 4, and 6), participants were more likely to select the HOTAT strategy for manipulating variables when the outcome was *positive*. That is, there was a tendency to hold the presumed causal variable constant in order to maintain the good result (but consistent with a confounded experiment). In contrast, when there was a *negative* outcome, the logically correct VOTAT strategy was chosen more frequently than HOTAT or CA, suggesting that participants were searching for the one variable to change in order to eliminate the bad result (consistent with the elements of a controlled experiment). Although the second- and fourth-graders were more likely to select the CA strategy for the negative outcomes (likely as a way to eliminate all possible offending variables), the youngest participants were influenced by the same desire to reproduce good effects and eliminate bad effects, which was true of both older children and adults. That is, the same tendency to choose a strategy based on pragmatic outcomes (rather than logical grounds) was evident in the youngest group of children.

Croker and Buchanan (2011) used a task similar to Tschirgi's, but included contexts for which 3.5- to 11-year-olds held strong prior beliefs (e.g., the effect of cola vs. milk on dental health). Half of the participants were presented with story problems where the evidence presented was consistent with prior belief, and the other half were presented with evidence that was inconsistent with prior belief (e.g., covariation evidence showing cola and healthy teeth, or milk and unhealthy teeth) and for which the outcome was either positive or negative. For all age groups, there was an interaction of prior belief and outcome type. The logically correct

VOTAT strategy was more likely to be selected under two conditions: (a) when the outcome was positive (i.e., healthy teeth) and consistent with prior belief, or (b) when the outcome was negative (i.e., unhealthy teeth) and inconsistent with prior belief. Even the youngest children were influenced by the context and the plausibility of the domain-specific content of the situations that they were reasoning about.

Bullock and Ziegler (1999) collected longitudinal data on participants, starting when they were age 8 and following them through to age 12. They examined the process skills required for experimentation, using separate assessments to tease apart an *understanding* of experimentation from the ability to *produce* controlled experiments. When the children were 8-year-olds, they were able to *recognize* a controlled experimental test. The ability to *produce* a controlled experiment at levels comparable to adults did not occur until the children were in the sixth grade. This study provides additional support for the idea that young children are able to understand the "logic" of experiments long before they are able to produce them.

Sodian, Zaitchik, and Carey (1991) investigated whether children in the early school years understand the idea that one can use an experiment to test a hypothesis. Children in first and second grade were presented with a story situation in which two brothers disagree about the size of a mouse (large vs. small) in their home. Children were shown two boxes ("mouse houses") with different openings (large vs. small) that contained food. In the *feed* condition, children were asked to select the house that should be used to make sure the mouse could eat the food, regardless of its size (i.e., to produce a particular outcome). In the *find out* condition, the children were asked to decide which house should be used to determine the size of the mouse and find out which brother was correct (i.e., to test the hypothesis). Over half of the first graders answered the series of questions correctly (with justifications) and 86 % of the second graders correctly differentiated between conclusive and inconclusive tests.

In the mouse house task, children were presented with a forced choice between a conclusive and an inconclusive test. In a second experiment, children were asked to *generate* (rather than select) a test of a simple hypothesis. In this case, story characters were trying to determine whether a pet aardvark had a good or poor sense of smell. Even with the more difficult task demands of generating a test for a hypothesis, spontaneous solutions were generated by about a quarter of the children in both first and second grade. For example, some children suggested placing food very far away. If the aardvark has a good sense of smell, it will find be able to find the food; if the aardvark has a poor sense of smell, it will not. Overall, Sodian et al. found that children as young as 6 can distinguish between a conclusive and inconclusive experimental test of a simple hypothesis when provided with the two mutually exclusive and exhaustive hypotheses or experiments. Some children in the early school years are also capable of generating tests for a simple hypothesis.

Piekny and Maehler (2013) used the mouse house task (Sodian et al., 1991) with younger children, including two groups of preschoolers (4- and 5-year-olds) and three groups of schoolchildren (7-, 9-, and 11-year-olds). They used the *feed* and *find out* conditions and examined both correctness of answers and justifications to questions about possible conclusive and inconclusive experiments. With respect to the critical variable of correctly differentiating between the *feed* and *find out* questions, a score was created to indicate those children who answered *both* correctly. Both groups of preschoolers scored significantly *below* chance. It was not until age 9 that children scored significantly above chance on this critical variable. It was not until age 7 that children showed a recognition of and justification for conclusive or inconclusive tests of a hypothesis

In the previously reviewed studies, the researchers made the decision to use story situations in which the hypotheses to be tested via experimentation were all *plausible*, so as to not confuse the participants (and as a control variable). Klahr, Fay, and Dunbar (1993) were specifically interested in how participants approach the task of testing hypotheses that are plausible or implausible. Klahr et al. provided third- and sixth-grade children and adults with hypotheses to test that were incorrect, but either plausible or implausible. When a hypothesis was plausible, all participants tended to go about *demonstrating the correctness* of the hypothesis rather than setting up experiments to decide between rival hypotheses. When given an implausible hypothesis to test, adults and some sixth-graders proposed a plausible *rival hypothesis*, and set up an experiment that would discriminate between the two. The third graders also proposed a plausible rival hypothesis, but would then ignore or forget about the initial implausible hypothesis to be tested. They got sidetracked in the attempt to demonstrate that the rival plausible hypothesis was correct. Klahr et al. (1993) identified two useful heuristics that participants used when engaged in hypothesis testing: design experiments that produce informative and interpretable results, and attend to one feature at a time. The third- and sixth-grade children were much less likely than adult participants to restrict the search of possible experiments to those that were informative.

When task demands are reduced – such as simple story problems or when one can select (rather than produce) an experimental test – even young children show competence with rudimentary science process skills. Children, like adults, are sensitive to the context and the content of what is being reasoned about. The goal of an experiment is to produce evidence that bears on a hypothesis, and that evidence must be interpreted.

## Interpreting and Using Data: Early Evidence Evaluation Skills

A key component of scientific reasoning is the ability to evaluate evidence and to interpret how that evidence relates to a hypothesis. One method of examining the developmental precursors to skilled evidence evaluation involves presenting children with evidence that is pictorial, in which there are representations of potential causes and effects. These are often simple representations like those between types of food and health (e.g., Kuhn, Amsel, & O'Loughlin, 1988) or plant treatment (e.g., sun, water) and plant health (Amsel & Brock, 1996). The pictures may depict situations in which there is perfect covariation between a potential cause and effect, partial covariation, or no covariation. The key process skill here is the ability to evaluate a pattern of evidence and induce or form a hypothesis about the causal status of a variable. The ability to make a distinction between a hypothesis and the evidence to support a hypothesis is an important part of skilled scientific reasoning (Kuhn, 2005, 2011). A number of studies provide evidence for when children begin to recognize this distinction.

Ruffman, Perner, Olson, and Doherty (1993) presented 4- to 7-year-old children with simple story problems involving one potential cause (e.g., type of food: red or green) and an outcome (tooth loss) to determine if children this young can distinguish between a hypothesis and evidence. In their first experiment, Ruffman et al. incorporated a "faked evidence task" to be able to determine if 4- and 5-year-old children could form different hypotheses based on varying patterns of evidence. For example, children would be shown a situation in which green food perfectly covaries with tooth loss: this situation represents the "real evidence." Next, the evidence was tampered with, such that anyone who was unaware of the original pattern would be led to believe that red food causes tooth loss (i.e., the "faked evidence"). Children were then asked to interpret which hypothesis the faked evidence supported. The key advantage of this type of task is that it is diagnostic with respect to whether a child can make a distinction between a hypothesis and a pattern of evidence to support a hypothesis. This task requires children to understand that their own hypothesis would be different from that of a story character who only saw the faked evidence. When considering the responses to *both* the initial hypothesis-evidence task and the faked-evidence task, only the 5-year-olds performed above chance level. Prior to this age, children do not seem to be able to evaluate how evidence relates to a hypothesis, and even then the skill is not yet fully developed.

In a second experiment, Ruffman et al. incorporated the use of partial covariation between cause and effect to determine if 5- to 7-year-olds could form hypotheses based on *patterns* of evidence. In this experiment, there were two cases in which the faked evidence would lead an absent story character to believe an incorrect hypothesis, and two cases where the faked evidence would lead to the correct hypothesis, despite the deception. When considering the responses across the set of hypothesis-evidence questions and faked-evidence questions, only the performance of the 6- and 7-year olds was above chance level performance, indicating that they were able to recognize patterns of evidence across the two different scenarios.

The science standards (NRC, 2012) make a distinction between *interpreting* patterns of data or evidence, and *using* that evidence (e.g., to support an argument or to construct an explanation). In a third experiment, Ruffman et al. (1993) examined whether 6- and 7-year-old children understood that a hypothesis formed on the basis of evidence could be used to make predictions about future events. The task involved two story characters wanting to know if a particular feature of a tennis racket (e.g., small vs. large) influenced how hard a tennis player could hit a ball. If a child can form generalizations about evidence, they should be able to answer questions about two future scenarios: (a) how hard or soft a next tennis serve should be, and (b) which size tennis racket would the story character want to buy. Again, children were presented with both veridical evidence and faked evidence to contrast their own hypotheses/beliefs with those of someone who only saw the faked evidence.

Most children were able to understand that different patterns of evidence (veridical vs. faked) would lead to different beliefs and different predictions. That is, evidence can be used not just to form a belief, but that the newly formed hypothesis can then be used to generalize to future cases. Across the set of experiments, Ruffman et al. showed that some of the very basic prerequisite process skills required for scientific thinking are present by as early as 6 years of age.

Koerber, Sodian, Thoermer, and Nett (2005) examined preschoolers' (4- to 6-year-olds) performance on a variety of evidence evaluation tasks. The goal was to build upon Ruffman et al.'s (1993) findings by using additional task formats, different patterns of covariation and non-covariation evidence, and to examine whether existing causal beliefs influence performance on evidence evaluation tasks in the preschool years.

Children aged 4–6 were presented with a potential cause and effect (e.g., chewing gum color and health of teeth). For the *revision of prior belief* task, children were told that a story character had an existing belief about which color of chewing gum caused bad teeth. They were than asked to interpret how the story character would respond to a pattern representing counterevidence for the character's belief. In the *faked evidence* task, the child and experimenter tricked an absent character by rearranging the evidence. Two different *partial evidence* tasks were used. Participants were first shown a complete set of partial (imperfect) covariation data, and asked to interpret what hypothesis it supports. Next, some of the pictures representing evidence were removed so that the remaining faked evidence indicated either (a) perfect but incorrect covariation between cause and effect, or (b) non-covariation between cause and effect.

Performance was at ceiling for all age groups on the revision of prior belief task. There was an age effect for the faked evidence task, with only the 6-year-olds performing at ceiling. For the partial evidence task involving perfect covariation evidence, all children were able to interpret that the faked evidence indicated causality in the opposite direction of what the real evidence showed. When the partial evidence task involved non-covariation evidence (i.e., faked evidence indicating no relationship between cause and effect), the performance of 4-year-olds was below chance and that of the 5- and 6-year-olds was not significantly different from chance level responding. In situations where there are no strong prior beliefs and the outcomes are equally plausible, preschoolers were able to correctly interpret perfect and partial covariation evidence, but they showed considerable difficultly dealing with non-covariation evidence. Piekny and Maehler (2013) found a similar pattern of results with respect to preschoolers' abilities to interpret perfect, partial, and non-covariation evidence. Even older children (aged 10–14) have difficulty with the concept of non-covariation (Kanari & Millar, 2004).

In a second experiment, Koerber et al. (2005) further explored preschoolers' (aged 5 and 6) difficulties with non-covariation and included stories where the content could invoke prior plausible beliefs (e.g., eating candy vs. apples and dental health) or neutral prior beliefs (e.g., red or blue fertilizer and plant health). A story character was described who did not believe that the potential cause and effect were related (e.g., plant heath is not affected by the color of fertilizer). After seeing the patterns of perfect or partial covariation, they were asked what the story character would now believe. In all cases, the patterns of evidence presented contradicted both the child participant's belief and the story character's belief.

When asked about neutral domains, children were able to correctly interpret the patterns of evidence as being contrary to the story character's belief (e.g., when the story character believed that color of fertilizer was non-causal, and the evidence showed that it was in fact causal, they were able to correctly interpret it). When the context was one in which there was prior belief (e.g., eating candy and having bad teeth) that was contradicted by a pattern of evidence, only 60 % of the children could correctly interpret the evidence when there was perfect covariation, with the number dropping to 17 % when the evidence was presented as partial covariation (Koerber et al., 2005). Preschoolers showed the same difficulty in evaluating evidence that contradicts prior belief, which is consistent with the performance of both older children and adults (Zimmerman & Croker, 2013).

Together, these research findings support the idea that young children demonstrate many early science process skills or precursors to those skills. There are, however, large developmental effects, and much room for improvement. As Bullock and Ziegler (1999) noted, "our first goal was to provide a description of developmental changes that would move us beyond a simple description of preadolescents' inadequacies" (p. 52). Now that we have sufficient evidence of young children's ability to engage in basic scientific activities and that they can benefit from science education, the next question to address is what should early science education look like?

## Learning to Do Science

In this chapter we have discussed a range of studies describing the development of science process skills, including question asking, experimentation, and evidence evaluation specifically. Although there are clear developmental trends for each of these skills, less is known about *how* the skills develop, and about the most effective methods of teaching them. Still, inclusion of science in early education is a growing priority at the state, federal, and even international levels.[1] As a result, both researchers and curriculum developers have begun to create materials for early science education. Though it has been suggested that preschool teachers tend not to support science learning because they feel unprepared or uncomfortable teaching science (Brenneman et al., 2009), both researchers and practitioners now acknowledge young children's ability to learn science. Preschool science curricula are slowly

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[1] For example, "Ready, Set, Science!", "National Science Education Standards" and other National Academies Press/federal government pubs, Next Generation Science Standards, AAAS/NRC/NSTA, Early Years Science SIG, European Science Education Research Association.

growing in number and finding a place in early education, for example, ScienceStart! (French, Conezio, & Boynton, 2002), the Young Scientist Series (Chalufour & Worth, 2003), Preschool Pathways to Science (Gelman & Brenneman, 2004), Mudpies to Magnets (Williams, Rockwell, & Sherwood, 1987); and elementary education science programs such as the Full Option Science System (Delta Education), Science Companion, among others. Curricula include activities and instruction intended to develop science process skills in young children, with a common emphasis of integrating other learning domains within science, such as general higher order thinking, literacy, and math learning (French & Woodring, 2013), as well as "using", "promoting" and "making the most" of children's curiosity. Many recent science programs have been developed in conjunction with basic researchers, and were designed with science process skills in mind. In this section, we discuss four examples of such programs, two preschool and two elementary school: the *ScienceStart!* and *Preschool Pathways to Science* (PrePS) preschool programs, and the Full Option Science System (FOSS) and Science Companion programs for elementary school. We also note when research evidence has been collected or is ongoing with respect to addressing the question of whether these interventions are effective.

For science at the preschool level (3–5 year olds), *ScienceStart!* (French et al., 2002; AKA LiteraSci, www.literasci.com) is designed to be developmentally appropriate and aligned with existing science standards, and focuses on teaching scientific processes. The curriculum includes both a general content goal of developing "a rich, interconnected knowledge base about the world around them," (French, Conezio & Boynton, 2002, p. 303) and science process goals, including problem identification, analysis, and solution, as well as more domain-general skills of self regulation, problem-solving skills and language skills. The science reasoning skills emphasized explicitly are: "reflect and ask", similar to what we describe earlier as recognizing and dealing with uncertainty; "plan and predict" and "act and observe," which we discuss as experimentation; and "report and reflect," including what we discussed as evidence evaluation. *ScienceStart!* emphasizes the ease by which other domains of learning, including language and literacy, mathematics, and social studies, can be integrated into science instruction. The program places a strong importance on using content that is relatable to children's everyday lives, cohesion, and integration across all domains of preschool learning. The effectiveness of the language development portion of the program has been empirically supported by studies of children's discourse (such as asking questions), use of explanations, and scores on the Peabody Picture Vocabulary test (French, 2004; NRC, 2005; Peterson, 2009; Peterson, & French, 2008). Student outcome measures on other aspects of scientific thinking and learning, however, have not yet been assessed.

Another approach to preschool curriculum development is that of the *Preschool Pathways to Science* (PrePS; Gelman & Brenneman, 2004), which utilized basic research on children's capability of relatively complex scientific thinking. PrePS provides teachers with knowledge of student learning and justifies the curriculum with research on this topic. For example, several studies demonstrated that if children are provided with a mental structure with which to guide their learning, they are able to build on this when experiencing new information (Gelman & Brenneman; NRC, 2005). Focusing on providing an initial mental structure of science and helping students build on this understanding, the PrePS program emphasizes specific science concepts, language, and processes. One way that teachers help to provide this structure, as well as prompting curiosity by creating uncertainty, is by asking children questions, and using questions to lead them through the other science processes. Much focus is put on teaching the vocabulary and processes of observing, predicting, and observing to check predictions, with the belief that having the vocabulary will greatly enhance children's learning of concepts. Although this program was designed upon a strong research foundation, there is not yet empirical support for its effectiveness.

Similar to the preschool curricula, the Full Option Science System (FOSS) and Science Companion are research-based science programs designed to be developmentally appropriate and focus on teaching science process skills. These programs aim to engage students in science content while integrating other academic subjects (Science Companion was designed specifically to align with a math curriculum of demonstrated effectiveness; Carroll & Isaacs, 2003; sciencecompanion.com). There are FOSS units available for kindergarten through middle-school levels and Science Companion units from kindergarten through 6th grade, with a wide range of science topics spanning the areas of life, earth, and physical science. Example FOSS units include "trees" in kindergarten, "solids and liquids" in grades 1–2, "solar energy" in grades 5–6, and "diversity of life" in middle school. Teachers are provided with the science background to understand the content, and are guided through teaching the different units with detailed information on common misconceptions, teaching methods and planning guides, and methods of assessing the targeted content and processes covered in the instruction. There is some support for the effectiveness of FOSS in classrooms, with studies finding that students in fifth grade classrooms using FOSS learned more science than children in control classrooms (Leach, 1992), as well as improving in problem solving in sixth grade students (Medress, 1993). Third and fifth grade classrooms using FOSS outperformed comparison classrooms on standardized tests of science, as well as math and reading (Dade County & Florida, 1996). Additionally, FOSS has been associated with an increase in science class and high school enrollment, and with standardized test scores in later grades (Plank et al., 2000). There is not yet published results on the effectiveness of Science Companion.

Though these science programs – and many others – were created with the goal of using and encourage children's curiosity and developing children's science process skills and content knowledge, little is known about whether or not science programs are achieving these goals. The program descriptions advise practitioners to utilize children's natural curiosity, and to model and use questions to foster curiosity and question asking, but there are no published reports of assessments of process skills beyond limited results from *ScienceStart!*. Standardized science assessments are beginning to be used in several states, however these are not typically administered until 3rd grade, if at all. Not only is science not assessed systematically in early education, but it is not clear how and what to assess in early science education (see Chap. 16 of this volume for a discussion on early science assessment). As a result, most studies of the effectiveness of early science education use measures of general intelligence, vocabulary, or teacher ratings of students, or look at the instruction and/or classroom materials rather than student performance. One notable exception to this claim is the *Science Learning Assessment* (SLA) that was developed for kindergarten students (Samarapungavan, Mantzicopoulos, Patrick, & French, 2009; Samarapungavan, Patrick, & Mantzicopoulos, 2011). The SLA includes items to assess both early process skills (e.g., asking questions, observing, predicting) and understanding of basic life and physical science concepts. Samarapungaven and colleagues used the SLA to investigate the effectiveness of science inquiry interventions, and found that the SLA effectively measured "instructional sensitivity." Moreover, children who received inquiry intervention had higher SLA scores than children at comparison schools.

Despite the limited empirical evidence on science education outcomes, we believe that children benefit from early science education, and that these curricula are providing developmentally appropriate learning opportunities to engage children's curiosity while promoting the development of early science skills like question asking, experimentation, and evidence evaluation.

## Discussion and Conclusions

The goal of our chapter was to focus on the development of domain-general science process skills in young children. We used the first dimension of the newly published science education standards (NRC, 2012), *Scientific and Engineering Practices*, as a guide when choosing three specific process skills to discuss: asking questions, conducting investigations, and interpreting and using evidence. Because we believe science revolves around identifying and resolving uncertainty, we look at children's curiosity as their desire to resolve uncertainty, question asking as a way of dealing with uncertainty, with exploration and identification as ways of resolving uncertainty. We address three questions related to the development of science process skills:

**What Types of Science Process Skills are Young Children Capable of?** Because of our assumptions about children's "natural" curiosity, we know that they are capable of recognizing uncertainty and are most motivated to engage in the process skills to resolve that uncertainty when there is an optimum amount. We know from observational and laboratory studies that children are capable of asking questions to learn about science topics and to gain specific information to resolve uncertainty. Even preschoolers are able to understand a simple experimental test of a hypothesis, to recognize controlled experiments, to interpret patterns of evidence, and to use that evidence to make decisions, generalizations, or predictions about future instances.

**What Do We Know About How Early Science Process Skills Develop?** Although most science process skills show a linear age trend, some skills require more scaffolding and specific instructional support than others. Even very young children are capable of asking questions, but develop the ability to use questions more effectively over time, with significant improvement between 6 and 7 years of age. When examining the evidence on children's experimentation and evidence evaluation, we see very young children conducting "experiments" through play to determine causal relationships, and children as young as six successfully identifying valid experimental designs. Children as young as five can recognize patterns in evidence, interpret the usefulness of evidence, and understand how evidence relates to a hypothesis. Though young children show competence in science processing skills on these extremely simple tasks, even older elementary-age children (and adults!) can have difficulty when task demands are increased. These results suggest that young children do not simply *learn* science process skills. Rather, children build up sets of skills over time that allow them to address uncertainty through questions, to find ways of gathering information in response to those questions, and to observe and reason about evidence in an attempt to resolve the uncertainty. Data on children's curiosity, in contrast, suggests that the desire to resolve uncertainty is present in young children, and remains at least through the early elementary years.

**In What Ways Can Basic Psychological Research on Scientific Thinking Inform the Science Education of Young Children?** We reviewed a sample of early childhood and early elementary school science curricula that are evidence-based and informed by psychological findings and theory. The first step of designing curricula has been accomplished. Although these programs use research to inform what and how they teach science, the published research on their effectiveness in developing young children's science process skills is still forthcoming. Much more research is needed to learn *how* different skills develop. As Klahr and Li (2005) suggest, research can inform educational practice, while at the same time being driven by the needs of issues of classroom practice. As the effectiveness of these different curricula becomes established, empirical questions about how to address specific challenges to science education will motivate further basic research. Likewise, new findings from research on the science of learning and how science process skills develop can be applied to improving current efforts to promote early science education.

The developmental trajectory of learning to do science is long. Though some mechanisms of science learning – like curiosity, asking questions, and exploration – seem to develop spontaneously in children, all science process skills require the support, scaffolding, and instruction from teachers and culture tools to mature into the sophisticated process skills seen in scientifically literate adults and trained scientists. Question asking can one day develop into creating theories and stating hypotheses; exploring to gather information can turn into identifying variables and designing controlled studies; observing and evaluating evidence can turn into using precise measurements and statistical models. Some prior theories and research about children's cognitive and metacognitive abilities suggested that practitioners wait until middle school to expose children to interesting and challenging science education, but this delay has been shown to be unnecessary. By decreasing task demands of different science activities, young children have the capability to address, explore, and resolve uncertainty in scientific ways, and the curiosity to do it. Researchers and educators now acknowledge that young children are far more capable than once thought – demonstrating signs of science abilities from increasingly young ages – and consequently educational reform efforts have focused on formal and informal learning of science for young children. As early science education efforts continue to grow, so will research and our knowledge of the development of young children's science process skills.

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# Chapter 8
# The Use of Technology in Teaching Science to Young Children

**Sedat Uçar**

## Introduction

Many studies have shown that children can develop a scientific understanding of natural phenomenon and exhibit science-based processing skills during their early years (Carey & Spelke, 1994; Kuhn & Pearsall, 2000; Opfer & Siegler, 2004; Saçkes, Trundle, Bell, & O'Connell, 2011a). In addition, young children are fond of observing natural events, and this quality could be promoted through early childhood curricula (French, 2004; Kallery & Psillos, 2001; Patrick, Mantzicopoulos, & Samarapungavan, 2009).

Roschelle, Pea, Hoadley, Gordin, and Means (2000) concluded that effective learning occurs under the following conditions: "(1) active engagement, (2) participation in groups, (3) frequent interaction and feedback, and (4) connections to real world contexts" (p. 79). The first and the third conditions are especially important for early childhood education because developing one's curiosity about the natural world is very important for facilitating scientific learning in later years through active engagement and frequent interaction. These four criteria could be limited met within traditional school systems or classrooms, especially in schools located in city centers, which have limited access to the natural world. However, the support of appropriate technology, especially visual (screen-based) technology, could facilitate accomplishment of this goal.

The use of technology in science teaching will be discussed from several perspectives. The integration of technology and scientific inquiry was presented at first to provide what the literature tells us about technology use in scientific inquiry. After that interconnectedness of science, technology, and mathematics teaching was provided because during early childhood teaching these three subjects are deeply

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integrated. Effects of technology use in early years are presented after that. What the literature tells us about different practical application of technology was presented briefly. The most important component of teaching which are teachers and their perception of technology use in science teaching are presented before the conclusion of the chapter.

## Integrating Technology and Scientific Inquiry

The National Science Education Standards (National Research Council [NRC], 1996) proposed scientific inquiry as a way to teach and learn science at all grade levels (NRC, 1996). Through such analytical inquiry, students gain first-hand experience with the event being studied, including collecting data and analyzing the data in an authentic way (Edelson, 2001). Songer, Lee, and Kam (2002) stated that scientific inquiry helps students deepen their content understanding, develop problem-solving abilities, and gain ownership of knowledge. Etkina, Matilsky, and Lawrence (2003) argued that students can learn content and processes better by adopting the way that scientists investigate problems. The only difference between scientists and students is that scientists inquire independently, whereas students require support and guidance from teachers (Lee & Songer, 2003). A scientist does not have to follow a program to reach the goals of a certain curriculum, but students have to follow the teachers' guidance in parallel to the curriculum. Unfortunately, conducting authentic activities is not always possible in science classrooms because of the limitations inherent in the classroom environment (Lee & Songer, 2003). Therefore, the potential role of technology in implementing science standards should not be ignored in science classrooms (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000). Technology provides an opportunity to conduct authentic learning, thereby enabling students to practice scientific methodologies (Lee & Songer, 2003).

At all grade levels, problem-solving is an effective science teaching method (Hurd, 1989). In particular, when a problem originates from the child's daily life, it increases curiosity and motivates the child to solve the problem. Carefully designed software could create developmentally appropriate problem situations. For instance, the software "Starry Night" helps children track moon phases and view the changing patterns easily, and it can be integrated with actual observations. Children sometimes observe the moon with the naked eye when it is visible, and at other times, children track the phases of the moon on computer screens, for example, when the weather is cloudy or in the city center, where observing the moon is sometimes limited. Inquiry-based education is accepted as an effective way to teach and learn science, and such inquiry can be further promoted by replicating real-world problems through technology (Edelson, Gordin, & Pea, 1999).

Development of scientific process skills in science classes could be promoted through integration of technology. Henderson, Klemes, and Eshet (2000a) reported that children' science process skills such as classification and inference improved significantly within simulation based learning environment. Similarly, Revelle, Druin, Platner et al., (2002) found that children developed scientific process skills such as sorting through the working on searching strategies with a computer search engine. Trundle and Hobson (2011) showed that several science process skills are developed within one activity. Trundle and Hobson (2011) investigated second and third-grade students understanding of moon phases, and they found that inquiry-based science instruction which facilitated technology leads students to develop science process skills such as observing, recording, sharing, predicting, and concluding.

Teachers usually choose problems that are somewhat static compared to their real-world counterparts, and computers can increase the representational richness of these problems (Hoffman & Ritchie, 1997). In addition, technology provides an opportunity to present the problems in daily, natural contexts. Another advantage of using computers for inquiry-based learning is that complex tasks can be separated into smaller parts to promote problem-solving (Plowman & Stephen, 2005). However, teachers should be mindful of the redundancy of information for the learners which means that the same materials should not be offered for the children in the similar format repeatedly. Children can repeat experiments or change variables easily with computers (Hoffman & Ritchie, 1997). Some examples include changing the angle of a ramp or ball when attempting to throw the ball over a wall.

Another advantage of computers is their ability to help identify children's learning patterns. Some software can track learning styles and provide children and teachers with specialized hints and guidance (Hoffman & Ritchie, 1997). This feature could be used by teachers to monitor children's development at school, and at home, if the computer is logged in within a network. Some software requires the user to login with a password so that progress can be noted by the teachers.

The role of technology in school is an important aspect of teaching science because, to incorporate technology within science instruction, both students and teachers must become familiar with the relevant technology, and the school culture should be receptive to its use. Many countries do not have adequate standards for teaching technology during early childhood. In most countries, technology is not taught as a discrete subject; instead, it is studied in crafts, social science and handicrafts, or science curricula (Rasinen et al., 2009). One of the aims of craft education is to improve motor skills (rather than developing an understanding of technology). Therefore, even though some materials aim to teach the use of technology, students do not acquire a good understanding of the subject. In this situation, it is mainly the responsibility of the science curriculum to help foster an understanding of technology along with science. Limited technology instruction affects the use of technology in school coursework, especially science instruction, and can affect students' career preferences in adulthood. Students' attitudes towards science and technology-related jobs are more negative than for other fields in later years. For example, the number of girls studying science and technology-related fields is less than the number of boys studying the same subjects in later years, and this trend starts in early childhood (Rasinen et al., 2009). Several reasons have been suggested for this phenomenon. For instance, a curriculum might not contain any material that is directly related to technology education. In addition, early childhood teachers are mostly female, and females tend not to teach technology or teach with the aid of technology (Rasinen et al., 2009).

## Teaching Science, Technology, and Mathematics

Research in science education has shown that students learn science best when they act as scientists during instruction. That is, students perform scientific endeavors by observing events and attempting to solve a problem based on their observations. Students then collect and classify data, make further observations, hypothesize, test, and reach conclusions. Obviously, children in K-12 cannot act as scientists by themselves due to their limited knowledge and experience. However, with appropriate parental or teacher guidance, they can perform science process skills. Roschelle et al. (2000) indicated that children learn science in a similar way to that adopted by scientists when they are engaged in "actively constructing knowledge from a combination of experience, interpretation and structured interactions with peers and teachers" (p. 79). The use of technological tools would enable young children to reach this goal. In particular, multimedia technologies bring to the classroom many opportunities to experience or observe natural events. In addition, interactions with multimedia tools enable students to manipulate data, change content, and create new ways to visualize the data.

Efforts to understand the natural world begin in infancy. When babies attempt to bite an object or look at it very carefully, they are attempting to understand the world around them. As young children develop physically and mentally, they begin to crawl and then walk to reach objects to observe them more closely. They use their five senses more systematically, and basic science processing skills start to take shape. Counting, classifying, measuring and matching are scientific processing skills that develop very early in a child's life. Through their engagement with nature and basic observation, children acquire concepts about their environment. Charlesworth and Lind (2010) defined three types of learning experiences for young children: *naturalistic*, *informal*, and *structured*. The main difference among these three types of experience relates to who controls the activity, the child or an adult. When the activity is controlled by children during their daily activities, the activity is classified as naturalistic. Young children need to be provided with rich environments to facilitate natural discovery. Informal types of experience are experiences in which adults provide minimal guidance when the child is not progressing naturalistically. Structural experiences are activities planned by adults. Effective learning occurs under all three of these types of learning experience. These experiences can be enriched by technological devices and by integrating other subjects.

Science learning in early childhood cannot be fully distinguished from mathematics learning (Saçkes, 2013). Charlesworth and Lind (2010) noted the commonalities between science and mathematics. Their argument was that science and mathematics learning go together because mathematical concepts are necessary for understanding scientific ones (Epstein, 2007). For instance, when a child makes an observation, counting observed things might be necessary. Therefore, teaching science with technology should be considered together with teaching mathematics. In software developed for teaching mathematics during early childhood education, we often see the counting of natural objects, such as counting the number of birds in a tree, stars, trees, etc. Furthermore, changing the angle of a cannonball to hit a target and changing the height of a ramp to make a car go faster are examples of games that include both mathematics and science. Prairie (2005) pointed that children could be taught math and science through use of technology in preschool and kindergarten. The integration of science, mathematics, and technology is also presented in the National Association for the Education of Young Children [NAEYC] accreditation criteria for science and technology. Criterion 2 F for mathematics, criterion 2G for science, and criterion 2H for technology demonstrate this association between mathematics, science, and technology learning (National Association for the Education of Young Children [NAEYC] [NAEYC], 2012, p. 19). Early childhood technological literacy develops along with scientific and mathematical literacy and knowledge. Children apply their science and mathematics background to master the development of technological skills (Mawson, 2011).

## Technology in Early Childhood Education

Almost none of the technological devices currently used in schools were originally developed for educational purposes. For instance, computers were developed for military purposes, and TVs and VCRs were developed for entertainment purposes. Educators integrated those technologies into the school curriculum. In doing so, classroom learning was integrated with social life. When the telephone was first invented, it took some time before it became widely available. With the development of science and technology, new generation multifunctional cell phones entered every household and ultimately became part of our daily routine. It changed our customs, society, and the way in which humans interact with each other and organize their lives. Similar developmental paths were seen for radio, television, and in the last three decades, computers. There is no way to separate people from technology because it has changed our society. Even when we do not use the technological devices that surround us, we are still affected by their effect on the society in which we live. Many kinds of technology surround us at home, school, and work, and young children are growing up in a society that has already been shaped by technology (Buckleitner, 2009; Kerawalla & Crook, 2002). Clement and Swaminathan (1995) stated that “Technology can change the way children think, what they learn, and how they interact with peers and adults” (p. 1). Technology is defined in a position statement as “the definition of technology tools encompasses a broad range of digital devices such as computers, tablets, interactive whiteboards, mobile devices, cameras, DVD and music players, audio recorders, electronic toys, games, e-book readers, and older analog devices still being used such as tape recorders, VCRs, VHS tapes, record and cassette players, light tables, projectors, and microscopes”

(NAEYC, 2013, p. 2). Based on this definition, almost everything in our lives in the twenty-first century is a technological device. Therefore, we cannot resist teaching with technological aids or using technology in schools. Research has shown that teachers are integrating technology in their instruction (Lynch & Warner, 2004) to various degrees.

There is a large body of research on both sides, which are against the use of technology and advocate to use of technology in class. Advocates have argued that the use of technology can sometimes increase attention span (Clements & Sarama, 2003), encourage cooperative learning (Clements & Nastasi, 1992; Heft & Swaminathan, 2002), and boost children's self-esteem (Hohmann, 1990). The main objection of the group that argues against the use of technology, especially screen-based technology such as TVs, computers, and game pads, is the relationship between technology use and the development of physical problems (Birch, Parker, & Burns, 2011), attention problems, low academic performance, and socialization and language development problems. Wainwright and Linebarger (2006) argued that although there are many critics of the use of technology during early childhood, the most important factor is the educational content of computers or TV programs. A reasonable level of the integration of technology into learning would not harm children in the ways stated above. The amount of time that children spend watching TV or playing with computers is important (Vandewater, Rideout, Wartella et al.,, 2007) and should be monitored carefully. Both the time spent in front of the screen and the appropriate use of technology in integrating technology into learning are important (NAEYC, 2013). Although technology can be used to support new learning, it should not replace outdoor activities, natural observation, and social interaction. The main role of technology, when used appropriately, at school has been stated in a position statement (NAEYC, 2013, p. 11) as follows: "It is the role and responsibility of the educator to make informed, intentional, and appropriate choices regarding how and when technology and media are used in early childhood classrooms for children from birth through age 8". Because teachers are responsible for providing appropriate practice with technology, they should have a good understanding of different technological applications and the appropriate integration of technology within the curriculum. Pre-service teacher training programs should equip teachers with appropriate skills to use technology for teaching purposes.

Several studies have reported that students improved their performance in science through purposeful computer use (Lei & Zhao, 2007; Kim, 2006; Weaver, 2000). Chang and Kim (2009) investigated the effects of computer access, purposeful use of computers, and frequent use of computers on 3rd and 5th graders on achievement in science. The Early Childhood Longitudinal Study database was used as a data source. Previously, these authors found that access to home computers and their purposeful use had positive effects on achievement in science. Computers might affect creativity negatively during early childhood education when it is not integrated appropriately into the curriculum (Haugland, 1992).

Studies of computer use have yielded mixed results. Roschelle et al. (2000) explained the reasons for these variations. The first reason is that different schools use different hardware or software, affecting the outcomes of the research conducted in these settings. The second reason is that the effectiveness of an educational system is dependent on factors other than the use of technology, for example, curriculum materials, teachers' qualifications, or assessment systems. Therefore, the effects of other components influence the effectiveness of technology. The third reason is that the studies conducted were mostly short-term studies, few of which considered the long-term effects of technology use in the classroom. Therefore, research reports supporting both sides of the debate appear in the literature.

## Children's Use of Technology

Young children have many experiences with technology before they enter the school system. As a result of these experiences, children are very familiar with and have confidence in using technology at a very young age. These early experiences with technology help children develop skills in mathematics and other school subjects (Chantel, 2003). Several types of technological applications for educational purposes are used in early childhood classrooms. Some of these practices will be presented briefly below. Due to the wide variety of technological devices available, not all of them will be presented here.

### *Searching*

The most frequently used technology at schools is the computer. Computers are used for different purposes, but their primary advantage is their ability to access information through searching. Young children's use of computer searching is greatly limited by their typing and reading skills. Therefore, audio or visual search aids are necessary in software developed for children. Children's searching strategies have been investigated by Revelle et al. (2002). Specifically, the research explored children's strategies within paper-based and computer environments. Paper-based and computer prototypes were prepared for animal categories, such as animals, where they live, how they move, and what they eat. Subcategories and secondary subcategories were also provided, e.g., under the animal heading, there followed subcategories such as birds, fish, insects, etc. The results showed that children can perform computer searches more effectively and accurately than paper searches. 8- and 9-year-old third grade children participated in this study, and the children were able to read and write. Minimal text was used in the software, indicating that young children can perform searches and organize hierarchical materials if text is replaced with media, such as sound. In addition, if the content is adjusted, younger children were also able to use this method. Revelle et al. found that young children are able to search very efficiently using the software "SearchKids." The main difference in this software is that it provides extensive educational scaffolding.

The use of educational scaffolding in software has proven more effective than educational software that does not use scaffolding (Shute & Miksad, 1997).

The effect of the level of “computer-provided scaffolding” (Shute & Miksad, 1997, p.237) was investigated with 57 preschoolers. Three groups exposed to different interventions, namely, substantial computer-provided scaffolding, minimal computer-provided scaffolding, and no computer-provided scaffolding (teacher-provided scaffolding), were exposed to an 8-week intervention. Scaffolding is defined as “…instructional assistance that enables someone to solve a problem, carry out a task, or achieve a goal that the person could not accomplish alone” (Paris, Wixton, & Palincsar, 1986, p. 109). Shute and Miksad found that computer-assisted instruction increased preschoolers’ language skills; however, cognitive skills were not improved by computer-assisted instruction more than by traditional scaffolding, and these authors do not believe that computers are “magical toys” (p. 245), as many teachers and parents believe. Shute and Miksad argued that previous studies regarding computer use could not detect the negative effects of computer use due to their small sample size, their use of inappropriate treatments, and their lack of control groups. Although cognitive skills were not increased in this study, language skills improved significantly (language skills are as important as cognitive skills in children’s early years).

Kumpulainen, Vasama, and Kangassalo (2003) attempted to understand children’s explanations in a technology-enriched science classroom. These authors used PICCO software, which supported children’s conceptual learning via self-initiated exploration. Children do not need any reading ability to use this program, and children were free to use PICCO multimedia according to their own interests. The results obtained showed that science activities that were enriched by technological resources improved children’s social interactions and their explanations of the scientific concepts presented.

## *Photobook*

Another creative way of integrating technology with the science curriculum is Internet photo-book technology, which enables children to share photos that are taken by the children or an adult and to talk about the pictures. Children enjoy taking pictures of things around them, making a photobook with those pictures, and discussing the books they have created (Katz, 2011). Keat, Strickland, and Marinak (2009) found that young children express themselves better with the photos they take on their own. Keat et al. gave cameras to immigrant children and asked them to narrate about their home and culture. Children felt more comfortable expressing their home life using photobooks. Similarly, Hoisington used photographs in science classroom inquiry, and it was reported that the children were able to analyze the data, reflect on the topic, and extend the investigation more effectively in this way. Katz used Internet photobook technology to investigate the development of a “child’s identity as a young scientist” (p. 527). Children first constructed a photobook that included their own pictures of exposure to the natural world and then talked about the photobook they had created. Very rich discussions emerged, and the children were motivated to involve themselves further in science. Currently, digital cameras are easy to access, simple to operate and are more affordable than previous (Katz, 2011).

## *Simulation*

Simulation was defined by Smetana and Bell (2012) as “dynamic models of the real world and its processes,…, Examples include animations, visualizations, and interactive laboratories” (p. 1338). Simulations are promising interactive technological tools that contain user-controlled features (Rieber, Tzeng, & Tribble, 2004). Many studies reported that simulations help increase student motivation in learning (Ke, 2008; Papastergiou, 2009). Some simulations create an environment that students cannot experience in their daily life (Akpan, 2002; Ucar & Trundle, 2011). For instance, tides cannot be experienced in most of the world, and the life span of a butterfly cannot be observed by children within the school context. Simulations and games that include a scientific background increase children’s curiosity.

An extensive review of literature about effectiveness of computer simulation in science teaching was conducted by Smetana and Bell (2012). Their critical review of the literature suggested computer simulations promote science learning and provide an environment for inquiry-based science activities. However, they suggest that computer should be used as supplements to other instructions. In addition, appropriate guidance and scaffolding should be provided (Henderson, Eshet, & Klemes, 2000b) for better integration of simulation. Some other advantages of simulations are supporting students-centered and inquiry-based environments (Flick & Bell, 2000, National Research Council, 1996), offering active engagement in promote-solving (Lee, 1999), reducing the cognitive load (De jong & Van Joolingen, 1998) during the instruction.

## *Robots*

Robots represent another type of technology that has both educational and entertaining properties for young learners. Children often play with Legos, which foster psychomotor and cognitive development. Robotics that integrates Legos and simple electronic equipment are creative tools that are also aimed at children. These devices have both entertainment and educational value for children. McDonald and Howell (2012) investigated the relationship between the use of robotics and the development of science, technology, and mathematics understanding in 5-year-old children. Using Legos, the children constructed and then programmed a robot. The results showed that students' motivation, literacy, numeracy, and interpersonal skills developed as a result of this activity.

Similar to robotics, design is another component of science learning that can encompass technology. Fleer (2000) investigated design questions that were asked by children during technology education at school; the children sampled were 5–6 years old and 10–11 years old. Design question refers to a question "that children ask as they work technologically in schools" (Fleer, 2000, p. 341) and these questions arose during technological activities. The study found that children tend to design questions based on what interests them. Fleer also found that questions and briefs arose at many points throughout the process. This represents an interesting finding because design requires knowledge about materials, the application of observations of the natural world, and some fundamental understanding of physics, particularly Newtonian mechanics. In other words, designing requires scientific knowledge and science process skills.

There is some concern that young students can become lost in the game aspects of educational technology rather than focusing on the educational aspects of the task (Henderson et al., 2000a). Since the playing is a natural activity for this age group, it is developmentally appropriate for children to be distracted by the game aspects of technology. Teachers' specialized capacity for choosing appropriate technological tools and software would help overcome this issue (Shaffer, Squire, Halverson, & Gee, 2005).

## *Microworld*

Microworld is an effective instructional tool developed by Rieber (1996), who described a microworld as "a small, but complete, version of some domain of interest" (p. 46). According to Rieber, microworlds are simplified versions of actual worlds, and learners live or imagine living in them. Rieber provided a helpful example for explaining how microworlds work. For instance, consider that the best way to learn a language is to go to a country where everybody speaks the relevant language. Another example is a sandbox that can be used to study volume and density, in which children use different buckets. Rieber described a microworld as being a very simple model of a complicated domain that can be shaped by the learner. In addition, a microworld should be tailored to the child's age and cognitive level so that it can be used with little or no training. For example, there is no need to train children how to play in a sandbox.

Microworld environments can be created with computer software and used for educational purposes. Henderson et al. (2000a) investigated a learning environment in which concepts are embedded in a computer-based microworld simulation. Seven-year-old second grade students studied fossils for 6 weeks within a computer-based microworld that allowed students to gather, interpret, and communicate data to understand the history based on the data obtained from fossil records in the microworld. The results revealed a significant improvement in the students' use of language, thinking skills, classifications, and inference skills.

### *Tablet PC*

Tablet computers have become very popular in recent years and have found their way into the classroom when equipped with specific software. In countries such as Turkey, tablet computers are loaned to children in middle school and high school. Children can confidently use these mobile devices by themselves without adult guidance (Couse & Chen, 2010; Michael Cohen Group & USDOE [US Department of Education], 2011). The Michael Cohen Group [MCG] (2011) investigated children's and their caregivers' perceptions and use of iPads and Apps with 60 children who were 2–8 years old. Specifically, MCG attempted to understand the iPad's potential for use as an educational tool during early childhood. The study included in-depth interviews and observations of young children, together with a survey for their caregivers. The findings showed that children as early as 2 years old can "assess, play and learn" with an iPad. Although the research reported improvement in many aspects due to engaging with the iPad, it was noted that "the device alone does not guarantee engagement and learning" (p. 5). This suggests that the creative integration of iPads into the school's curriculum is critical. Another important finding was that the progression from novice to expert occurs very quickly. Considering the very short attention span that children devote to specific tasks, the iPad could be a promising device with regard to overcoming this issue.

## Teachers and Technology

Using computers are getting easier and easier for the children who could follow the direction on the screen and type on the keyboard easily (Clements & Nastasi, 1993). Many children have strong technological skills and knowledge when they begin primary school, and these competencies are not recognized by many early childhood teachers and curriculum developers (Mawson, 2011). The lack of training in technology and attitudes toward technology use in class could be one of several reasons for this.

According to a previous study (Public Broadcasting Service & Grunwald Associates, 2011), preschool teachers do not use technology and digital resources frequently compared to teachers in upper grade levels. Additionally, preschool teachers' use of technology is limited to digital cameras and downloading images from cameras to computers. As a result, although technology is easily accessible, inexpensive, and user-friendly, it is not widely used in schools (Web-based Education

Web-based Education Commission, 2000). One of the reasons is that teachers are not sufficiently prepared to use technology in their classrooms effectively (Becker, 1999).

Early childhood teachers' attitudes, skills, and practice with computers were assessed, and the factors affecting these parameters were examined (Chen & Chang, 2006). The study found that confidence in using computers was not related to having a higher degree. Having computers at home and having had training were, however, related to increased confidence in using technology. Therefore, greater exposure to technology is important. Teacher training programs should offer more technology courses and provide additional opportunities to use technology. Similarly, this study found that teachers who own a computer at home and had computer training were more skilled in that area. However, two-thirds of teachers do not know how to select appropriate software for children. Teachers need more than just technology skills to integrate technology into their science instruction; they also need to use appropriate software. Similarly, teachers who own computers and have more training can create computer-generated material more easily.

Research has shown that teachers' attitudes toward the use of computers determine their intention to use computers in instruction (Levine & Donitsa-Schmidt, 1998). Yilmaz and Alici (2011) investigated pre-service early childhood teachers' attitudes toward using computers in science activities and found that they generally have positive attitudes toward computer use in science activities. In addition, there was no significant gender difference in attitude scores of pre-service teachers toward the use of technology for science instruction.

Other factors affecting attitude are computer experience and ease of learning in how to use technology. Greater experience with computers is related to more positive attitudes toward their use (Kutluca, 2011). Early childhood pre-service teachers' acceptance and use of whiteboards was investigated by Wong, Russo, and McDowall (2013) who found that pre-service teachers tended to use interactive whiteboards more frequently when they believed that using them would help them improve their job performance and that the use of this technology would not incur much effort. Vincent (2007) reported that when whiteboards were integrated appropriately with the pedagogy, they added considerable value in enhancing early childhood learning and teaching. However, as pointed by Clements (1991) that teachers should not be too close to the children during computer-assisted instruction instead teachers should be nearby to provide support as needed.

Some studies also showed that pre-service teachers could use technology while learning new science topics. Bell and Trundle (2008) investigated conceptual understandings of early childhood pre-service teachers regarding moon phases. An inquiry-based instruction combining "Starry Night Backyard" software with instruction in moon phases from Physics by Inquiry, by McDermott (1996), was used as an intervention. The results showed that pre-service early childhood teachers improved their conceptual understanding of lunar phases within well-designed computer simulations. The finding of Bell and Trundle (2008) study was also confirmed by Hobson, Trundle, and Saçkes (2010). Hobson et al. (2010) found that Stary Night software facilitated young children learning of moon phases. Ucar, Trundle, and Krissek (2011) investigated pre-service early childhood teachers' understanding of tides and showed that these teachers improved their conceptual understandings within technology-enhanced inquiry-based instruction, indicating that pre-service teachers may understand science better when it is taught using technology.

Although the pre-service teachers were able to use technology effectively in their daily lives or while being instructed in science content, their limited knowledge of science and mathematics presented difficulties in developing creative curricula that integrate science and technology (Bers & Portsmore, 2005). New standards for early childhood curricula require teachers to integrate mathematics, science, and technology; however, because of low competency in these domains, these teachers do not implement the requirements suggested in the reform documents (National Education Goals National Education Goals Panel, 1997). One of the reasons behind the low integration of mathematics, science, and technology is that the teacher training programs for pre-service teachers lack professional development or mentorship for in-service teachers (Bers & Portsmore, 2005). To overcome this problem, a partnership model was developed by Bers and Portsmore (2005) for pre-service early childhood teachers. In this model, pre-service early childhood teachers were paired with engineering students to develop, implement, and evaluate mathematics, science, and technology curricula with a teaching tool called "robotic". Although it was not a research study, both pre-service teachers and engineering students' evaluations of the partnership experience were positive. Pre-service early childhood teachers gained the vision to develop technology-rich curricula in mathematics and science.

## Conclusion

Nothing can replace the feeling of touching a bird's feather, or feeling its heartbeat, or observing the full moon at night. No computer technology can provide a complete alternative to real-world experience. However, not all children have opportunities to touch birds in school settings or to go out at night to observe the night sky. With the creative integration of technology in science classes, children can have greater opportunities to experience nature through their senses. In addition, young children's curiosity about nature and science learning could be promoted through creatively designed science classes that integrate technology.

Children mostly learn by observing their parents and other adults (Vygotsky, 1978). For instance, if parents brush their teeth every day regularly, children observe their behavior and attempt to do the same thing. We cannot hide our cell phone use, and we cannot hide our iPad, TV, VCR, etc. Children learn to use these devices by modeling our actions. In this context, it would be unrealistic to expect a preschool not to use any technological devices. Parents do have concerns about the potential harm caused by computers to young children. However, harmful or not, these tools are already in the classroom, and we should consider how to use them effectively.

To better prepare younger children for the future, we have to first prepare our teachers to be sufficiently skilled in the use of technology, integrating technology into science curricula, and organizing creative lessons for younger children. Teachers should be aware of the instructional power of technology as well as its potential harm so that technology can be used more effectively. To summarize, as Nikolopoulou (2007, p. 178) stated, "The computer is only a tool that has the potential to support the teaching and learning process, so even the best software needs to be used wisely."

Early childhood teachers need training in technology. This training must include the use of up-to-date technology and the integration of this technology with science and other subjects (NAEYC, 2012). When technological opportunities are provided for pre-service teachers and teacher trainers in the program, pre-service teachers can use technology to communicate, to prepare teaching materials, and to effectively prepare presentations for their courses. Most importantly, pre-service teachers can plan to use technology to prepare materials for children and to communicate with peers, administrators, and parents (Laffey, 2004). Similar to teachers, young children's exposure to the technology should be enlarged in the classroom to increase the "long-term development of computer skills" (Saçkes, Trundle, & Bell, 2011b, p. 1702) along with the science learning.

Future research should focus on the curriculum which is the starting point of technology use in science classes. Although there are some studies of the curriculum and technology integration, more research should be concentrated on teachers understanding of the curriculum and the extension of the teacher's application of curriculum. Parent's understanding and use of technology for education purpose should be investigated too because parents are the mostly technology providers for young children at home. Early-childhood education starts at home and continues at school. Therefore, parents are the first teachers of the children, and their practices should be analyzed and documented to better integrate the technology in science teaching. In addition to curriculum and parents, teachers' tendency and attitudes toward using technology in science classes should be investigated in dept. Both positive and negative attitudes toward teaching with technology should be documented to shape the early-childhood teacher training programs.

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# Chapter 9
# Physical-Knowledge Activities for the Development of Logico-mathematical Knowledge

**Constance Kamii**

This volume is about various aspects of science education such as life science, physical science, earth science, and space science. For many years, however, I have argued on the basis of Piaget's theory that young children's knowledge is not yet differentiated into academic subjects. When they play house, for example, they boil water to make "coffee" (science), go "shopping" (social studies and math), and say "Daddies don't go into the kitchen!" (social studies). In block building, too, they balance blocks (science), complain that somebody else has more blocks (math), and build roads and gas stations (social studies).

Early childhood education covers the first two of the four periods Piaget distinguished—the sensory-motor period (birth to age 2), the preoperational period (to age 7–8), the concrete-operational period, when children's thinking becomes reversible, coherent, and logical starting around 7–8, and the formal-operational periods (when adolescents' reasoning becomes even more logical). In this chapter, I focus mostly on the preoperational period because early childhood education concerns mainly children between the ages of 2 and 7–8.

## Piaget's Theory and Research

### *The Three Kinds of Knowledge Distinguished by Piaget*

Piaget made a fundamental distinction among three kinds of knowledge according to their ultimate sources: physical knowledge, logico-mathematical knowledge, and

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social-conventional knowledge (Piaget, 1967/1971, 1945/1951). **Physical knowledge** is knowledge of objects in the external world. The knowledge that a ball bounces when it is dropped on the floor is an example of physical knowledge. The ultimate source of physical knowledge is objects in the external world. Another example is the fact that a rattle makes a noise when it is shaken. The fact that a glass breaks when it is dropped on the floor is another example of physical knowledge.

The ultimate source of **social-conventional knowledge** is conventions that people create over time. Examples of social-conventional knowledge are languages like Spanish and English, and holidays like Christmas. The fact that we must say "Thank you" under certain circumstances is also an example of social-conventional knowledge.

While physical and social-conventional knowledge have sources outside the individual, the ultimate source of **logico-mathematical knowledge** is inside each child's head. If I show the reader a red ball and another ball that is identical except that it is blue, you will probably agree that the two balls are "different." In this situation, if I asked the reader if this difference is knowable with our eyes only, the answer will probably be "Yes."

Piaget, however, would disagree with this empiricist answer. He would say that our eyes are necessary to see the redness and blueness of each ball, but the **difference** between the two balls is a **mental** relationship that each individual makes (constructs) in his or her head. The redness of one ball is observable and is an example of physical knowledge, and the blueness of the other ball is also observable and is an example of physical knowledge. But the **difference** between the two balls is not observable because it (the difference) does not have an existence in the external world.

Another example of a mental relationship we can create (construct) between the two balls is "similar." It is just as true to say that the two balls are "similar" as it is to say that they are "different." "Different" and "similar" are mental relationships we make in our heads, and if we think about the two balls as being "similar," they become similar for us at that moment.

A third example of a mental relationship we can make (construct) between the two balls is the numerical relationship "two." When we think about the red ball as "one," it becomes "one" for us at that moment, and if we think about the blue ball as "one," it also becomes "one" for us at that moment. "Two" is thus a **mental** relationship (logico-mathematical knowledge) that human beings make (construct).

At what age do children begin to construct logico-mathematical knowledge? Mothers in many audiences in many countries have told me that within 10 days after birth, their babies became able to respond differently to a rubber nipple and a real nipple. This knowledge of nipples is an example of physical knowledge, but to construct this physical knowledge, babies need to construct logico-mathematical knowledge at the same time. In other words, they begin to make the relationship of "different" and recognize a rubber nipple as being different from a real nipple.

Babies thus construct physical and logico-mathematical knowledge at the same time starting on the first day of life.

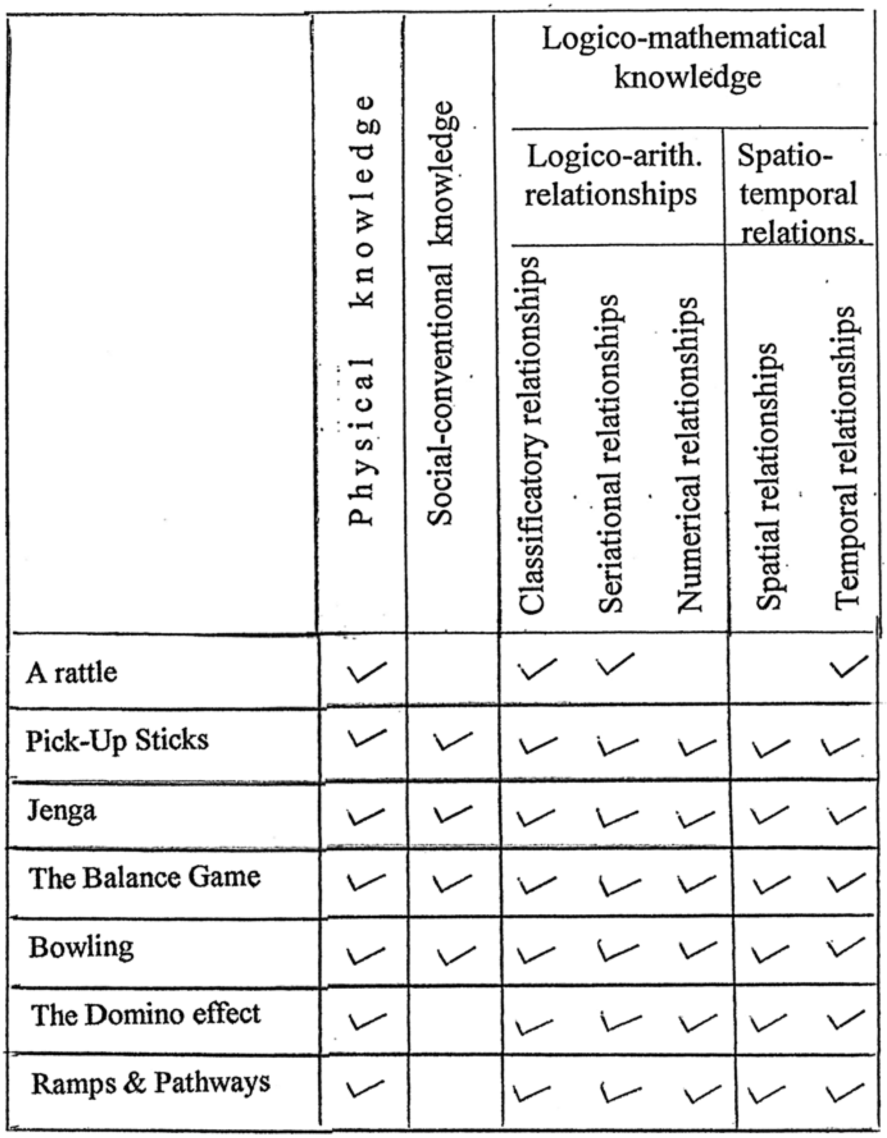
A few months later, babies learn that a rattle makes noises when it is shaken (Piaget, 1937/1954). When they get this physical knowledge of a rattle, they go on to shake other objects such as spoons and blankets to find out if they, too, make noises when they are shaken. This is also an example of babies' use of classification (logico-mathematical knowledge) to acquire physical knowledge. By finding out that the spoon and blanket react differently from a rattle, babies find out that a rattle is different from the other objects. This experimentation can be described as evidence of the baby's **thinking. It is by thinking that babies and children simultaneously construct physical and logico-mathematical knowledge.**

Figure 9.1 shows the relationship between physical and social-conventional knowledge on the one hand, and logico-mathematical knowledge on the other. Physical and social-conventional knowledge are knowledge of contents (like rattles and spoons). Logico-mathematical knowledge is subdivided into the five kinds of mental relationships that Piaget especially studied in depth for decades. The five are classification, seriation (Inhelder & Piaget, 1959/1964), number (Piaget & Szeminska, 1941/1965), spatial relationships (Piaget & Inhelder, 1948/1956; Piaget, Inhelder, & Szeminska, 1948/1960), and temporal relationships (Piaget, 1946/1969). The example of a rattle has been entered in this framework to show that logico-mathematical knowledge is necessary for babies to acquire the physical knowledge of rattles.

To know the nature of a rattle, babies shake it and stop shaking it, over and over. By repeating these actions, babies make the correspondences between shaking the rattle and hearing or not hearing the noise (**classification**). In other words, babies **think** when they make these correspondences. Without making these **temporal relationships**, babies could not acquire their knowledge of rattles. This is why an "X" has also been entered in Fig. 9.1 for "temporal relationships."

**Seriation** means to order things from "small" to "bigger," "even bigger," and "biggest," or from "silent" to "makes a sound" to "makes a louder and louder noise," etc. To show that babies shake the rattle gently or vigorously to study the variation in their action and the object's reaction, an "X" has also been entered in Fig. 9.1 for "seriation." The more vigorously they shake the rattle, the more loudly it reacts. The relationships they thus make clearly reveal babies' **logico-mathematical thinking**.

Logico-mathematical knowledge is what makes Piaget's theory different from all the other theories that are used in early childhood education. As we saw in the example of a rattle, children construct more logico-mathematical knowledge as they construct more physical knowledge. In fact, logico-mathematical knowledge constitutes the framework through which children and adults organize the totality of their knowledge (Piaget, 1937/1954, p. 400) as will be seen in the following examples from Piaget's research.



| | | | Logico-mathematical knowledge | | | | |
|---|---|---|---|---|---|---|---|
| | | | Logico-arith. relationships | | | Spatio-temporal relations. | |
| | Physical knowledge | Social-conventional knowledge | Classificatory relationships | Seriational relationships | Numerical relationships | Spatial relationships | Temporal relationships |
| A rattle | ✓ | | ✓ | ✓ | | | ✓ |
| Pick-Up Sticks | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Jenga | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| The Balance Game | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Bowling | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| The Domino effect | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ramps & Pathways | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |

**Fig. 9.1** Piaget's framework of knowledge

## *Three Examples of Piaget's Research Related to Early Childhood Science Education*

**Conservation of Matter and of Weight** Conservation of matter refers to the ability to deduce logically that the amount of clay remains the same when the shape of one of two identical clay balls has been changed. In the conservation-of-matter task

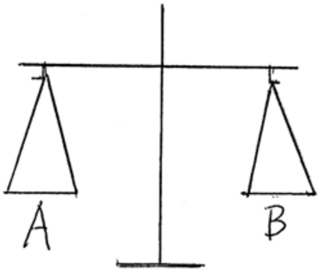


**Fig. 9.2** A balance used in Piaget's experiments

(Piaget & Inhelder, 1941/1974), the interviewer presents the child with two clay balls and ascertains the child's belief that the two balls have the same amount of clay. The interviewer then asks the child to "watch what I am going to do" and rolls one of the balls into a "sausage." The question put to the child is "Does this sausage have as much clay in it as this ball, or does the sausage have more, or does the ball have more?"

Until the age of about 7, most children say that the sausage has more clay in it than the ball and explain this judgment by saying that the sausage is bigger (or longer) than the ball. These children are said to be nonconservers. At the age of about 8, by contrast, they deduce logically that the two objects have the same amount of clay. When asked how they know this, 8-year-olds give one of the following three arguments:

(a) You didn't add anything or take anything away.
(b) The sausage is longer, but it is thinner.
(c) I could roll the sausage back into a ball, and you'll see that the two balls have the same amount.

The child's knowledge about the fact that a clay ball can be rolled into a sausage is physical knowledge, but the thinking necessary to conserve the amount is logico-mathematical knowledge.

When a child can thus conserve the amount of clay, the interviewer can bring out a balance (see Fig. 9.2) and ascertain the child's knowledge that if an object is placed in pan A, pan A will go down, and pan B will go up. Holding the clay ball and "sausage" above each pan, the interviewer then asks, "If I put this ball in this pan (A) and the sausage in the other pan (B), will the two pans stay at the same level, or will this one (A) go down, or will this one (B) go down?"

At age 8, half of the children reply that the pan holding the ball will go down, and the one holding the sausage will go up because the ball is heavier than the sausage (Piaget & Inhelder, 1941/1974). Eight-year-olds have just told the interviewer that the **amount** of clay is the same in the ball and sausage, but they intuitively feel that the ball will press down hard on the plate at one point, whereas the weight of the sausage will be distributed over its entire length. This is why they think that the pan holding the ball will go down.

Around the age of 9–10, however, 75 % of the children conserve weight and predict that the two pans will stay at the same level because the ball and sausage have the same weight. When asked how they know that the two objects have the same weight, they invoke one of the same three arguments:

(a) You didn't add anything or take anything away.
(b) The sausage is longer, but it is skinnier.
(c) I could roll the sausage back into a ball, and you'll see that the two balls have the same weight.

Again, children's knowledge that clay balls have weight is physical knowledge, but the judgment about the equality of weight is logico-mathematical knowledge. When children's logico-mathematical thinking has become strong, they reason that the weight on both sides of the balance **has to remain the same**. Conservation of weight is thus deduced with the force of logical necessity.

**The two pans of a balance cannot both go down**. As reported in *Experiments in Contradiction* (Piaget, 1974/1980), a balance like the one in Fig. 9.2 was shown to many young children, and part of the interviews went as follows:

- The child was asked what would happen if a washer was placed in pan A (or pan B).
- The child usually predicted that A would go down and B would go up.
- The child then observed that A indeed went down and B went up when a washer was placed in A.
- The interviewer held a washer in each hand above A and B, and asked the child what would happen if a washer was placed simultaneously in A and in B.

Four- and 5-year-olds sometimes reacted in confused ways, but all their predictions included the belief that both pans would go down. By age 7, however, all the children predicted that both pans would stay where they are, at the same height. They made this prediction by coordinating the weight of one washer pressing down in A with the weight of the other washer pressing down in B.

Why did the 7-year-olds predict that neither pan will go down? In *Epistemology and Psychology of Functions,* Piaget (1968/1977) reported on a new structure that he conceptualized at 4–5 years of age, during the preoperational period. He called it a "function," which is a mental relationship children make between two things in a unidirectional way. Four- and 5-year-olds can easily predict that as a function of A's going down (in Fig. 9.2), B will go up, but this relationship is unidirectional. Four- and 5-year-olds cannot coordinate this relationship with another function that goes in the opposite direction (as a function of B's going down, A will go up). This is why 4- and 5-year-olds predict that both A and B will go down if a washer is simultaneously placed in A and in B. By age 7, however, they become able to coordinate the two functions and predict that neither A nor B will go down. Again, weight itself is physical knowledge, but the relationship about what the two weights do is logico-mathematical knowledge.

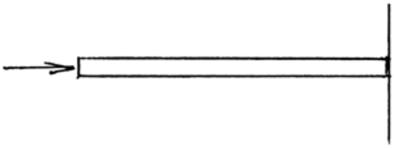


**Fig. 9.3** A heavy ruler placed on a line and tapped very lightly

**"Nothing + nothing + nothing + . . . ." cannot result in "something."** Among the other experiments described in *Experiments in Contradiction* (Piaget, 1974/1980) is one that especially illustrates well the difference between preoperational and concrete-operational thinking. The interviews conducted in part as follows revealed that, at the age of 5–6, "nothing + nothing + nothing + . . . . " can result in "something."

- The child was first shown a heavy, metal ruler 50 cm long placed on the table on a line as illustrated in Fig. 9.3.
- The interviewer tapped the ruler very lightly with a thin rod on the end indicated by the arrow.
- The taps did not make the ruler move at first, but it moved beyond the line after several taps.
- Predictions were asked for, and the child was asked after each tap whether or not the ruler had moved and why.

Five- and 6-year-olds said that the first taps did not make the ruler move, but the third, sixth, or eighth tap did. When asked why the ruler started to move on the third, sixth, or eighth tap, many children explained, "Because you tapped a little bit harder." Some of the others made incoherent statements that are not possible to summarize.

By the age of 9 or 10, however, children had constructed the idea of an infinitely small force that had a cumulative effect (logico-mathematical knowledge). For example, ARI, who was 9 years and 5 months old, said that the fourth tap made the ruler move because the third tap had shaken it a little bit. He thus explained that the first tap had started to shake the ruler, that the second tap shook it "a little tiny bit," and that the third tap also shook it even though the movement could not be seen.

Countless other examples could be given to show that according to Piaget (1968/1977, 1971/1974, 1972, 1974/1976, 1974/1978, 1983, 1978) children's physical knowledge develops as their logico-mathematical knowledge develops. It seems best to define our educational goal as the development of children's logico-mathematical knowledge because their logico-mathematical knowledge will serve as a framework for children not only to elaborate their physical knowledge but also to organize all the knowledge they will go on to construct (Piaget, 1937/1954). Having explained this decision, I now turn to some general ideas about education that Piaget published.

## Piaget's Ideas About Education

In *Understanding Causality,* a book about children's explanation of physical phenomena, Piaget (1971/1974, p. 17) highlighted the importance of thinking for children to develop logico-mathematical knowledge. He said,

> The child may on occasion be interested in seriating for the sake of seriating, in classifying for the sake of classifying, but, in general, it is when events or phenomena must be explained and goals attained through an organization of causes that operations [logico-mathematical knowledge] will be used [and developed] most.

He was saying here that what motivates children to think hard is their desire to know the "why" of phenomena and events, and the "how" of attaining goals. The significant point he seems to be making here is that educators do well to base their practice on children's desire to know the *why* of phenomena and the *how* of producing them.

More generally, in a book about education, Piaget (1969/1970) advocated new methods of teaching (developed by Decroly, Claparède, Dewey, etc.) as opposed to "old" or "traditional" methods. In the old school, he said, the child is expected to labor and acquire knowledge simply because the school requires it. In the new school, by contrast, the child is believed to be "an active being whose action, controlled by the law of interest or need, is incapable of working at full stretch if no appeal is made to the autonomous motive forces of that activity." (p. 153)

The activity that results directly from young children's needs and interests is play. Play was important for Piaget because it can be explained only "by the biological process according to which every organ develops through use." (Piaget, 1945/1951, p. 87)

I thus decided to develop physical-knowledge activities for young children. In physical-knowledge activities, children act on objects to produce a desired effect. An example is Pick-Up Sticks (Fig. 9.4) in which children try to pick up as many sticks as possible without making any other stick move (Kamii, Rummelsburg, & Kari, 2005).

An advantage of physical-knowledge activities is that children can tell immediately whether or not they were successful, without needing a teacher to evaluate their actions. If a child was unsuccessful, he or she immediately thinks about how

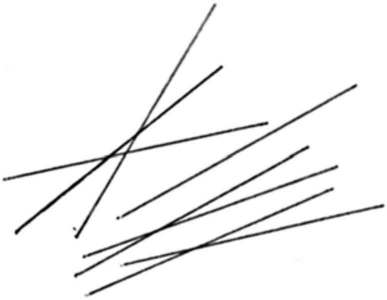


**Fig. 9.4** Pick-up sticks with only eight sticks

to be successful next time. In Pick-Up Sticks, for example, they are likely to notice how they unwittingly moved another stick, and try to avoid making the same error next time.

With the sticks in Fig. 9.4, children first **classify** them into "those that are touching other sticks" and "those that are not touching any other stick" and pick up first those in the latter category. An X has therefore been entered in Fig. 9.1 for **classification** for Pick-Up Sticks. Children then **seriate** the sticks into "those that are a little harder to pick up," "those that are even harder to pick up," etc. When they notice that one stick is on top and across another, they make a **spatial** and **temporal relationship**. At the end of the game, they count the sticks they have collected to decide who won the game. An X has thus been entered for **seriation**, **numerical relationships, spatial relationships**, and **temporal relationships**. There is an X for social-conventional knowledge, too, because all games have rules that are established by convention.

In physical-knowledge activities, children thus think hard as they play. When they play, they are, of course, intrinsically motivated, but certain principles of teaching must be followed to maximize this motivation. These principles concern the number of sticks that are made available, the number of children in a group, and whether or not the rules of the game can be changed.

- The number of sticks must be limited to about eight for children to be able to put them into relationships. When there are too many sticks, it is impossible even for adults to find those that are not touching each other or those that are touching only one or two sticks.
- The number of children in each game must be limited to two or three. When there are four, the players must wait for the fourth child to take a turn, and most children do not think when they are waiting for others to have a turn.
- Children must be encouraged to change the rules of the game to maximize their possibility of thinking. In Pick-Up Sticks, each player is usually allowed to continue playing until he or she makes another stick move. However, children sometimes change this rule to "On each turn everybody gets only one try at picking up a stick." Children then have the possibility of being mentally more active because the time they have to spend waiting is shortened. It is best to let children change a rule when everybody or the majority agrees to a proposed change.

I said earlier that physical-knowledge activities are those in which "children act on objects to produce a desired effect." I used to think that "to act" meant to act physically on objects. I later came to understand that when Piaget spoke of an action, he was referring to a physical **and mental** action. Even babies act differently, both physically and mentally, on a piece of string at age 1;0 (7) [1 year, 0 months, and 7 days] and at 1;0 (29). Below is an account of one of Piaget's experiments with Jacqueline, his older daughter. (Piaget, 1936/1952, p. 291)

When Jacqueline, was 1:0 (7), she was seated in her bassinet whose handle was supported by a table facing her. Piaget showed Jacqueline her swan whose neck had a string attached to it. He put the swan on the table, leaving the string in the bassinet. Jacqueline grasped the string immediately and pulled it while looking at the swan.

But as the string was long, she did not stretch it out and was limited to waving it. Each shake of the string made the swan move, but it came no nearer.

After many attempts of the same kind, Piaget moved the swan farther away stretching the string out. Jacqueline still shook the string, without pulling it. The swan fell, but Jacqueline held onto the string and resumed shaking it.

The next day, Piaget resumed the experiment. Jacqueline shook the string at first and then pulled it. When the swan was near enough, she tried to reach it directly with her hand. But she did not succeed and gave up. On the following days, she shook the string less and seemed to pull it more.

Finally, at 1;0 (19). Jacqueline drew the object to her by pulling the string, but she never did this without shaking it beforehand. Only 10 days later did she pull it immediately. Contrary to what behaviorists say, the stimulus does not stimulate the child. It is the child who acts on the object, mentally and physically, and the same string is not the same object for the child at 1;0 (7) and 22 days later.

## Other Examples of Physical-Knowledge Activities

I started to invent physical-knowledge activities by thinking about the physical actions children can perform on objects. Some examples are sketched below without any organization:

Blowing

  With a straw to move objects
  With a straw to make soap bubbles
  In blow painting

Hitting

  With a stick

Pushing

  With a stick to make an object slide on the floor (like in deck golf)

Rolling down an incline
Dropping (into a container)
Running

  With a book on one's head
  Horizontally holding streamers or newspaper cut into streamers

Balancing

  Making a "tall construction" with junk objects such as plastic milk containers
  Making Rolly-Poly dolls with half a Ping-pong ball, clay, and a tongue depressor
  The Balance Game (with a flimsy paper plate balanced on an empty bottle)

Throwing

Like in Ring Toss
Into a wastepaper basket

Jumping

On a large lever (a board placed on a roller)

Tilting

A board with marble-size holes and hairpins or paperclips

Sucking

With a straw, to move small objects from one place to another

Swinging

A pendulum

Twirling
Pulling out (like pulling blocks out in Jenga)

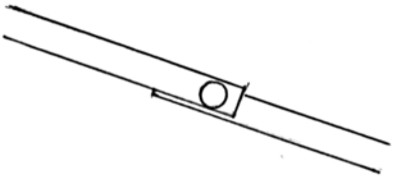
In the first edition of *Physical Knowledge in Preschool Education* (Kamii & DeVries, 1978), DeVries and I wrote about two types of physical-knowledge activities: (a) those that involve the movement of objects and (b) those that involve changes in objects. Although this book was theoretically hazy in retrospect, this dichotomy still seems useful for teaching young children. An example of the former is Pick-Up Sticks, and cooking is an example of the latter. When we put an egg in a frying pan, for example, the egg changes from a liquid to a solid.

DeVries and I conceptualized the following four criteria for the movement of objects (Kamii & DeVries, 1978/1993, pp. 8–9):

1. ***The child must be able to produce the movement of objects with his/her own action.*** By blowing through a straw to make an object move, the child can find out how each object reacts. By contrast, touching many objects with a magnet is not an example of producing an object's reaction with one's own action. One object may stick to the magnet while another that looks identical may not.
2. ***The reaction of the object must be observable***. Pick-Up Sticks is useful because all the sticks are observable in this activity. By contrast, when an opaque tube is used in water play, neither the water nor the objects in the tube are observable. Therefore, even if the child varies his or her actions on the tube, he or she cannot make correspondences between an action and the object's reaction.
3. ***The child must be able to vary his or her action***. When all that the child can do is to push the button of an electronic toy, these actions cannot be varied. By contrast, when the child tries to make a ramp with two pieces of cove molding (see Fig. 9.5), he or she finds out that if the piece on the lower side is on top of the other, the marble gets stuck (Fig. 9.5b). By placing the piece on the higher side on top, they find out that the marble can continue to roll down (Fig. 9.5a). This activity thus makes children think to make spatial and temporal relationships.

**Fig. 9.5** Two ways of assembling the moulding

**a** A way that lets the marble continue to roll down.



**b** A way that causes the marble to get stuck.

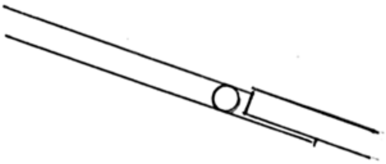
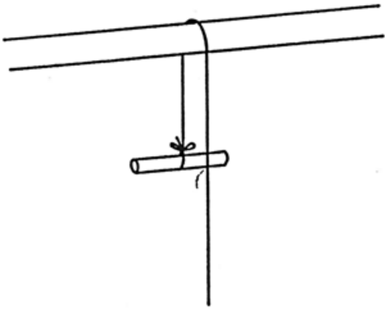


**Fig. 9.6** Raising and lowering an object by pulling and releasing a rope



4. ***The reaction of the object must be immediate***. The child can stand on the floor and raise an object to the top of a jungle gym by pulling the rope as shown in Fig. 9.6. By contrast, the weights of a cuckoo clock work so slowly that the correspondence between the lengthening of one end of the chain and the shortening of the other end is impossible to observe. The cuckoo clock is thus an example not only of an object that reacts too slowly but also of a phenomenon that is not produced by the child's own action.

Having made these introductory remarks, I now describe five physical-knowledge activities. They are Jenga, the Balance Game, Bowling, the Domino Effect, and Ramps and Pathways.

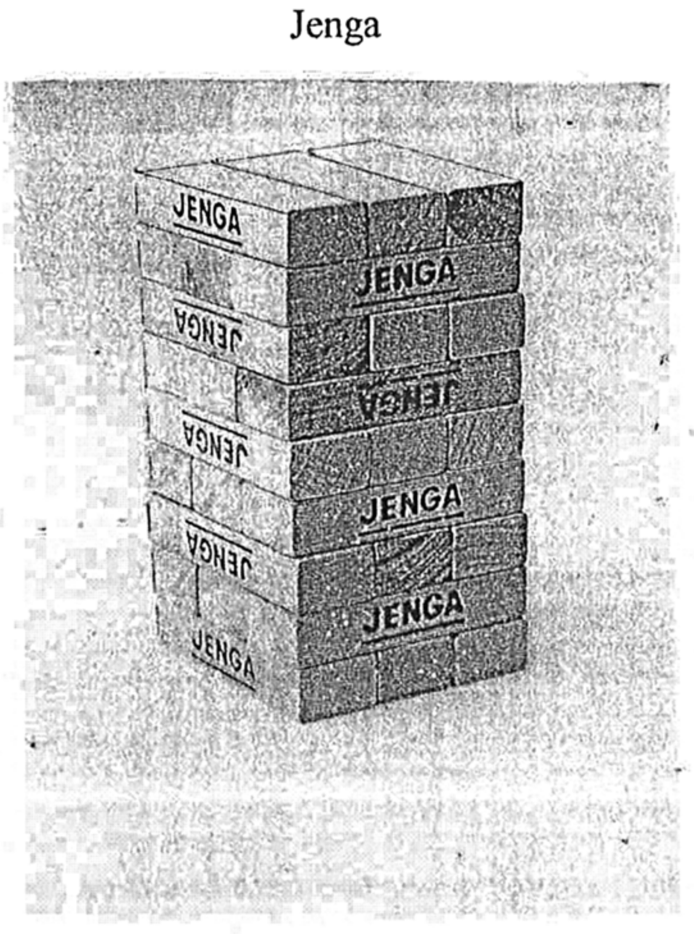


**Fig. 9.7** Jenga

## *Jenga*

In Jenga, (Fig. 9.7; Kamii, Rummelsburg, & Kari, 2005) children try to pull one block after another out of the tower without making it fall. When they decide which block to pull out first, second, and third, they **seriate** the blocks from “the easiest to try to pull out” to “the hardest (at the bottom of the tower).” This **seriation** is related to the **spatial** and **temporal relationships** they make. At the same time, children also try to get as many blocks as possible and think about **number**. After pulling out the block in the middle of a layer of three blocks, they notice that it is now impossible to use the other two that are on the edges. They then **classify** the three blocks on each layer into “the two on the edges that should be used first” and “the one in the middle that should not be used first.” This classification is based on **temporal, spatial,** and **numerical relationships**.

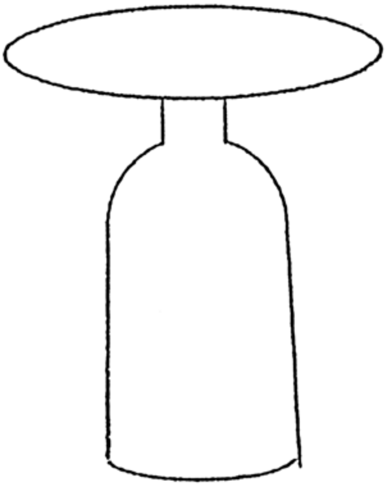


**Fig. 9.8** The balance game

Because the purpose of all physical-knowledge activities is to encourage children to think, it is necessary to change some of the rules of Jenga that are printed on the box. First, there are too many blocks in a box for young children to put into relationships. The number must therefore be reduced to a maximum like the number that can be seen in Fig. 9.7. Second, the rule on the box states that the players must not hold the tower down with their free hand, but for young children this rule must be eliminated. Children hold the tower down **because they are thinking**, and telling them not to hold it down interferes with this thinking. Third, the rule on the box says that when children pull a block out, they must put it on top of the tower. This rule, too, must be eliminated because children want to keep the blocks they succeeded in pulling out. Telling them to place them on top of the tower would reduce their motivation to think.

## *The Balance Game*

This two-player game uses a flimsy paper plate balanced on an empty plastic bottle that can contain some sand for stability (Fig. 9.8; Kamii et al., 2005). Each player is given five Unifix Cubes of the same color at the beginning, and the number can later be increased to 10, 20, 30, or more. The players take turns putting a Unifix Cube on the plate without making it fall. If it falls, the player who caused the fall loses the game. The one who uses up all his or her cubes first wins.

Young children usually put the first cube on the edge of the plate and make it fall. Teachers are often tempted to tell children how to be successful and why. However, such help prevents children from doing their own thinking. The center of gravity is not directly observable, but children sooner or later make the **spatial relationship** between the top of the bottle and the middle of the plate. If they get frustrated because they cannot make the necessary relationships, they can always choose to play some other game.

After figuring out the center of gravity, the next challenge involves symmetry. Children have to imagine a line that cuts across the center of gravity and put a cube alternately at the same distance from the center (one on the left side followed by one on the right side, with the same distance from the center). These **spatial relationships** all have to be constructed from within, and some kindergartners soon begin to show off a mountain of cubes they succeeded in piling up. Figuring out the need to think about symmetry involves making **spatial** as well as **temporal relationships.** As children make these relationships, they also make the **classificatory relationship** of "the plate stayed up (success)" and "the plate fell (failure)."

In the Balance Game, **Seriation** can take place in decreasing order. As the **number** of cubes placed on the plate increases, its stability increases, and the players can become less careful about where to put a cube. In other words, when a player places the first and second cubes on the plate, he or she has to be exact in thinking about symmetry. As the child places the 15th or 20th cube on the plate, the distances away from the center can become less exact.

The social interactions among the players are important to note. Kindergartners are not as competitive yet as first and second graders, and they often offer advice to the others. These interactions must be encouraged because children need to learn about how other people think. To figure out what advice to give, children have to decenter and think from another person's point of view. From the standpoint of the recipient of advice, a suggestion made by a peer is not the same thing as the same suggestion made by a teacher, who is in a position of authority (Piaget, 1932/1965).

## *Bowling*

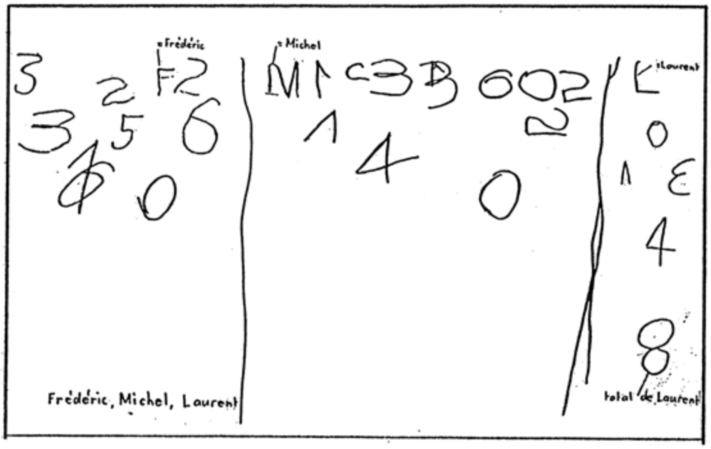
This game uses 5–10 empty plastic bottles (that can contain some sand for stability) and a tennis ball (Kamii, 1982, pp. 52–56). Each child begins by arranging the bottles (pins) and rolls the tennis ball to knock down as many pins as possible. The person who knocks down more pins than anybody else is the winner.

Bowling can be played alone, and 4-year-olds arrange the pins in a variety of ways. The game gradually becomes social, but there is at first no rule about taking turns. Whoever catches the ball gets a turn. There is likewise no rule about distances to the target, and each player can roll the ball from anywhere. As disagreements emerge about who is getting too many turns, children may suggest making a rule. If they do not, the teacher needs to suggest the desirability of making a rule.

A characteristic of Bowling among older children is that they want to take more than one turn and cannot remember who knocked down how many pins. The need for recording the numbers knocked down thus emerges, and Fig. 9.9 shows the kind of progress that appears in their writing.

Figure 9.9a shows the score sheet produced by three 6-year-olds in Geneva, Switzerland—Frédéric, Michel, and Laurent (indicated by "F", "M", and "L"). It

**a** At age 6



**b** At age 6 years and 4 months

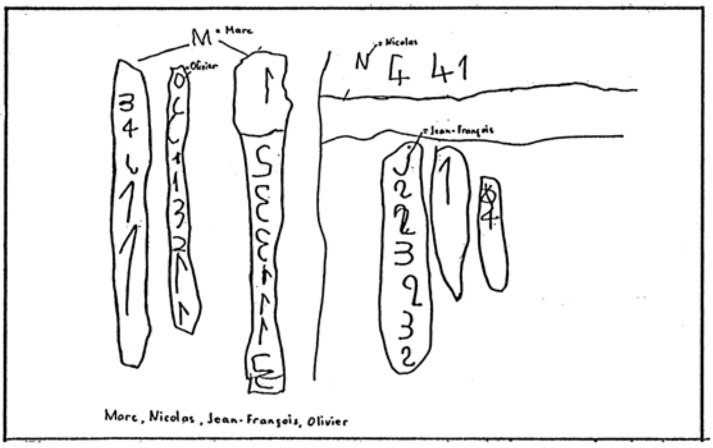


**Fig. 9.9** Score sheets from a bowling game

can be seen in this illustration that Laurent was the only child who added 0, 1, 3, and 4 and got a total of 8 points. Laurent was also the only child who used **space** to represent the **temporal order** in which he made these points. Four months later, as can be seen in Fig. 9.9b, all the children attempted to use **space** to represent **temporal order**. Keeping score in an understandable way requires thinking and discussing how to use writing in a way that makes sense to everybody.

**a** An imitation by a beginner (age 3)

**b** An imitation by an older and more experienced child (age 3 years 5 months)

**Fig. 9.10** Two ways of imitating the teacher's arrangement

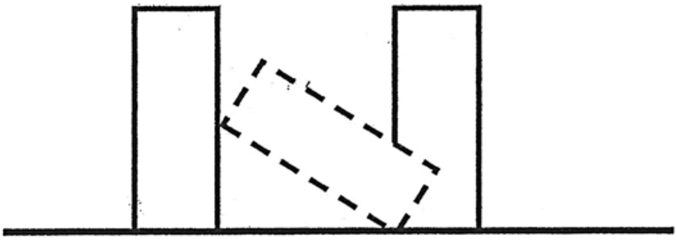


**Fig. 9.11** How one Domino makes the next one fall

## *The Domino Effect*

The reader must be familiar with the domino effect, where the child stands many dominoes in a line and pushes the one at one end to make all the other dominoes fall one after the other (see Figs. 9.10 and 9.11). An article about beginners and more advanced children can be found in Ozaki, Yamamoto, and Kamii (2008). In this article, the reader can see that there are children who doggedly persist in trying to succeed and those who give up immediately. If children are not interested in the activity, it is best to let them choose another that seems more attractive to them.

The teacher first arranged the dominoes and demonstrated the domino effect. The 3-year-old who tried to imitate her made the arrangement in Fig. 9.10a, with no space between the dominoes. At the age of 3 years 5 months, another child who had had some experience with this activity imitated the teacher with the arrangement in Fig. 9.10b. Her arrangement was better, but the spaces between **b** and **c**, **d** and **e, f** and **g,** and **h** and **i** were greater than the dominoes' height. As a result, when she lightly pushed **a**, only the first five dominoes fell over. When she then pushed **c**, only the next three fell over. She went on to push **e**, **g**, and **i** to make all the dominoes go down.

These imitations are another example of Piaget's statement that human beings do not see the same thing when they look at it. Human beings see only what their logico-mathematical knowledge enables them to see. In other words, we act mentally on objects when we look at them. The 3-year-old who made the arrangement in Fig. 9.10a acted on the teacher's demonstration with the spatial relationships he was capable of making. He was not yet able to make the relationship illustrated in Fig. 9.11. The older child who made the arrangement in Fig. 9.10b noticed the spaces between the dominoes, but these distances were not yet based on the exact spatial reasoning illustrated in Fig. 9.11. When the child logico-mathematically understands how each domino pushes the next one, he or she feels the necessity of arranging them with exactly the same distance between them.

If the dominoes are available in the classroom all the time, children can play with them during free play day after day. They go on to make long and elaborate arrangements, often in collaboration with two, three, or more children. They think of making an arrangement like a "Y" that separates into two "paths". This is not easy, and children think hard as they engage in trial-and-error.

If the teacher puts a small box on the floor, children think very hard to figure out how to make a path that goes up to the top of the box, across the box, and down on the other side. The spatial and numerical relationships they make in making a kind of "stairway" going up and down are truly admirable.

## *Ramps and Pathways*

This is an activity in which children assemble pieces of cove molding and roll a marble down its groove (see Fig. 9.5a). Cove molding is "a decorative wooden edging used to conceal the seam between ceiling and wall around the perimeter of a room. It can be purchased at builder supply stores (DeVries & Sales, 2011, p. 8)." The kind I recommend is 1¾ in. wide and cut into lengths of 1, 2, 3, and 4 ft. It has a flat backing and a single groove down the center.

The first physical fact that young children notice is that a marble in the groove does not move if the molding is placed on a flat surface. The next fact may be that the marble gets stuck in the situation in Fig. 9.5b. The child may then figure out the spatial relationship that is necessary for the marble to continue rolling. This relationship becomes much more complicated when the child wants to make the marble turn by $90^0$.

*Ramps and Pathways* (DeVries & Sales, 2011) describes classroom research conducted at the University of Northern Iowa and has many excellent photographs that suggest what else teachers and children can invent. Children continue to invent many arrangements in second grade. As can be seen in Fig. 9.12, the spatio-temporal relationships second graders invent are so intricate that adults have trouble trying to imitate them. For children's elaboration of such complex spatial relationships, it is obvious that it is important to leave the materials out for children to use during their free time.

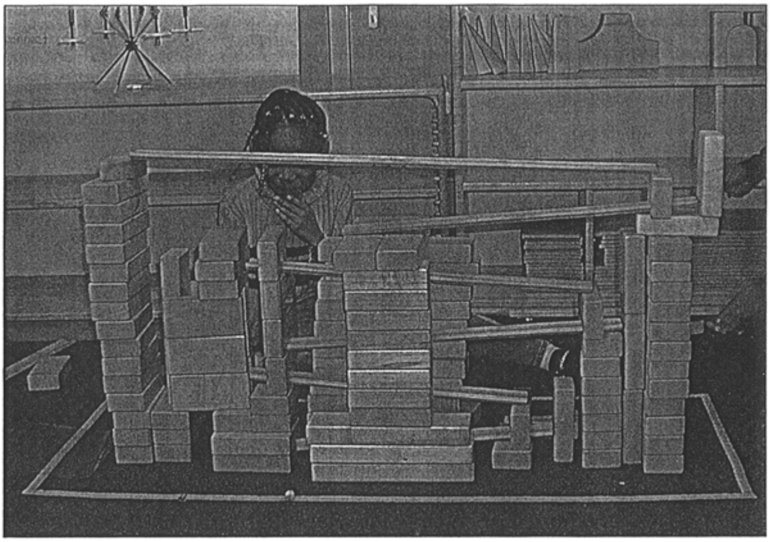


**Fig. 9.12** A second grader's response to the teacher's challenge to use many blocks and pieces of molding in a small area

Many other ideas for physical-knowledge activities can be found in Kamii and DeVries (1978/1993). However, this book was originally written in the 1970s, when our knowledge of children and Piaget's theory was superficial. Other activities that stimulate the development of logico-mathematical thinking can be found in Kamii (2003), Kamii, Miyakawa, and Y. Kato (2004), Miyakawa, Kamii, and Nagahiro (2005), Kato, Honda, and Kamii (2006), Kamii, Miyakawa, and T. Kato (2007), and Kamii and Nagahiro (2008).

## Principles of Teaching

It is important first of all to note that it is not the activities themselves that foster the development of logico-mathematical knowledge. It is **the thinking children do** during the activity that is important. I therefore list two principles of teaching and elaborate them later.

1. When children are not successful in producing the desired effect, do not show or tell them how to be more successful.
2. When children are successful, refrain from saying "That's good" or "Good job!"

Traditional educators want children to be successful and have a tendency to show children how to be more successful. However, physical-knowledge activities are good for children precisely because they encourage children to think. If we show them how to be successful, we deprive children of opportunities to think. They can always leave the activity and choose another one when they get frustrated.

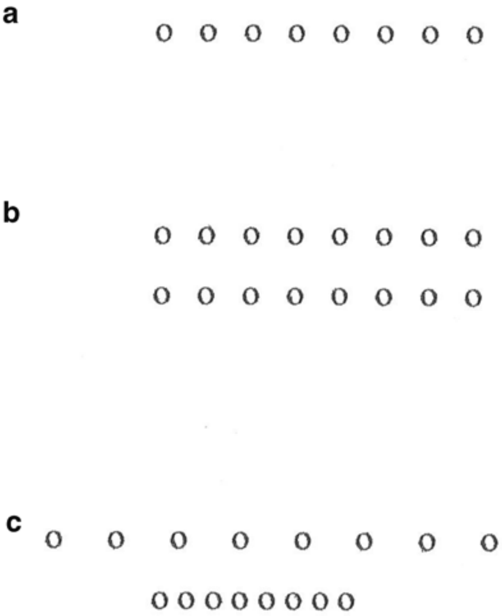
Traditional educators generally believe that the “correct” response has to be reinforced and too often say “Good job!” In a physical-knowledge activity, the child already knows it when he or she is successful. Being praised diverts their attention from the activity to what the teacher says. It is good for the teacher to express genuine pleasure when a child is successful, but we too often hear “Good job!” uttered mechanically and excessively.

## Evidence of the Effectiveness of Physical-Knowledge Activities

In a Title-I school in California, a group of 26 children (out of a total of about 100) came to first grade without any number concepts. We knew that these children did not have any number concepts by giving them two tasks: the conservation-of-number task (Piaget & Szeminska, 1941/1965) and a hiding task recommended by Richardson (1999).

The conservation-of-number task is given in the following way: The interviewer aligns eight chips (see Fig. 9.13a) and asks the child to “put out the same number (or ‘the same much’).” If the child puts out the same number as shown in Fig. 9.13b, the adult says, “Watch what I am going to do,” shortens one of the lines, lengthens the other line (see Fig. 9.13c), and asks, “Now, are there still as many in this line (one of the lines) as in the other, or does this line have more (pointing), or does this line have more (pointing)?” The children who answer that the two lines have the

**Fig. 9.13** The arrangement of chips in the conservation-of-number task



same number "because all you did was move them" are said to be conservers, who have constructed the logico-mathematical idea of number. Those who reply that the longer line has more because it is longer are said to be nonconservers.

In the hiding task, all the children could count out four chips when asked to. The interviewer then hid some of the four chips under a hand and asked, "How many am I hiding?" The answers given by the 26 first graders were "Ten," "Eight," or some other random number.

These children thus did not have any number concept, but the law required that we give them an hour of math instruction every day. We therefore decided to divide the 26 children into two groups of 13 and gave physical-knowledge activities to them to build their logico-mathematical foundation for number. For about half a year, we continued to give physical-knowledge activities during the math hour to encourage the children to think.

In the middle of the school year, to find out whether or not the children were "ready" for math instruction, we played a game with them called "Piggy Bank" (Kamii, 2000). In this game, 10 cards each of four kinds of cards were used—cards with one dot, 2 dots, 3 dots, or 4 dots, making a total of 40 cards. The object of the game was to find pairs of cards that made 5 (such as $1+4$ or $2+3$). If a pair made a total of 5, the player could keep it. The one who collected more pairs than anybody else was the winner. Almost all 26 of the children thus proved to be "ready" for math by spring and spent the rest of the school year with the kind of instruction recommended by Kamii (2000). This instruction, too, was based on Piaget's constructivism and heavily emphasized children's own thinking.

To evaluate the effectiveness of physical-knowledge activities, we compared our 26 children with 20 similar first graders who were in a nearby Title-I school. The 20 children also came to first grade without any number concepts but were given regular math instruction throughout the school year with a state-approved textbook and workbook, supplemented with activities recommended by Burns and Tank (1988) and Richardson (1999).

The achievement of the two groups of first graders was compared at the end of the school year in two individual interviews—one consisting of mental arithmetic and one consisting of word problems. In the mental-arithmetic part, the child and the interviewer both had a form with 17 addition problems photocopied in a column on the left-hand side (see Table 9.1). The child was asked to give the answer orally to each question and to slide a ruler down to the next question. The interviewer recorded what the child said and used one dot per second of silence to record the child's reaction time.

In the interview with word problems, each problem was photocopied on a separate sheet. The child was given a pencil and told, "You can draw or write anything you need to, to solve this problem." The following four problems were read to the child as many times as desired:

1. People started to get in line to go to lunch. I was standing in line and counted 3 people in front of me and 6 people in back of me. How many people were in line altogether at that time?

**Table 9.1** Two groups of first graders giving correct answers within 3 s at the end of first grade (in percent)[a]

| | Constructivist (*n*=26) | Comparison (*n*=20) | Difference | Signif. |
|---|---|---|---|---|
| 2+2 | 100 | 90 | 10 | n.s. |
| 5+5 | 92 | 90 | 2 | n.s. |
| 3+3 | 77 | 85 | -8 | n.s. |
| 4+1 | 88 | 65 | 23 | 0.05 |
| 1+5 | 88 | 70 | 18 | n.s. |
| 4+4 | 88 | 65 | 23 | 0.05 |
| 2+3 | 81 | 40 | 41 | 0.01 |
| 4+2 | 58 | 25 | 33 | 0.05 |
| 6+6 | 50 | 40 | 10 | n.s. |
| 5+3 | 58 | 35 | 23 | n.s. |
| 8+2 | 69 | 45 | 24 | 0.05 |
| 2+5 | 62 | 40 | 22 | n.s. |
| 4+5 | 42 | 30 | 12 | n.s. |
| 5+6 | 24 | 5 | 19 | 0.05 |
| 3+4 | 38 | 15 | 23 | 0.05 |
| 3+6 | 38 | 10 | 28 | 0.05 |
| 4+6 | 35 | 20 | 15 | n.s. |

[a]From Kamii, Rummelsburg, and Kari (2005)

**Table 9.2** Two groups of first graders giving correct answers to word problems at the end of first grade (in percent)[a]

| | Constructivist (n=26) | Comparison (n=20) | Difference | Signif. |
|---|---|---|---|---|
| 1. Line | 8 | 0 | 8 | n.s. |
| 2. Crackers | 19 | 5 | 14 | n..s. |
| 3. Cookies | 50 | 0 | 50 | .001 |
| 4. Candy | 73 | 25 | 48 | .001 |

[a]From Kamii, Rummelsburg, and Kari (2005)

2. I am getting soup ready for 4 people. So I have 4 bowls. If I want to put 2 crackers in each bowl, how many crackers do I need?
3. There are 3 children. There are 6 cookies for them to share. How many cookies will each child get?
4. Let's pretend that I had 12 pieces of candy. If I gave 2 pieces to my mother, 2 pieces to my father, and 2 pieces to my sister, how many pieces would I have left?

The findings about mental arithmetic are presented in Table 9.1, and those about word problems appear in Table 9.2. It can be seen in Table 9.1 that the 26 first graders (referred to as "Constructivist") who had physical-knowledge activities did much better in mental arithmetic at the end of first grade than the similar group of 20 children in the Comparison Group. The "Constructivist" group did better on 16 out of 17 questions. On 8 of the 16 questions, the Constructivists excelled with statistical significance.

It can be observed in Table 9.2 about word problems that the Constructivist group did better on all the word problems, and the differences were highly significant on two of the four problems. Since the numbers involved in the word problems were small, all the first graders were able to deal with them. The word problems can therefore be said to be a test of the children's logic.

The first problem about the line of children turned out to be too difficult for both groups. Almost all the first graders were too egocentric to think about themselves, and the great majority (85 % and 80 %, respectively) did $3+6=9$.

The second problem was also very difficult for both groups. About a fourth of both groups added all the numbers they saw and did $4+4+2=10$.

The third problem produced a clear and significant difference. Half of the Constructivist group gave the correct answer, but none of the traditionally instructed group answered the question correctly. The fourth problem, too, produced a clear and significant difference between the two groups.

We can conclude from the preceding data that half a year of physical-knowledge activities served to strengthen the logico-mathematical foundation of children who came to first grade without any logico-mathematical concept of number. The thinking they did during the physical-knowledge activities enabled these children to think not only numerically but also logically as evidenced by their ability to solve word problems.

Before concluding this chapter, it may be desirable to address a question the reader may have: What is the relationship between logico-mathematical knowledge and the science process skills discussed in Chap. 7 of this volume? As stated earlier, I do not think that "science" exists as a differentiated subject during the preoperational years. Furthermore, I do not think that preoperational thinking is logical enough to formulate hypotheses, plan experiments, interpret data, and evaluate evidence. In fact, Chap. 7 does not mention the role of logic in these "science process skills."

The thinking preoperational children do in physical-knowledge activities heavily contributes to their development of logico-mathematical knowledge. Higher-level logico-mathematical knowledge does enable children to formulate more logically conceptualized hypotheses and experiments during the concrete-operational and formal-operational periods. During the preoperational period, however, their thinking seems too pre-logical to "do science."

In conclusion, young children really like to think if they are allowed to do their own thinking. If an activity is too easy, they become bored with it, and if it is too hard, they also avoid it. Early childhood educators will do well to plan classroom activities in which children think hard while they play.

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# Chapter 10
# Science and Literacy: Considering the Role of Texts in Early Childhood Science Education

**Laura B. Smolkin and Carol A. Donovan**

From the realistic, prehistoric visual representations of animals found on cave walls to the clay-pressed cuneiform, astronomical recordings of Mesopotamia to the medical treatments suggested in papyrus hieroglyphics and birch-bark Sanskrit to Philo's ancient Greek descriptions of escarpment mechanisms to Leonardo da Vinci's remarkable notes and drawings to Galileo and Isaac Newton's detailed, scientific notebooks to today's very common practice of accessing articles on the Internet to learn more about a particular science matter – science and literacy have been connected since humankind began representing its knowledge in a recorded form.

However, within the world of K-12 education, this linkage has been more tenuous. Despite the fact that our goal for the majority of Americans is that they be scientifically *literate* adults (e.g., National Research Council [NRC], 2011), there have been concerns about an over-emphasis on reading during science instruction since the late 1800s, when science committee members of the National Education Association (NEA) began advocating a greater role for directly observing the world. "The study of books is well enough and undoubtedly important," explained members of NEA's Committee of Ten, "but the study of things and of phenomena by direct contact must not be neglected" (National Education Association, 1893, p. 119).

There should no longer be any doubt that inquiry, as part of reform-based science education, is essential to America's children's understanding of the enterprise of science and to the development of their own investigative skills (e.g., Duschl, Schweingruber, & Shouse, 2007; NRC, 2011; although we do note here struggles in

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California in which legislation attempted to limit the amount of hand-on instruction, see Cervetti & Barber, 2009). But what should be the place of literate-activity within that endeavor? And is there a place for science literacy elsewhere in the early childhood day?

In science education, as Pearson, Moje, and Greenleaf (2010) explain, there developed a tension between those who wish children to experience science and classrooms where textbook study of science continued to dominate (see Banilower et al., 2013 for the most recent percentages). This tension resulted in a period during which "text … suffered neglect on the part of the science education community" (Magnusson & Palincsar, 2001, p. 152); some science educators went so far as to insist that strong science questions could only arise through hands-on experiences (e.g., Rutherford, 1991).

Within early childhood education, this situation has been even more complex. Certain beliefs about developmentally appropriate practice and children as constructors of their own knowledge led numerous preschool teachers to eschew not only reading and writing but also direct instruction of any type for their young charges (Bowman, Donovan, & Burns, 2000; Dickinson, 2002).

Happily, we find ourselves in a new period. Early childhood policies have changed, and literacy and highly scaffolded instruction are both now welcome (Copple & Bredekamp, 2009). Not only have researchers substantiated the strong role reading plays in the work of scientists (e.g., Phillips & Norris, 2009), but major conceptual documents impacting both language arts instruction (Common Core State Standards for English Language Arts [CCSS], 2012) and science education (NRC, 2011) suggest that science texts will be an important part of all elementary school children's education.

Our goal in writing this chapter is to examine the existing texts of early childhood science and the ways those texts are being used in classrooms as documented by research. We begin with a look at the nature of science texts and the special challenges they create for readers. We then review the research on texts of early childhood science, organizing those sections by the purposes for which the texts are created and used – commercial textbooks, children's literature trade books, and finally researcher-created texts employed in promising Text Integrated Inquiry Science (TIIS) programs. We conclude with some final thoughts about the ways in which researchers approach their studies and about future work in this important area.

## The Challenges of Science Texts

Simply stated, reading science texts is not easy (Graesser, Leong, & Otero, 2002). To begin, many of the ideas addressed are quite challenging, often describing phenomena readers have never seen or experienced; these ideas are typically presented in lexically dense text (Halliday & Martin, 1993), where sentences are packed with considerable content information presented in frequently challenging, technical, discipline specific terminology. Much of this terminology relies upon interlocking terms, whose definitions depend upon one another (consider *radius, circumference, diameter*). Exposed to this challenging new technical vocabulary, children learn the nouns of science more quickly than they do the adjectives and adverbs, but this learning process does not necessarily proceed quickly or smoothly; multiple exposures in multiple contexts are necessary (e.g., Dockrell, Braisby, & Best, 2007).

Not only are these lexical items challenging, but readers of science texts will also encounter morpho-syntactic structures seldom found in oral discourse (Ravid, 2004). Including the conjunctions, prepositions, and verbs that capture logical-semantic relationships (*yet*, *in the event of*, *co-occur with*), these morpho-syntactic structures prove challenging for children at the eighth grade level and even through college (Fang, 2006; Goldman & Murray, 1992; Olshtain & Cohen, 2005).

Compounding the complexity, textual communications in science are typically multimodal. Complicated verbal texts are accompanied by a range of images often essential to the text's meaning (e.g., Fang, 2005; Kress & van Leeuwen, 1996; Lemke, 1998) because scientists communicate with one another through multiple channels, as they

> integrate verbal text with mathematical expressions, quantitative graphs, information tables, abstract diagrams, maps, drawings, photographs and a host of unique specialised visual genres seen nowhere else. (Lemke, 1998, p. 88)

Such graphical representations place additional demands on both learners, who must interpret both text and visual representation, then integrate that information (e.g., Hannus & Hyönä, 1999; McTigue & Flowers, 2011; Smolkin & Donovan, 2005; Walpole, 1998; Walpole & Smolkin, 2004), and their teachers as well, whose chief strategy for increasing children's graphical literacy is pointing at graphics (Coleman, McTigue, & Smolkin, 2011; Smolkin & Donovan, 2004a).

With this sketch of the challenges of science text in mind, we now consider the two most common sources of science texts found in early childhood classrooms – commercially produced materials (intended for sale to schools) and those created by the trade (for sale to libraries and the general public). For each, we review related studies on challenges and uses.

## Commercially Produced Texts and Trade Books

Banilower et al. (2013) recently released their 2012 National Survey of Science and Mathematics Education, which indicates that commercially produced materials (here we include both science textbooks and science modules/kits) guide science instruction in 69 % of United States elementary science instruction; the remaining 31 % of teachers reported relying upon non-commercially available materials, most likely science-oriented trade books. This survey suggests the importance of trade books and textbooks, as well as any text materials accompanying purchased modules, in early elementary science instruction.

## *Science Textbooks*

The textbooks of science have been roundly criticized. Studies report that they fail to address students' commonly held misconceptions (e.g., Kesidou & Roseman, 2002), fail to include accurate information (e.g., Hubitz, 2001), rely too heavily on lower level questions to support students' learning (e.g., Shepardson & Pizzini, 1991), and are frequently written in ways that impact their comprehensibility (e.g., Best, Rowe, Ozuru, & McNamara, 2005). As well, science educators note that textbooks fail to represent the *enterprise* of science, becoming little more than compendia of facts and generalizations of scientific findings (e.g., Phillips & Norris, 2009; Yager, 2004).

**Changes to Textbooks: The Dominance of Images** Like so many other aspects of our lives, textbooks have been influenced by our new digital age: changes in publishing have impacted the types, frequencies, and layout of visual representations in science texts. Moss (2003) provided an insightful discussion of the non-linear layout and impact of the Dorling Kindersley double-page spread, in which pictures abound. Rather than a major "running text" serving as the major source of information, in these science texts, visual representations and their related paragraphs operate as "self-sufficient units… [which] can effectively be read in any order" (p. 82), with little emphasis on constructing a cohesive understanding. In the mid-1990s, textbook publishers followed suit, changing from the linearity of text-heavy textbooks to textbooks as multimodally-designed objects (Walpole, 1998).

There are relatively few studies that examine the visual environment of these graphics-heavy textbooks intended for early childhood classrooms. Walpole (1998), examining these new textbooks, found that layouts of double-page spreads varied considerably throughout a single textbook. These new textbooks contained less text and, importantly for comprehension, fewer cohesive ties; captions, following the Dorling Kindersley model, altered from brief descriptions of visual representations to substantial paragraphs, serving as major sources of information, information no longer contained in the textbook's running text. As to visual representations, Fingeret (2012) examined 8 second and third-grade social studies and science textbooks. She found photographs dominating the visual representations (66.9 %), with diagrams (important in science representations) accounting for only 6.7 %.

**Changes Lead to Reader Challenges** The lack of linearity of these textbooks confused Walpole's (1998) child informants. Unsure where to begin reading on a page, they started with many different paragraphs, and not a single child examined all the text and visuals on the studied page.

Beyond the confusions related to layout, the visual representations themselves challenge children. McTigue and Flowers (2011) presented their participants (including some second graders) water cycle diagrams taken from science textbooks. Children expressed that the diagrams served to "help the reader know what the text is talking about" (p. 584); in other words, students did not recognize that the visual representations might be presenting information absent in the running text.

Children also reported that they only sometimes or rarely looked at diagrams in their books, a finding confirmed recently (Roberts et al., 2013) in results that suggest that perhaps only one-third of preschool through third-grade students are aware that visual representations may provide new and important information. McTigue and Flowers also noted that children often "lacked the vocabulary to name labels, text boxes, arrows, captions, and the like" (p. 584), though they found such features helpful; additionally they noted children's tendency to misinterpret diagrams superimposed over pictures.

McTigue and Slough (2010) suggested that student accessibility be more strongly considered for science textbooks. Important changes would include increased concreteness (examples and analogies supporting important information); increased presence of signal words, particularly connectives (words such as *because* and *as a result*); and changes to captions to increase readers' engagement with and integration of visual information. Regarding visual aspects of science textbooks, McTigue and Slough further suggested that these be selected for increasing comprehension of major content, not as inviting decoration. As well, the authors suggested that the heavy presence of photographs in science textbooks (see Fingeret, 2012), along with the challenges that photographs present (e.g., Donovan & Smolkin, 2002; Pozzer-Ardenghi & Roth, 2005), do not support student success with the tables, diagrams, flowcharts, and graphs, typically found on state science tests (e.g., Yeh & McTigue, 2009).

**Changes to Commercially Produced Materials: Texts Designed to Work with Inquiry** Textbooks are not the only commercially prepared text materials: science kits/modules are increasingly accompanied by texts; Martin (2011) particularly notes texts related to the AIMS, GEMS, and FOSS programs. Among these literacy-enhanced kits, the text materials created by Seeds of Science/Roots of Reading (SSRR, e.g., Cervetti & Barber, 2009; Cervetti, Barber, Dorph, Pearson, & Goldschmidt, 2012; Cervetti, Jaynes, & Hiebert, 2009; Pearson et al., 2010), designed to enhance existing GEMS science modules, have been singularly well researched. Regarding SSRR, Pearson et al. (2010) explained that this research effort has been "based on the fundamental principle that literacy is best enacted as a set of learning tools that support knowledge acquisition rather than as a set of independent curriculum goals" (p. 461), which may be seen as a literacy-in-service-of-science stance. SSRR texts range in function from modeling scientists' observations to analyzing evidence to proposing explanations to presenting examples of science writing (Cervetti & Barber, 2009). Intended for use from 2nd grade up, SSRR materials are presently unavailable for younger early childhood students.

**Changes to Commercially Produced Materials: Leveled Science Readers** Likely related to increased calls for informational texts (e.g., Duke, 2000; and see our upcoming section on science trade books in early childhood classrooms), various companies (e.g., Delta, Dominie, Dorling Kindersley, National Geographic, Pearson) began producing short, carefully leveled science texts. With the CCSS (2012) emphasis on informational texts, these "little" science books will likely be used with increasing frequency during children's literacy instruction as well as during science instruction. Not much research exists on these texts; however, they have been included in various TIIS programs. In her review of such little books, Fingeret (2012) noted that over 80 % of the visual representations in these texts are photographs, with diagrams occurring even less frequently than in textbooks or trade books.

## *Trade Books*

Trade books have long been recommended for inclusion in science instruction (e.g., Billig, 1930). In this section, we review research on the nature of the books themselves, the issue of genre (particularly in light of CCSS, 2012), and the manner and impact of employing these texts.

**Linguistic Properties of Trade Books Used in Science Instruction** Pappas (1986, 1993, 2006) has been singularly important in explaining how science trade books are constructed. Relying heavily upon principles of Systemic Functional Linguistics, Pappas, in speaking of the books' organization, or macrostructure, described a set of obligatory and optional elements that combine to create the structures of typical science information trade books. Pappas has consistently identified four obligatory structural elements, which must be present for a book to be considered a part of the genre: Topic Presentation, Description of Attributes, Characteristic Events, and Final Summary. (Her latest analysis, 2006, described eight optional elements, which may or may not be present in informational science trade books – Prelude, Category Comparison, Historical Vignette, Experimental Idea, Afterward, Addendum, Recapitulation (often a review of vocabulary), and Illustration Extensions (labels or captions addressing visual aspects of the book). These optional elements reflect the unique aspects of an author's presentation of the science content.

In addition to macrostructural elements, Pappas (1986, 1993, 2006) called the field's attention to particular micro-structural lexical aspects of science information books, such as the typical use of the timeless present (present tense reflecting the ongoing nature of science phenomena), generic nouns (referring to classes, not particular members of a class), relational verbs (linking attributes to objects), material verbs (representing typical actions), and technical terms (noted previously as a challenge of all science texts). Many authors (e.g., Donovan & Smolkin, 2001, 2002; Duke, Caughlan, Juzwik, & Martin, 2012) now rely upon Pappas in describing information trade book features.

**Visual Aspects of Science Trade Books** Like science textbooks, early childhood science trade books emphasize visual aspects (Smolkin & Donovan, 2004a, b, 2005). A chief difference lies in the conception of the visual aspects; rather than a committee approach to determining which types of visual representations will be present, the visual aspects of early childhood science trade book are often determined by the single illustrator of that book (Smolkin & Donovan, 2005).

Fingeret (2012), in her content analysis of 126 informational trade books (88 on science topics), devised a typology of eight major categories of graphical representations: photographs, images (chiefly realistic and cartoon drawings), diagrams, flow diagrams, graphs, tables, maps, and timelines (but, also see Roberts et al., 2013). Within the trade books Fingeret examined, the most frequently occurring types were images (50 %) and unenhanced photographs (36.2 %), accounting for 86.2 % of all visual representations. At a rather distant third were diagrams (simple, scale, and cross-sectional, 8.8 %). Pertinent to earlier discussion, Fingeret categorized 63.2 % of trade book visual representations as extensional, meaning that these representations in trade books supplied information not provided in the verbal text. This is important for educators who support early childhood teachers to know, as research (Smolkin & Donovan, 2004a) shows teachers generally do not explicate visual representations for their students.

**Genre and Trade Books Used in Science Instruction** Genre is "the way in which texts are structured to serve different purposes in specific contexts for specific social purposes" (Donovan & Smolkin, 2001, p. 419). We (Donovan & Smolkin, 2001, 2002) examined the texts found in collections of recommended books for science instruction (e.g., Barber et al., 1993) and created a typology to represent the various genres. We distinguished first between those trade books with the chief purpose of providing information on scientific matters (information books) and those texts with the chief purpose of providing entertainment – stories. Within the information book category, we noted two typical realizations – the narrative information book, which presents "a sequence of factual events or occurrences over time" (Donovan & Smolkin, 2001, p. 419; often life science in content, such as the development of plants or animals, but occasionally earth science as well) and the non-narrative information book, in which the passage of time may play some role, but where the hierarchical structure of topics and subtopics is dominant. Among the science story trade books, we noted two dominant types – the informational story and the dual-purpose text. Informational stories are narratives in which fictional characters encounter and potentially learn about science phenomenon; dual-purpose texts represent a hybrid form in which a fictional story provides the running narrative while sidebars and other visual elements provide the scientific content. (The best-known dual-purpose texts are Cole and Degen's original *Magic School Bus* books). Stories, as described by Stein and Glenn (1979), involve a character with a goal that is achieved through a series of episodes. Many stories do contain factual aspects – one can certainly learn a lot about Dublin by reading James Joyce's (1934) *Ulysses*, but the thoughts of main character Leopold Bloom and his actions are entirely imagined by the author. Other researchers employ different terms for these science trade book genres (e.g., Duke & Bennett-Armistead, 2003; Kletzien & Dreher, 2004; Pappas, 2006), but no matter the term, the genre matters, as upcoming sections show. These impacts have led certain researchers (e.g., Pappas, 2006) to recommend that only information books be used during science instruction, not storybooks.

*Impact of Genre on Adult Talk During Read Alouds* Of particular interest to those concerned with modeling high quality language for early childhood students are studies examining the impact of genre on teachers' talk. Since the early 1990's (e.g., Smolkin, Yaden, Brown, & Hofius, 1992), researchers have been documenting the differential impacts of genre (stories and informational texts) on adults' interactions with children during read alouds. We have known since that early time that read alouds of stories and information books differ: the read alouds of information books consume more time and are more interactive as both children and adults are not plot-driven, but participate actively in a learning process (e.g., Smolkin & Donovan, 2001; Smolkin et al., 1992).

Within the last decade, researchers have focused more intensively on the cognitive demands involved in adults' scaffolding of science trade books for children. Moschovaki and Meadows (2005) had 20 kindergarten teachers read the same four books – two stories, one non-narrative informational science book, and one narrative informational science book. Using a modification of the coding system created by Blank, Rose, and Berlin (1978), they coded utterances to determine whether the teacher-child extra-textual discourse could be considered high cognitive demand (predictions, analysis, reasoning), medium cognitive demand (vocabulary development, personal connections, evaluations) or low cognitive demand (labeling, recall, personal reaction). Teachers' high cognitive demand utterances elicited high cognitive demand utterances from their kindergarten students. Genre impacted the frequency of high cognitive demand discourse: 19 of the 20 teachers led more high cognitive demand discussions with the informational texts; 18 of the teachers led more low cognitive demand discussions with the story texts.

Price, Kleeck, and Huberty (2009), who had 62 parent-preschooler dyads read aloud one story and one information book, had similar findings. Like Moschovaki and Meadows (2005), Price et al. employed the Blank et al. (1978) coding system to examine the parents' extratextual utterances. Like Moschovaki and Meadows, Price et al. found that both parents and preschoolers produced higher cognitive demand utterances when reading science information books than when reading stories.

Two additional studies examined the nature of adult talk during the read aloud of science information trade books, again making use of the Blank et al. (1978) coding scheme cognitive demand. We (Smolkin, McTigue, & Donovan, 2008) examined 12 first, second, and third grade teacher's talk during read alouds of Gail Gibbons (1995) *Planet Earth/Inside Out*. Concerned about low levels of elementary teachers' explanatory talk during science instruction (e.g., Newton & Newton, 2000; Roth et al., 2006), we were particularly focused on Blank et al.'s Level 4 discourse (highest cognitive demand) because that level addresses reasoning related to cause, condition, and effect, noted by Zimmerman (2000) as essential to children's science understandings. In contrast to the 8 % explanatory teacher talk recorded during Newton and Newton's observations of classroom science teaching, we found 25.3 % of first grade teachers' and 19 % of second grade teachers' extratextual talk to be explanatory in nature.

More recently, Zucker, Justice, Piasta, and Kaderavek (2010) examined the high cognitive demand talk of 25 preschool teachers as they read aloud the dual-purpose science trade book, *The Noisy Airplane Ride* (Downs, 2003). They, too, reported very high percentages (45 %) of inferential (high cognitive demand) teacher questions during this book reading as contrasted with the 30 % inferential questions typically seen during a story read aloud. Moreover, they, like Moschovaki and Meadows (2005), found significant correlations between teachers' elevated high demand talk and the preschoolers' high demand talk. Explained the authors, "these findings imply that inferential questioning effectively pushes preschool children to use language output for the cognitively challenging tasks of inferencing and analysis" (p. 79), again, both key reasoning skills in inquiry science.

High cognitive demand discussions with adults have been correlated with children's own high cognitive demand utterances 1 year later (van Kleeck, Gillam, Hamilton, & McGrath, 1997). As well, interactive read alouds in preschool predict fourth grade vocabulary knowledge (Dickinson & Porche, 2011). It would seem, then, that interactive science information book read alouds, through the high cognitive demand discussions they foster, may ultimately support some of the very reasoning skills essential to the meaningful conduct of science inquiry.

*Impact of Informational Stories on Student Understanding of Science Content* Two researchers, each working with early childhood students, examined children's learning from Simon's (1991) *Dear Mr. Blueberry*, an informational story that might be classified as a refutational text (e.g., Guzzetti, Snyder, & Glass, 1992; Sinatra & Broughton, 2011), in that the teacher character, Mr. Blueberry, seeks to correct a young girl's misconceptions about whales. Jetton (1994) worked with two groups of second graders; one group was instructed to listen for information about whales, the other that they would be listening to a story about a little girl. In post-reading recall, no matter the condition, children recalled more information about the story than they did about whales. This same book was used in Mayer's (1995) small-scale study with kindergarten through third grade students, two boys and two girls from each grade level. Of the 16 total children, 9 reported learning nothing new from the story, while 5 others reported new learning that was, in fact, misconception based upon the young girl's statements. Mayer concluded, "The results of this study indicate that some fiction may impede content acquisition" (p. 19).

Brabham, Boyd, and Edgington (2000) had preservice teachers read two informational stories two times each to second, third, and fourth graders. Their results show second graders to be less capable of distinguishing fact and fiction and less capable of comprehending these works than third or fourth graders. However, the differences in vocabulary learned by students at each grade level were not significant; from the two readings of each text, children made significant vocabulary gains of four to five words. These studies, along with recent upper elementary grade findings (Cervetti, Bravo, Hiebert, Pearson, & Jaynes, 2009), suggest potential confusions (with resulting misconceptions) may arise when informational stories are used in science instruction, reinforcing Pappas's (2006) suggestion that information books, and not informational stories, be featured in early childhood science read alouds.

Additional support for Brabham et al.'s (2000) findings on vocabulary growth from science trade book read alouds is seen in Gonzalez et al.'s (2011) study. Seeking to address the vocabulary gap that exists for low-income preschoolers (e.g., Hart & Risley, 1995), these researchers supplied intensive vocabulary instruction before, during, and after read alouds of related information and story trade books on science topics. Children experienced significant growth on both standard and researcher-created receptive measures of content-area vocabulary. Similar to the Marulis and Neuman (2010) meta-analysis, children with higher pretest scores in the Gonzalez study benefitted more from the intervention than those with lower pretest scores.

Brabham et al. (2000) and Gonzalez et al. (2011) both point to growth in vocabulary and science knowledge when trade books are read interactively with children, and when children have the opportunity to encounter science vocabulary/concepts on multiple occasions.

**Science Trade Books in Early Childhood Classrooms: A Notable and Important Absence** Beginning with Pappas (1991, 1993), literacy researchers became increasingly conscious that early childhood education was dominated by stories. Duke (2000), in her study of 20 first grade classrooms, confirmed this imbalance – an overly heavy presence of stories, a virtual absence of informational text (only some of which would be science-focused). Whereas Duke focused only on first grade, Yopp and Yopp (2006) surveyed early childhood teachers from preschool through third grade regarding books they were reading aloud; they again confirmed the minimal attention to informational texts. Narrative (story) texts dominated – percentages ranged from a low of 68 % (preschool) to a high of 89 % (third grade) – while informational text read alouds never rose above 9 % of the total read alouds, being least well-represented in preschool and third grade classroom read alouds (5 %). Of note, though the information books read aloud were minimal, 85 % of information books read aloud by teachers were science trade books (Yopp & Yopp, 2012). Pentimonti, Zucker, and Justice's (2011) preschool-classrooms-only study recorded percentages quite similar to those reported by Yopp and Yopp (2006): story texts were utilized in 85.8 % of teacher read alouds, whereas informational texts were found in only 5.4 %.

Researchers (e.g., Donovan & Smolkin, 2001) have noted that teachers frequently express that children will find greater enjoyment from stories or dual-purpose texts. This particular teacher belief, however, is not supported by research that investigates children's preferences (Brabham et al., 2000; Caswell & Duke, 1998; Mohr, 2006; Pappas, 1991); informational text can actually be quite motivating for students (Alexander, 1997).

In fact, when information books are present in early childhood classrooms, children select these texts virtually in proportion to their presence. Studying student selections in an information book-enriched, first grade classroom (34.2 % information books, 61 % story books), we (Donovan, Smolkin, & Lomax, 2000) found both girls (32.6 % information book choices) and boys (40 % information book choices) to frequently choose such book for their independent reading period. The absence of information trade books in early childhood denies children the opportunity to pursue science interests.

**Limitations to the Use of Science Trade Books** Science trade books, then, offer many benefits when used in early childhood classrooms. They increase high demand language for both teachers and children; they offer opportunities for science vocabulary and conceptual growth; they acquaint children with the language and structures of science texts. There are, however, certain cautions regarding their use. First, the disciplines of science are not equally represented in science trade books; the vast majority of published science trade books address the life sciences. Ford (2004), culling a corpus of texts from three sources producing highly recommended science trade book lists, found that fully 64 % of these books addressed life sciences; other content areas lagged far behind (earth sciences, 8 %; physical sciences, 7 %; space sciences, 8 %). Commented Ford, "there is a serious lack of quality physical science trade books" (p. 285), a problem we confronted when we sought to examine science trade books for their explanatory aspects (Smolkin, McTigue, Donovan, & Coleman, 2009).

These percentages matter. In Yopp and Yopp's (2012) study, 75 % of the science trade books preschool through third grade teachers read aloud were life science; 16 % of were earth and space science topics; 9 % addressed engineering and technology; and 0 % of the study teachers read aloud a science trade book on a physical science topic (perhaps also a reflection of elementary teachers' meager sense of being well prepared to teach this particular science disciplines, see Banilower et al., 2013). Saçkes (2012) also noted the impact of material availability on kindergarten teachers' presentations of various science disciplines. Again, presence matters; we (Donovan & Smolkin, 2006) have documented the negative impacts of minimal-to-non-existent physical science trade book read alouds on young children's physical science knowledge.

A second, major limitation to the use of science trade books is the inaccuracies found in some of these texts, directly impacting their quality and appropriateness for use (see Saul & Dieckman, 2005 for a discussion on quality). Researchers from various disciplines have reported science trade books inaccuracies in both verbal text and visual representations (e.g., Donovan & Smolkin, 2001; Owens, 2003; Rice, 2002; Schussler, 2008; Trundle, Troland, & Pritchard, 2008).

A third major limitation to using science trade books in science instruction is their place in the inquiry process of science instruction (see Ford, 2004, 2006). As Ford established, most science trade books do not address science as inquiry (but, see Saçkes, Trundle, & Flevares, 2009 for thoughts on this matter).

## Inquiry Science and Text Integrations

In this section, we examine programs of research that have featured both inquiry science and literacy as major constructs of science instruction for early childhood students, with particular attention to texts used and created by children in those programs. Although multiples definitions for integration abound, in this review, we include both those programs where the emphasis has been on literacy in the service of science and those in which the emphasis on science and literacy "is balanced" (Cervetti et al., 2012, p. 634). We have organized these studies chronologically so readers can see changes over time in interpretations of Text Integrated Inquiry Science (TIIS), as well as the impact of one program on another. Of note, we do not address the highly regarded, highly effective TIIS program, Concept Oriented Reading Instruction (CORI, e.g., Guthrie et al., 1998), as no subjects in these studies were early childhood students.

## *Science IDEAS (In-Depth Expanded Applications of Science): Textbooks, Trade Books, Leveled Books*

The Science IDEAS model, created by Romance and Vitale (1992; 2001), represents one of the earliest TIIS efforts. This researched model converted traditional 2-hour literacy instruction blocks to 2-hour science blocks in which literacy skills supported science instruction that included inquiry, journal writing, science content reading (textbook and trade books), concept mapping, and discussions. Results contrasting the treatment students with a demographically similar control group indicated that not only had the treatment students significantly improved in their reading and science achievement, but they had also developed more positive attitudes towards and greater self confidence in science. Reading activities followed hands-on activities, thus developing firsthand background knowledge prior to reading. Romance and Vitale (2001) described the expansion of Science IDEAS from third through fifth grades with similar positive results.

Recently, Vitale and Romance (2011) adapted Science IDEAS for early childhood students in first and second grades. In this work, they did not replace the traditional literacy block, but instead included an additional 45 min block that featured reading age-appropriate science materials (likely leveled books; no additional information is supplied), combined with inquiry activities, concept mapping, and writing (journaling for first grade; writing to inform others for second). Although it is possible that increased time for both reading and science instruction accounted for gains over their demographically similar control group peers, the researchers nonetheless report significant differences between the two groups.

## *GIsML (Guided Inquiry Supporting Multiple Literacies): The Notebook Text*

GIsML (Magnusson & Palincsar, 2001; 2004), like Science IDEAS, is a much-cited TIIS program (e.g., Pearson et al., 2010). In this research, Magnusson and Palincsar identified an important distinction between firsthand (hands-on inquiry, guided by specific questions) and secondhand (text-based) inquiry. With strong professional development, teachers and children employed a unique science text, the science notebooks of fictional researcher Lesley Park, in conjunction with their own experimentations. Lesley's notebook is essentially her thinking aloud, documenting

> the purpose of her investigation, the question(s) guiding her inquiry, the investigation procedures in which she is engaged, the ways in which she is gathering and choosing to represent her data, the claims emerging from her work, the relations among these claims and her evidence, the conclusions she is deriving, and the new questions that are emerging from her inquiry. (Magnusson & Palincsar, 2001, p. 174).

These notebooks, in conjunction with their visual representations of Lesley's diagrams, figures, and tables, demonstrate the habits of scientists: Lesley cites her reading, describes her interaction with colleagues, and presents the continual revision of her thinking. Researcher-created assessments with fourth graders demonstrated the superiority of the GIsML notebooks to reading a well-crafted science text.

In Magnusson and Palincsar (2004), GIsML extended into early childhood science learning; the authors created a case study of a second grade class. The notebooks were adapted into "big book" formats (for use with kindergarten through second grade students), and additional pictures were added, supplying the context that led to Lesley's investigations. Teachers were expected to share Lesley's notebooks in an interactive manner, encouraging children to critique the fictional scientist's thinking. Pre- to post-assessment of children's knowledge of motion on what was likely a researcher-created measure demonstrated statistically significant growth. The case study teacher was documented guiding her children through the interpretation of tables, creating their own visual representations of the scientific phenomena, considering how to conduct a fair trial, accounting for variability in results, conducting their own experiments, and creating their own scientists' notebooks. Hapgood and colleagues highlighted the importance of teacher knowledge in supporting children's meaning-making efforts. As well, they stressed aspects of their scientist's notebook that supported children's thinking: multiple representations of data, Lesley and her colleagues' thinking processes, establishing the sources for scientist's questions, and finally, the engaging, narrative qualities of Lesley's strongly-voiced thinking. Hapgood et al. concluded that appropriately designed texts, fostering secondhand science inquiry as well as firsthand inquiry, can advance "young children's conceptual understanding and scientific reasoning" (pp. 496–497).

### *Science Start! Science Related Trade Books/Child-Produced Reports*

The Science Start! curriculum (Conezio & French, 2002; French, 2004) involves inquiry activities, read alouds of science related trade books, and children producing their own written products. In this research, children consulted texts; they jointly produced multimodal science reports (an important genre in school science, see Veel, 1997); and individual students kept science journals. As well, children created graphical representations, including charts and graphs. The inquiry process was highlighted through the four components of each science activity: "'Reflect and Ask,' 'Plan and Predict,' 'Act and Observe,' and finally, 'Report and Reflect'" (French, 2004, p. 142). Program creators stressed the coherence of their approach, which enabled children to revisit and revise science knowledge on related topics over a period of weeks to months. Unfortunately, data on the effectiveness of the program are presently limited to an increase in vocabulary scores.

## *ISLE (Integrated Science-Literacy Enactments): Science Information Books/Child Produced Information Books*

In a highly theoretically framed, TIIS program, Varelas and Pappas (2006, 2013) stressed that learning science is a multimodal effort, in which scientists enact, read, discuss, create visual representations, and write. Describing their TIIS units for first, second, and third grade children, Varelas and Pappas (2013) noted that instruction featured dialogic (interactive) read alouds of science information trade books, designed to inform and extend "hands-on explorations" and introduce children to "typical science communication" (p. 6); inquiry, which included observations and experiments; journaling through science notebooks, where children could multimodally record science ideas encountered throughout the program; teacher-child created visual displays recording ideas explored in the units; murals presenting science ideas and relationships; and children's own information book creation. This research resulted in numerous published studies.

Varelas and Pappas (2006) noted that the interactive science trade book read alouds incorporate many elements of inquiry teaching, providing opportunities to engage, explore, explain, extend, and evaluate ideas as scientific concepts are presented by the text; these semiotic tools support both language growth and scientific thinking. This research highlighted the frequency of "event-links" during science trade book read alouds – children's frequent contributions of relevant personal experiences in making sense of science concepts. Although second in frequency to event-links, children also brought forward ideas from their inquiry activity; these increased when inquiry preceded the read aloud, although teachers more commonly initiated these discussions than did children. As the units progressed, event-links became less frequent and inquiry links increased.

Instead of standard or researcher-created assessments, the researchers relied upon child-created information books and an interview process to determine what children had learned. Pappas, Varelas, Gill, Ortiz, and Keblawe-Shamah (2009) presented six child-created information books, which demonstrated how ISLE students adopted the language of science information books (timeless present, generic nouns, technical terms, and relational and material processes) in their own books. As well, children included minor text (captions) and visual representations, such as labeled diagrams and magnified insets, similar to those displayed in the information books read aloud to them. Such features had not been specifically taught; children included them after frequent exposure to science trade books within the context of the entire ISLE curriculum. (But, see Bradley & Donovan, 2010 for an example of directly instructing children in generic features.) Information included in children's science information books, written on self-selected science topics, was chiefly scientifically accurate. Varelas, Pappas, Kokkino, and Ortiz (2008) described individual conferences with children about their information books; a scoring system of inaccurate, emerging, and correct was applied to information represented in both text and pictures.

## *SLP (Science Literacy Project): Science Information Trade Books/Children's Science Notebooks*

The Science Literacy Project (SLP), created by Samarapungavan, Mantzicopoulos, and Patrick (2008; Mantzicopoulos, Samarapungavan, & Patrick, 2009), was designed to enhance kindergarten children's understanding of inquiry, as displayed through their participation in inquiry activities that highlighted explaining and revising "their models of the world" (Mantzicopoulos et al., p. 325). The researchers described three key instructional aspects of the Science Literacy Project: increasing conceptual coherence in the science program (see French, 2004, above), improving inquiry activities, and integrating literacy components within inquiry. Like researchers in ISLE, Mantzicopoulos et al. viewed young children as emerging into science understanding, seen as socially constructed. Science content focused chiefly upon life sciences, but a unit on force and motion (see Hapgood, Magnusson, & Sullivan Palincsar, 2004 above) is also included. Beginning with a unit highlighting inquiry science, the five featured units stressed literate activity through science nonfiction trade books (presented through interactive read alouds), leveled nonfiction books (see Vitale & Romance, 2011, above), researcher-created nonfiction books, and children's science notebooks, which included, among other aspects, investigation-related structured activity sheets and children's observations complete with digital photographs. SLP participants were assessed fall, mid-year, and spring through researcher-created puppet interviews, which explored science competence and enjoyment; children in the science-as-usual control group were assessed in spring only. Spring assessments also included the researcher-created "What I Learn in Kindergarten" (p. 346). Regarding the first assessment, whereas only 19.5 % of treatment children discussed science content or processes in the fall, by spring 88.6 % of the children did so. Importantly, in their puppet narratives, children referred not only to their inquiry activities but also to reading books and recording in their science notebooks as well. In contrast, in the control classrooms, 82.9 % of children indicated that they did not have science at their school. Regarding science knowledge growth, Samarapungavan, Patrick, and Mantzicopoulos (2011) reported statistically significant gains for SLP students on standardized measures as well.

## *Seeds of Science/Roots of Reading (SSRR): Researched, Inquiry-Supportive Texts/Writing in Multiple Science Genres*

Earlier we described research on the unique science texts created to enhance the GEMS curricula. In addition to science inquiry supported through unique texts, SSRR also stressed that children must learn to write science, with its unique structuring of information and text features, in its multiple recognized genres. Published research (e.g., Cervetti et al., 2012) focused on the impact of this TIIS program on fourth grade students. However, an unpublished manuscript (Barber, Catz, & Arya, 2006) related findings on program effectiveness with second- and third-graders. Barber et al. examined the impact of three units on children's science content knowledge. In the most developed study, the researchers employed three treatment groups – one TIIS, one inquiry only, and one SSRR texts only – in addition to a science-as-usual control. Science knowledge assessments were researcher-created multiple choice and short answer questions, set within a narrative framework, seen as providing a "real world and coherent context" (p. 16). Children participating in the TIIS treatment outperformed those in the inquiry science only treatment. A related evaluation study for this cohort (Wang, 2005), again using researcher-created assessments, found significant differences on all science and literacy measures between the TIIS treatment students and students in the control, science-as-usual classrooms.

## *CALI (Content Area Literacy Instruction): Child by Instruction Interactions*

The final study (Connor et al., 2012; Connor & Morrison, 2013) we review in this section reported the results of a very elegantly designed, child x instruction exploration of science instruction, which followed second graders into third grade. Increasing numbers of studies, noted the researchers, have demonstrated that reading instruction success depends not only on the instruction itself (including activity type and whether the child works with peers or teacher) but also on individual child characteristics, which, for reading, include existing language and literacy skills. For science instruction, the researchers hypothesized that existing content knowledge, vocabulary, and reading comprehension abilities might interact with time, various types of science activities, and levels of teacher support in determining student outcomes.

Their methods and findings are important for the field of TIIS research. All science and literacy measures were standardized. Regarding the impact of inquiry of students' science success, Connor and colleagues found these hands-on activities in which children worked together to have a generally positive impact on outcome measures; this, however, was not the case for children who entered the year with weaker content knowledge. To the degree that these children were engaged in teacher guided (as opposed to teacher lecture or self-discovery) activities, they "made important gains in content knowledge, vocabulary, and reading" (Connor & Morrison, 2012, p. 229). In short, one size science instruction may not serve all equally well; individual background knowledge and skills must be addressed.

Subsequent to their observational study, Connor and colleagues (Connor et al., 2010; Connor & Morrison, 2013) created CALI, based upon Bybee's 5-E learning cycle, utilizing SSRR materials (adapted for readability), employing a scientist's notebook (the included science-activity recording sheets were available at multiple readability levels), and emphasizing how to read science text. For this more individualized science instruction, children were flexibly grouped by incoming comprehension and fluency abilities, making the small groups heterogeneous in terms of children's science content knowledge. Results were impressive; even those students with weaker fall science and literacy skills made gains as great as those of students who began with stronger skills.

## Discussion and Conclusions

This review of literature has made clear the multidimensional components of effective TIIS for young children. Researchers have considered the relative contributions and roles of adult reading styles, of science texts themselves, of different activities, of classroom organization, of different levels of support, of time for science instruction, and of the increased value of TIIS approaches. In this section we address methodological concerns, the importance of the science trade book read aloud for young children, and then promising TIIS practices.

### *Methodological Concerns*

Throughout our review, we have continually filtered studies through Banilower et al.'s (2013) findings on elementary teacher's sense of personal preparation for science instruction. Whereas 81 % of teacher respondents felt well prepared to teach reading and language arts, only 39 % felt very well prepared to teach science. Within the science disciplines themselves, 29 % felt very well prepared to teach life science, 26 % felt very well prepared to teach earth science, and only 17 % felt very well prepared to teach physical science. No matter what approaches are taken to TIIS, not even a simple science trade book read aloud during literacy instruction will be as effective as possible without knowledgeable teachers. Methodologically, TIIS studies must give greater attention to teacher knowledge and attitude towards the science content. Various studies have included professional development, but in going to scale with interventions, many teachers will not have access to such considerable support. Readers of such research are left knowing how an intervention works in the best possible circumstance, but not how it will work should it go to scale (keeping in mind Duschl et al.'s [2007] cautions about such challenges).

As well, the work of Connor and colleagues (Connor et al., 2010; Connor et al., 2012; Connor & Morrison, 2013) emphasizes that children's entering science knowledge and literacy skills impact their success in TIIS programs. Connor and colleagues' work suggests that there are limitations to whole class science instruction, particularly when all children are expected to read the same texts by themselves to participate in inquiry activities. Thus, future studies must also address both children's entering science knowledge and literacy skills.

Further, there is the question, as always, of measures. Researcher created measures will certainly be more sensitive to student growth on particular topics taught, but the use of such measures only does not allow the field to contrast the results of one TIIS effort with another. Here, again, researchers may turn to Connor and colleagues for guidance on possible standardized measures.

Finally, from our perspective, there is the confounding variable of additional time for science in interventions when researchers use science-as-usual classrooms as controls. As research demonstrates (e.g., Banilower et al., 2013; Connor et al., 2012; Saçkes, 2012; Saçkes, Trundle, Bell, & O'Connell, 2011), very little time is spent on science instruction in science-as-usual classrooms (11 min per day as contrasted with 92 min per day for language arts, Connor et al.). Future studies must address this impact of additional instructional time on students' achievement.

### *Background Knowledge: The Significance of Science Trade Book Read Alouds and Science Little Books*

TIIS represents the sine qua non of early childhood science education, but this review has stressed again the minimal amounts of time spent on science in young children's education. As we become increasingly aware of the importance of children's background knowledge in their school success (e.g., Pinkham, Kaefer, & Neuman, 2013; Saçkes et al., 2011), a key question for the field becomes: what additional steps can be taken to rapidly increase the scope of young children's science background knowledge?

One potential path for supporting children's rapid, increased scope of science background information is through the read aloud of science information trade books. We recognize that this instructional strategy may not be regarded the most "effective science learning environment" (Duschl et al., p. 17), but it contains promise nonetheless. Although research may indicate that the gains from many teacher read alouds can be limited (e.g., Mol, Bus, & de Jong, 2009; National Early Literacy Panel, 2008), what we do know is that reading aloud interactively in the early years results in vocabulary gains, and, hence, increased background knowledge in later academic years (e.g., Dickinson & Porche, 2011). Simply put, frequent, interactive read alouds of science information trade books can enable early childhood students to develop networks of science information to which they can attach new learning as they move through their school years. Reading multiple books aloud on a single topic or related topics both enhances these knowledge networks (e.g., Heisey & Kucan, 2010) and increases the likelihood that children will more rapidly develop these networks of understanding.

Such read alouds can not only impact vocabulary and conceptual knowledge, but they can also increase children's exposure to the explanatory aspects of science text (e.g., Smolkin et al., 2008; Smolkin et al., 2009). We have found that, though relatively few in number, physical trade books, in particular, can foster attention to the explanations of science (Smolkin et al., 2009; Smolkin, McTigue, & Yeh, 2013). Not only do particular aspects of explanatory science trade books increase children's exposure to such explanations, but they also compel greater high demand discussions of science ideas between teachers and students (Smolkin & Donovan, 2015).

CCSS (2012) are also impacting the quantity of science reading in which young children themselves engage. Leveled, "little books," designed for use during reading instruction, offer an additional channel for increasing science background knowledge for early childhood students. Consequently, researchers may wish to attend more closely to the quality and accuracy of these works, which afford additional time and opportunity for building science background knowledge.

## *Promising Practices in Text Integrated Inquiry Science*

To increase our national science literacy, to increase the numbers of students pursuing scientific careers, children must experience science in effective environments (Duschl et al., 2007). These environments do not consist solely of the conduct of experiments; they consist of scientific practices that involve discussions, replications, and readings of others' works. We are particularly taken with Magnusson and colleagues' innovative scientist notebooks; these provide children a window into the thinking of scientists as they proceed through their inquiries – how their attention is captured by a phenomenon, how their curiosity leads them to carefully controlling variables and creating "fair tests," how their lives involve others in their field. The strength of this work, both powerful in terms of science inquiry and powerful in appropriate use of science text, is acknowledged and reflected in the innovative SSRR. Here, a gamut of texts support students at different phases of their science inquiry, some enabling students to see how others, including actual scientists, deal with the phenomenon they themselves are examining. Such commercially prepared texts, combined with literacy instruction in the science genres (including visual representations and the range of science texts, see Veel, 1997) genuinely support science learning.

We also appreciate the coherence of instruction described in many of these TIIS programs; they are clearly not "a mile wide and an inch deep" (Duschl et al., 2007, p. 20). Work such as Science Start!, ISLE, and SLP present important models for repeated, in-depth opportunities for young children to build conceptual knowledge and understanding of both the science phenomena examined and the science processes involved.

Finally, regarding children's representations of their science learning, we commend the practices found in Science Smart!, ISLE, and SSRR that press young children to express their science understandings through compositions (particularly multimodal compositions). Science notebooks (e.g., Brenneman & Louro, 2008) featured prominently in many programs described above, but it is important for children to add conjecture and explanation to longer science compositions that address the evidence children themselves have collected. Future TIIS research should increase attention to such child-produced texts, which can both promote and represent important aspects of science inquiry.

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# Chapter 11
# Role of Play in Teaching Science in the Early Childhood Years

**Berrin Akman and Sinem Güçhan Özgül**

> At planning time, Gabrielle says, "I'm going to play with the doggies and Magnatiles in the toy area. I'm making a tall elevator." At work time, Gabrielle builds with the magnetic tiles while playing with the small toy dogs, as she planned. She stacks the tiles on top of one another in a tower-like form—her "elevator"—then places some dogs in it. The elevator then falls over. She repeats this several times but the elevator continues to fall over. Gabrielle then arranges the magnetic tiles into squares, connecting them to form a row. Gabrielle says to Shannon, her teacher, "I'm making doghouses because the elevator keeps falling down." Shannon says, "I was wondering what you were building, because you planned to make a tall elevator going up vertically, and now you are using them to make doghouses in a long horizontal row. You solved the problem by changing the way you were building." Gabrielle uses pretend talk while moving the dogs around. At one point she says, "Mommy, Mommy, we are hungry" and opens one of the doghouses and moves the dog inside where a bigger dog is placed. Gabrielle says, "Mommy says the food's not ready, so go play." While moving the dogs around, Gabrielle says to herself out loud, "We have to find something to do until the food is ready." Gabrielle says to Shannon, "Let's pretend we are going to the park." Shannon agrees and says, "I'm going to slide down the slide three times and then jump off the climber." As Shannon pretends to do this with one of the dogs, Gabrielle watches then copies her and says, "My dog jumped higher than yours." She then says, "Mommy says we have to go home now. We need to move our dogs over there so they can eat." The pretend play continues. At recall time, Gabrielle is using a scarf to hide some objects she played with. When it is her turn to recall, she gives clues about what is under the scarf. She shows the group a couple of magnetic tiles and dogs. Shannon asks her what she did with these materials during work time. Gabrielle talks about the problem with the falling "elevator" and then recounts the story about the doggies (Lockhart, 2010, pp. 1–2).

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## Introduction

In the scenario, Gabrielle plans what she will do during her play, follows her plan and recalls what she has done. From this example, how do we explain the main cognitive functions such as memory, self-regulation, private speech, the ability to organize, focus, plan and practice skills that will later affect academic success? How are these cognitive skills or executive functions acquired in the most effective and convenient way? The researchers in the field of early childhood education indicate that one of the most effective tools in the development of early cognitive skills is play. Early childhood educators often emphasize that children acquire several cognitive skills through play (Lockhart, 2010; Ross, 2013).

Cognitive development encompasses all of the mental processes that maintain an individual's interaction with the immediate environment, beginning at birth. Cognition provides information with respect to the environment and assists in acquiring, storing, reorganizing and using information. The individual becomes competent in cognitive processes both qualitatively and in terms of content. Cognitive development demonstrates that the child is thinking with respect to the objects the child sees, hears, touches and tastes. The thought process involves the impulse-response relationship, the understanding of a succession of events, the appreciation of the similarities and differences between objects, the categorization of objects and rational response (Ministry of National Education (MONE), 2011). With respect to cognitive development, it is important that children reach conclusions as a result of their own efforts by attempting different ways of solving problems and by using their imagination and being physically and mentally active. There is a close relationship between play, which includes all of the aforementioned processes, and cognitive development.

Play constitutes an important part of a child's life and prepares a child for life experiences by creating the opportunity to develop a personality and skills (Egemen, Yılmaz, & Akil, 2004). According to Kelly-Vance and Ryalls (2008), play is an activity that excites, entertains and motivates children. The laughter and smiles that typically accompany play reinforce its fun nature. However, it is often overlooked that play is educational as much as it is fun. Certain parents believe that play contributes significantly to a child's development, whereas others consider play unnecessary and pointless (Johnson, Christie, & Yawkey, 1998). The research demonstrates that there is a strong relationship between play experiences and cognitive, emotional, motor and language skills. Children of all ages have a need to play and play forms the primary work of any child from any culture and of any condition (the types, materials and other characteristics of play may change) (Kindler, 2009).

From a development perspective, toys are an inseparable part of play, and through toys, a child is able to link the real world with imagination (Egemen et al., 2004). Toys assist a child in learning with respect to themselves and their environment and introduce several concepts. Through play a child will recognize and name the object or toy, understand its function, form cause and effect relationships, make selections, focus, and direct himself to a purpose. Play also promotes the functioning of cognitive processes such as classifying, analyzing, synthesizing, assessing and problem solving (MONE, 2009).

Historically, play has been considered the most important element in child development. In addition to the belief that children play for egocentric reasons, there is the belief that play supports cognitive, emotional and social development; a theory that is also applied to adolescents and adults (Daw, 2009). For children of a young age, especially, play is an indispensable element of the learning process. Play provides learning opportunities; preschool children enhance their mental capacity for creativity and develop social and self-regulation skills and, for older children, play continues to support the reinforcement of self-regulation and literacy skills. Academically, play helps children to become self-oriented and self-motivated individuals and to enjoy the learning process (Bonura, 2009). Children use different cognitive strategies during play. For example, a child's ability to learn from a mistake or failure is a reflection of their problem-solving and cognitive skills (Bow & Quinnell, 2001).

The theorists, researchers and educators from various disciplines have discussed play and its contribution to the learning and development of children (Erikson, 1985; Freud, 1961; Piaget, 1962a; Vygotsky, 1966). Although the researchers that study play present different perspectives with respect to its characteristics (Krasnor & Pepler, 1980; Rubin, Fein, & Vandenberg, 1983), there is a consensus that play is a human behavior that demonstrates certain typical characteristics. These characteristics include that play is self-selected, self-directed, open-ended, voluntary, enjoyable, flexible, and motivating and represents an individual or group activity (Isenberg & Jalongo, 2001).

The theories that feature different dimensions of play present the relationship between play and cognitive development as a serious of ideas that they provide with respect to the definition, goals and importance of play. The following section provides an explanation of the different theories with respect to the concept of play (Bodrova & Leong, 2010; Bonura, 2009; Güler, 2007; Johnson et al., 1998; MONE, 2009; Nicolopoulou, 1993; Reid, 2001; Rothlein & Brett, 1987; Sevinç, 2004; Sutton-Smith, 1979; Sutton-Smith, 1998).

Play theories can be divided into two categories: classical theories and modern theories. The classical theories emerged in the nineteenth century and attempt to explain the focus and the source of children's play activities. The modern theories appeared after 1920 and focused on understanding the effects of play with respect to the development of the child. Although the classical theories, such as Hall's recapitulation theory, have encouraged the systematic monitoring of children's play that has resulted in an explanation of the phases of play that compose the modern phase theories (for instance Piaget's theory), this present study will highlight only the relationship between play and cognitive development and, therefore, only the modern theories will be described.

## The Modern Play Theories

The modern play theories explain play and its contribution to a child's development and the antecedent conditions that cause play behavior to occur. In the following section, the play theories from two theoretical perspectives are described: psychoanalytic and cognitive.

## The Psychoanalytic Theories of Play

### *Freud's Theory*

Freud believed that play has a significant role in the emotional development of a child. According to Freud, play may possess a cathartic effect that cleanses a child of negative emotions concerning traumatic events. It is a natural dimension of development in healthy children, whose imaginary and dramatic defense mechanisms are in the early stages of development and who are experiencing the pressure of id energy. Play ends with the start of rational thinking, which is related to the development of ego (Johnson et al., 1998; MONE, 2009).

Repetitive play is another mechanism that allows children to process deal with unpleasant events. A child who repeats a negative experience during play can divide the experience into small and manageable parts. The child can therefore, piece by piece, slowly internalize the negative experience. Brown, Curry, and Tinnich (1971) explain the therapeutic value of repetitive play with the following examples: a group of preschool students experienced an unfortunate event and witnessed a worker become seriously injured when he fell nearly 6 m. The students watched the administering of first aid before the injured individual was transported to hospital by an ambulance. Initially, the majority of the children was influenced by the event and often reenacted the event during dramatic play (falling, death and injury, ambulances, hospitals). Only after a significant amount of time was there a decrease in the frequency of play and the discomfort of the children (as cited in Johnson et al., 1998).

### *Erikson's Theory*

According to Erikson, play advances in stages that reflect the psychosocial development of children. Children form case models that assist them in learning to manage real life through play. Erikson emphasized that play is a mirror of a child's psychosocial development. Through play, a child creates new models to cope with real emotions, thoughts and events. Erikson, who focused on the effects of play on ego development, considers that a child dramatizes, through play, uncertainties, concerns and desires (Johnson et al., 1998).

## The Cognitive Theories of Play

### *Piaget's Theory of Play*

According to Piaget (Piaget, 1962b), children are interested in the play type that relates to their cognitive development level (Table 11.1). For instance, children under age 2 may be interested in play that is oriented to practice (that is, repetitive physical actions) and simple role activities. Because their necessary cognitive and social skills are not yet formed, they cannot effectively take part in more advanced dramatic or imaginary play (Nicolopoulou, 1993).

Piaget (1962b) described three types of play that correspond to a child's cognitive development level: sensorimotor play, imaginary play and games with rules. For babies and young children, the child's sensorimotor actions are the first dominant types of play. These self-centered body movements reflect the narcissistic character of the first level of psychological development and the formation of the first sense of belonging for the child. During the preschool period, a child's play includes fantasy and symbolization and, in symbolic play, strong feelings and magical thoughts are common. When children begin primary school, their play becomes more realistic and complex and includes interpersonal interactions and events (Reid, 2001).

Piaget (1962b) accepts play as a phenomenon in which the child combines experiences, knowledge and understanding. The child controls these factors through play. While doing this, the child enters a process of equilibration by using the current schemas that the child possesses. Because this equilibration is always subject to change, the process rather than the results is significant in free play. With respect to children's play, assimilation and accommodation behaviors are generally activated at the same time; however, one may dominate at any given moment. At an early age, a child's desire and curiosity for learning initiates play activities. Play requires imitation with respect to the events that necessitate accommodation behavior. In this situation the child is required to make a change within his cognitive structure. This behavior is repeated until it is assimilated and initiates the play phenomenon. If the knowledge presented to the child is different from the child's current schema, the presented knowledge becomes unintelligible for the child to the degree that the assimilation and accommodation mechanisms are not able to assist the child in understanding that information (Sevinç, 2004; Wadsworth, 1989).

Piaget's constructivist theory posits that children acquire knowledge through their own experience and not from the knowledge that is presented by families and

**Table 11.1** Piaget's play theory

| Age | Cognitive level | Dominant play type |
|---|---|---|
| Age 0–2 | Sensorimotor | Practice play |
| Age 2–7 | Pre-operational | Symbolic play |
| Age 7–11 | Concrete operational | Games with rules |

Source: Johnson, Christie, and Yawkey (1998) teachers. For example, young children develop mathematical understanding and knowledge by interacting with their environments. Play-based mathematical activities provide a child with the opportunity to try more than one solution and to observe and improve social interaction (Bonura, 2009).

## *Vygotsky's Theory of Play*

According to Vygotsky(1978), young children have difficulty understanding abstract ideas because the meanings and objects are combined as a whole. Consequently, young children cannot think about a horse without seeing it. When children begin imaginary play and the use of objects (such as a piece of wood) to represent something else (such as a horse), the meaning begins to separate from the object. Eventually, children consider meaning to be independent of an object. Vygotsky's view with respect to play is a comprehensive one. He separated development into three levels: "Actual development" (independent performance), "potential development" (aided performance) and the *zone of proximal development*, or the distance between the actual and potential development levels. Play can contribute to development by operating as a stepping stone within the zone of proximal development and can enable children to reach higher levels of performance (Bodrova, 2008; Johnson et al., 1998).

Vygotsky considers play to be a type of magnifying glass that reveals new skills in formal learning environments. He does not overlook the biological basis of play activity in humans because these tendencies can also be observed in animals. However, he posits that symbolic skill is a part of humankind's hereditary nature. Vygotsky states that the realization of symbolic skill includes a social process and the nature of this process is an important research topic for psychology (Bodrova & Leong, 2010; Johnson et al., 1998; Nicolopoulou, 1993).

According to Vygotsky, true play has three components (Bodrova & Leong, 2010):

- Children create an imaginary event.
- Children adopt roles and play games.
- Children follow a series of rules determined by the specific roles.

The creation of an imaginary event and role play are considered a common characteristic of pretend play. Vygotsky argued that play is not something that develops spontaneously but is formed based on several rules. Imaginary situations and role playing are planned, and there are rules for joining the game. The main effects of play are the following (Bodrova & Leong, 2010):

- Play creates a zone of proximal development for the different areas of cognitive development.
- Play facilitates the separation of thought from actions and objects.
- Play facilitates the development of self-regulation.

- Play promotes motivation.
- Play promotes the adoption of perspective skills.

The common aspects of modern theories are that children find ways to express themselves with pretend play or imaginary play and that play is a setting used to meet these desires (Johnson et al., 1998; Rothlein & Brett, 1987; Sevinç, 2004).

## An Overview of the Studies on Play and Cognitive Development

Nicolopoulou (1993) presents a critical approach to play research concerning cognitive development and presents an analysis of two important theoretical frameworks; Piaget and Vygotsky. Nicolopoulou favors Vygotsky's play approach. Nicolopoulou argues that play promotes cognitive development and provides a micro learning environment within which children practice and develop the cognitive skills that are critical for elementary grades and beyond. Wood and Attfield (1996) suggest that recent play studies in developmental psychology focus on the cognitive benefits of play for young children and that they support the view that play provides a unique context for children to develop cognitive skills and conceptual understanding with respect to social and natural phenomena.

The studies concerning the relationship between play and cognitive development suggest a positive correlation (Coolahan, Fantuzzo, Mendez, & McDermott, 2000; Howard, Jenvey, & Hill, 2006; Howes & Smith, 1995). Howes and Smith (1995) demonstrated that playing mental games enhances a child's cognitive skills. Cherney, Kelly-Vance, Glover, Ruane and Ryalls (2003) investigated the effect of stereotypical toys on the complexity of young children's play and the resulting cognitive development. The results indicated that non-stereotypical toys increase the complexity of preschooler play and have the potential to support cognitive skills. Gmitrova & Gmitrov, 2003 examined the effect of teacher-centered and child-centered pretend play on the cognitive development of preschool children. The results demonstrated that during the child-centered pretend play, children were more likely to engage in sophisticated cognitive skills. A study by Shaklee and Demarest's (2006) demonstrated that playing with blocks supported a child's learning of mathematics and science concepts. Levine, Ratliff, Huttenlocher and Cannon (2012) found that early puzzle playing experiences are likely to support the development of children's spatial transformation skills.

Pretend play includes imaginary behaviors and the use of objects to represent imaginary objects (for example, pretend eating, enacting a pretend tea party). This behavior is common in the pre-operational stage and constitutes approximately 17 % of preschool and 33 % of day care games (Bonura, 2009). Vygotsky (1978) states that pretend play is a spontaneous child activity, and children typically perform at the highest level of their zone of proximal development. The basic skills that are reinforced with pretend play involve working memory (children need to remember their roles while acting out the characters), cognitive flexibility (they must regulate the decisions that other children make) and creativity. Creative play is geared more toward self-regulation and the reinforcement of working memory. However, whereas a realistic stage setting including costumes and devices may be considered necessary for young children, older children use symbolic equipment to develop their creativity (Bonura, 2009).

## Learning Through Play

Learning and playing are natural, intertwined processes in early childhood (Osborne & Brady, 2001; Pramling Samuelsson & Asplund Calsson, 2008). Certain researchers have defined the relationship between play and learning as "inseparable" and "complementary" (Osborne & Brady, 2001; Pramling Samuelsson & Johansson, 2006) and have suggested that the connection between play and learning has led most people to perceive play and learning as vital, at least for young children. Play has a crucial role as a "learning medium" that helps young children to explore their environment, practice novel situations, and seek knowledge (Bergen, 2009; Elkind, 2008; Pelegrini, 2009; Pramling Samuelsson & Johansson, 2006). A strong connection between play and learning has long been emphasized in the early childhood education literature (Bergen, 2009; Bodrova & Leong, 2007; Broadhead, 2006; Henricks, 2008; Piaget, 1976; Pramling Samuelsson & Johansson, 2006). Whereas most studies have focused on theoretical backgrounds, definitions and categorizations of play, certain contemporary studies have focused on other aspects of play including its role within the early childhood curricula, the developmental characteristics of play (such as social or physical), and the pedagogical effectiveness of play (Bodrova & Leong, 2010; Broadhead, 2006; Henricks, 2008; Pelegrini, 2009; Trawick Smith, 2009, 2012).

Young children have substantial competency and curiosity in the exploration of the world around them (Eshach & Fried, 2005; French, 2004; Gelman & Brenneman, 2004; Ginsburg & Golbeck, 2004; Mantzicopoulos, Samarapungavan, Patrick, & French, 2009; Saçkes, Trundle, Bell, & O'Connell, 2011; Trundle & Saçkes, 2012; Tu, 2006; Zimmerman, 2000). Children's innate drive to learn creates a foundation for future academic life (Eshach & Fried, 2005; Trundle & Saçkes, 2012). Young children learn from experiences, explorations, interactions (Broadhead, 2006), imitation and variation (Lindahl & Pramling Samuelsson, 2002). Play has the potential to offer a rich and developmentally appropriate learning environment where young children have the opportunity to explore, interact and imitate (Bergen, 2009; Pelegrini, 2009).

Learning through play has been considered an effective pedagogical tool in supporting the development and learning of young children (Trawick Smith, 2009, 2012). Play has also been emphasized in the early childhood curriculum and position statements of many countries and, with respect to professional organizations, as a developmentally appropriate way of supporting the learning and development of young children (see the National Curriculums of Sweden, Turkey, Tasmania and the position statements of National Association for the Education of Young Children-NAEYC). However, the empirical evidence concerning the effectiveness of play in facilitating the acquisition of concepts and skills by children is limited (Cheng & Stimpson, 2004; Codone, 2001; Schulz & Bonawitz, 2007). The limited number of research studies that have been conducted with preschoolers were designed to reveal a child's achievement and performance on learning tasks as a response to direct instruction, play based activities or scaffolding activities in certain tasks (Bulunuz, 2013; Holton, Ahmad, Williams, & Hill, 2001; Sarama & Clements, 2009). The results of these studies demonstrated that children involved in play-based activities perform better on learning tasks.

## Science Through Play

Science is an experience and part of everyday life, even for young children (Saçkes, Trundle, & Smith, in press; Van Schijndel, Singer, van der Maas, & Raijmakers, 2010). Because children have an innate curiosity and motivation for exploring new things in their environment (Mantzicopoulos, Patrick, & Samarapungavan, 2008), a child's first encounter with science is actualized as soon as they independently discover and interact with an interesting entity (Tu, 2006). Science is described as both the body of knowledge and the activities that expose that knowledge (Zimmerman, 2000). Science consists of two distinct types of knowledge: domain specific knowledge and domain general knowledge (Zimmerman, 2000). The domain specific knowledge includes knowledge concerning objects and their relationships in certain areas of science such as astronomy and biology (i.e., animate and inanimate entities), and the domain general knowledge includes the cognitive skills that are required to understand and produce the domain specific knowledge, also termed science process skills or scientific thinking skills (i.e., observation and classification) (Eshach & Fried, 2005).

The traditional view (see Piaget's and Flavell's works) concerning the competence levels of early childhood claims that children are incapable of performing certain cognitive tasks (i.e., conservation and reversibility). However, the findings of recent studies have suggested that children possess remarkable cognitive abilities that help them understand how things function in the natural world (Andersson & Gullberg, 2012; French, 2004; Mantzicopoulos et al., 2009; Metz, 1995; Nayfeld, Brenneman, & Gelman, 2011; Peterson & French, 2008; Wellman & Gelman, 1998). This phase of learning "how things work" directly reflects a domain specific knowledge of science. The studies have demonstrated that children develop conceptual understanding of various domains of science in early childhood. For example, Vosniadou and Brewer's study (1992) reveals that children use their initial reasoning skills to explain the appearance of the earth using their daily experiences. The results of Opfer's study (2002) demonstrated that 5-year-olds can utilize sophisticated criteria to decide what is "alive". The majority of young children can recognize the changes in clouds before rainfall; however, this recognition appears not to promote their understanding of the composition of clouds (Saçkes, Flevares, & Trundle, 2010). The studies have demonstrated that children have notably distinct natural world models that differ from scientific models (See Chaps. 3, 4, and 5). These alternative mental models (or initial explanatory frameworks, naïve ideas, or misconceptions) of young children can be based on any science topic (Gelman, 2005) and are usually resistant to change (Chi, 2008). According to Pine and Aschbacher (2006), the longer a nonscientific idea is held by a child the more difficult it is to influence.

The second science knowledge type, domain general knowledge, is composed of scientific reasoning or thinking skills and includes skills such as observing, inferring, classifying, measuring, problem solving, and finding patterns (See Chap. 7). The studies have demonstrated that even preschool children are capable of performing these skills to a certain degree (Akman, Üstün, & Güler, 2003; Carey & Spelke, 1996; Eshach & Fried, 2005; Opfer & Siegler, 2004; Zimmerman, 2000). According to French (2004), science is considered a privileged content area in preschool classrooms because it coheres with a child's tendency to explore his surroundings. An emphasis on science in early childhood education is consistent with the theories and findings with respect to conceptual development and can complement the early competencies, attitudes and natural curiosity of young children (Pine & Aschbacher, 2006).

The integration of both domain specific and domain general scientific knowledge into preschool classrooms requires extensive research on developmentally appropriate, inquiry-based science curricula for early childhood education. Such efforts should be supported by the research that examines early childhood learning with respect to science, including the findings and beliefs concerning early childhood competency and interest in science. The developmental theory and educational practices are frequently considered as separate domains (Gelman & Brenneman, 2004); therefore, the preparation of knowledge-rich scientific teaching programs and learning activities that integrate theory and practice has become essential. To broaden the repertoire of science teachers and to facilitate planning, distinct and unique science programs for early childhood have been developed (e.g., French, 2004; Gelman & Brenneman, 2004). French's ScienceStart! and Gelman and Brenneman's PrePS curricula aim to create an environment that includes a broad range of materials, opportunities and support for young children to improve their science knowledge. In addition to the science programs, play activities are accepted as a support and facilitator of early childhood science teaching (Yoon & Onchwari, 2006). Similarly, the nature and philosophy of science are relevant to early childhood dispositions worldwide and offer children the opportunity of "doing science" independently (National Research Council, 1996). Because children learn and play, science teaching through play is a current issue for early childhood education scholars (Nayfeld et al., 2011; Yoon & Onchwari, 2006).

The scholars of early childhood education attribute new meanings and philosophical frameworks to the play and science relationship. Lazslo (2004) defined science as the playing of ideas in an innovation and discovery process. Similarly, Abrahams and Millar (2008), stressed the definition of science as the interaction of ideas and observation in science-based physical activity. Throughout childhood, children take advantage of play in their social, emotional, physical and, especially, intellectual development (Hirsh, 2004; Youngquist & Pataray Ching, 2004). When children are asked to name their favorite activity, the answer always includes play (Pramling Samuelsson & Asplund Calsson, 2008). The integration of play in the learning environment naturally facilitates the involvement of children and the reaching of educational goals. Thus, the active participation of children in science activity in play settings develops self-perception as a science learner, understanding of various science concepts, and the perception of science as interesting (Mantzicopoulos et al., 2008). The research studies demonstrate that preschool teachers do not present playful science activities although they may be aware of the importance and benefits of play in childhood science learning and other domains (Nayfeld et al., 2011; Cheng & Stimpson, 2004; Saçkes et al., 2011; Tu, 2006). Because many studies stress that the teacher role in play is crucial (Bodrova, 2008; Taylor et al., 2004; Trawick Smith, 2012; Wu & Rao, 2011), early childhood teachers must develop an awareness of the relationship between play and science (Youngquist & Pataray Ching, 2004). Bulunuz (2012) stressed that to incorporate science teaching through play, it is required that both science and play are weighted equally in terms of value. Similarly, Travick-Smith (2009) indicated that play must be conducted in a theory-grounded, planned and assessment-based classroom. The advancement of science teaching through play depends on the development and dissemination of practical and effective implementation methods. The inquiry-based teaching approach that is commonly used and valued in science education at the elementary level (Pine & Aschbacher, 2006; Tatar & Kuru, 2006) can be a practical and effective way to provide developmentally appropriate, play-based science learning experiences for young children.

## The Research on Play-Based Science Instruction for Young Children

The studies that have focused on the influence of children's play on scientific thinking skills and conceptual understanding of natural phenomena are limited. Cook and colleagues (2011) designed two experiments that examined the exploration patterns of children using beads and a custom-built machine. The children's task was conducted under different conditions (e.g., given information and ambiguity). In the experiments, researchers provided different levels of information and different types of evidence (ambiguity or unambiguity) to children with respect to the activation and exploration of the machine. The children interacted and played with the machine for 1 min. Each child's interaction data with the machine (e.g., duration and the functions explored) was recorded by the researchers. The results demonstrated that children can distinguish both the presence of evidence and the complexity of the evidence available. The children were able to recognize and use the effective evidence to generate novel interventions to gain additional information. The researchers indicated that various factors are integrated and are used in the completion of tasks by children. These various factors, such as prior knowledge, evidence and recent experience, are important for guided exploratory play. These results are relevant with respect to the studies concerning the connection between scientific inquiry and children's play.

The study by Bonawitz and colleagues (2011) investigated the effect of pedagogical intervention in children's spontaneous exploration and self-discovery. A new toy, designed by researchers was presented to children with different types and amounts of intervention (Exp 1. pedagogical, interrupted, naïve and baseline conditions, Exp 2. direct, indirect child, and indirect adult and intentional conditions). The different conditions were based on different types of interaction among the adults, the children and the toy, and there was a gradual diminishing of intervention from pedagogical to baseline conditions. The results of the first experiment demonstrated that teaching constrains a child's spontaneous exploration and self-discovery, and the second experiment supported the findings of the first experiment that children have a tendency to discover new properties independently rather than through other intentional conditions. The researchers highlighted the dichotomy of instruction in children's exploratory play. Instruction has certain positive effects on learning-instructed information; however, it also causes certain undesired effects on the spontaneous exploration of untaught information.

In another study, Schulz and Bonawitz (2007) hypothesized that children are able to distinguish confounded and unconfounded evidence and that children tend to engage in more exploratory play when evidence is ambiguous. The researchers designed an experiment to reveal the play preferences of children concerning a familiar and novel toy when the evidence was confounded or unconfounded. The results of the study supported the prediction of researchers that children tend to select and explore confounded evidence while experiencing a new object or condition. The researchers suggest that childhood exploratory play can be associated with childhood causal learning and scientific inquiry skills; however, there is a need for further research in these areas.

In a recent study, Bulunuz (2013) investigated children's understanding of science concepts with respect to direct instruction versus a science through play dichotomy. The quasi-experimental design research was conducted in two typical public kindergarten classrooms. The children studied were all 6-years-old. Two groups of children were taught certain science concepts/phenomena (i.e., float/sink, air, living/nonliving) through instructional intervention or direct instruction. The experimental group experienced lesson plans and hands-on activities that were prepared by the researcher, whereas all lesson plans for the comparison group were prepared with the advice of the teacher. The learning through play for the experimental group consisted of three steps; introducing all concepts throughout the semester, implementing several activities and integrating science activities with other subjects. The results according to the quantitative analysis of pre-test and post-test interviews demonstrated that children in the experimental group were more effective at learning science concepts through a science through play approach than the children from the comparison group who experienced the direct teaching. The results demonstrate that a goal-oriented curriculum and materials for integrating play and science teaching in kindergarten classrooms are required.

The findings of these four studies emphasize that exploratory play provides a broad range of opportunity for early childhood science education. Children are likely to benefit from structured pedagogical interventions. However, unstructured learning experiences appear to initiate the use of scientific thinking skills in early childhood. More studies are required to examine the influence of different types of play on the learning of science concepts and the development of science process skills.

## Inquiry-Based Science Teaching

There has been more focus on the teaching of science and science education since the introduction of educational reforms of the mid-twentieth century. The National Science Education Standards (NRC, 1996) recommend inquiry as a method for teaching and learning science. The National Research Council provides a comprehensive definition for the inquiry:

> "Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results." (NRC, 1996, p. 23)

The inquiry-based learning process is promoted as a "gold standard" in the science education literature because it is effective in facilitating the conceptual understanding of scientific phenomena (Trundle & Saçkes, 2012). The inquiry-based instruction investigates a set of phenomena and draws individual or group conclusions based upon evidence (Kuhn, Black, Keselman, & Kaplan, 2000; NRC, 1996). Inquiry is a method for teaching science in addition to a method to be mastered by children (Padilla, 2010). Scientific inquiry is central to science learning. Scientific inquiry promotes the active learning processes and the integration of all students, in addition to the cultural and intellectual diversity of contemporary science in classrooms (NRC, 1996). The NRC (2000) highlights five important features of classroom inquiry: (1) the posing of scientific questions, (2) the use of evidence to provide an explanation, (3) the evaluation of explanations, (4) the noting and assessment of alternative explanations, and (5) the discussion of explanations. These active processes of scientific inquiry encourage children to construct new knowledge and develop science process skills. Similarly, Samarapungavan, Patrick and Mantzicopoulos (2011) specified certain characteristics of effective science instruction in early childhood classrooms; these include domain specific and contextually relevant themes and engagement in the process of inquiry with the use of science process skills (e.g., asking questions, making predictions, gathering data through observations and tools, evaluating the coherence of evidence and predictions, drawing conclusions and sharing findings with others).

The scholars have offered different categorizations for the inquiry-based method of teaching based on the complexity of tasks and the amount of support provided. Bell, Smetana and Binns (2005) proposed four levels of inquiry: confirmation, structured, guided and open inquiry. Lederman (2009a) has offered a similar hierarchy; exploration, direct inquiry, guided inquiry and open ended inquiry. Within this hierarchy of inquiry–based instruction methods, moving from confirmation to open inquiry causes the nature of instruction to become more complex and less scaffolded. For instance, at the exploration or confirmation level, children receive direct support from teachers, whereas at the open-ended inquiry level, children plan and implement their own inquiry experiences. The researchers suggest using guided inquiry-based science teaching activities in early childhood classrooms, where research problems and materials are incorporated and children are expected to create their own solutions (Howitt, Lewis, & Upson, 2011; Lederman, 2009b; Trundle & Saçkes, 2012). Samarapungavan and colleagues (2008) posited that guided inquiry within the context of early childhood classrooms provides an investigative context that encourages children to construct meaningful new knowledge.

The research findings with respect to inquiry-based learning at the elementary-grade level have demonstrated that most children develop scientific thinking skills and construct a rich understanding of scientific concepts (Metz, 2004). The studies have demonstrated that children are actually more capable of developing richer scientific thinking skills than some Piagetian and non-Piagetian researchers imply (Metz, 1995). Mantzicopoulos, Patrick and Samarapungavan (2013) indicated that as children engage in scientific inquiry activities in early childhood, they are able to develop a foundational understanding of inquiry. In classrooms that utilize the inquiry-based approach, children, as do scientists, conduct research on problems and questions. This method of teaching is likely to promote science achievements among children (Bell, Smetana, & Binns, 2005; Tatar & Kuru, 2006; Wu & Hsieh, 2006). The inquiry-based science curriculum offers children the opportunity to explore, observe, predict, and reflect (Wu & Hsieh, 2006). The learning cycle is one of the most well-known and widely used inquiry-based approaches to teaching science.

Karplus and Atkin, with the support of the National Science Foundation, developed the 3E learning cycle as an instructional strategy within the scope of the Science Curriculum Improvement Study (SCIS) program (Abraham, 1997; Ajaja & Erawvoke, 2012). The 3E learning cycle was based on Piaget's mental functioning model (Abraham, 1997; Marek, 2008). According to the model, mental functioning processes correspond to learning cycle phases that are labeled exploration, explanation (concept development), and extension (expansion) (Marek, 2008). When a child is exposed to a new condition, it is called disequilibration and results in assimilation between the existing concepts and the new concept. The exploration phase of the 3E learning cycle is similar to the equilibration process used when children begin to learn new knowledge in the inquiry-based learning environment. The re-equilibration process accommodates new schemas for novel knowledge/conditions. In the explanation phase of the 3E learning cycle, children are able to progress in concept development. During the final process of mental functioning, children organize schemas. This process of mental functioning is similar to the extension phase of the 3E learning cycle. The 3E learning cycle suggests that through scientific exploration, children can be encouraged to first explore materials and then to construct a conceptual understanding and to implement or expand the concept to other situations.

The 5E learning cycle was developed by Bybee in the 1980s within the context of the Biological Sciences Curriculum Study (BSCS) that aims to organize developmentally appropriate experiences for systematic science education (Bybee, 2006). Detailed information with respect to the 5E learning cycle is presented in the report of the BSCS for the Office of Science Education National Institutes of Health (Bybee, 2006). The five phases of the model are described as engagement, exploration, explanation, elaboration and evaluation (Bybee, 2006; Bybee et al., 2006). The first phase, engagement, includes the preparation of methods and learning opportunities to reveal relevant pre-knowledge and actions with lesson content. The exploration phase includes experiences in which a child's existing understanding is challenged by various learning opportunities such as activities and discussion. The explanation phase introduces scientific concepts that cohere to a child's scientific explanations. The elaboration phase is composed of activities that are required for reflection on the scientific concepts and vocabulary in new conditions. The last phase, evaluation, provides a concluding activity for children to evaluate their understanding. According to Yoon and Onchwari (2006), the 5Es instructional model provides learning opportunities that can encourage children to follow their innate curiosity, explore the natural world, and develop problem-solving skills. Many studies on learning cycles have demonstrated that students display higher achievement, positive attitudes, and improved development of concepts and process skills after learning cycle-based instructional interventions (Miller, Trundle, Smith, Saçkes, & Mollohan, 2012).

## Conclusion

Children have a tendency and an inborn curiosity for exploration of the natural world. During early childhood, children should be exposed to a variety of science learning opportunities in a playful context. The inquiry-based learning cycles supported by play appear to be a promising method for planning and implementing developmentally appropriate science learning activities for early childhood settings. The blending of child-friendly pedagogical methods may promote the early childhood learning of science in preschool classrooms.

Play "as an act of inquiry" (Youngquist & Pataray Ching, 2004) may inform the design of inquiry-based science learning activities in early childhood. Because play functions as an inner drive to learn and explore, it can be incorporated into early childhood educational activities more effectively than any other method. Childhood education professionals should recognize that play is the most effective and natural way for a child to learn (Bredekamp & Coople, 1997). The use of an inquiry-based approach and learning cycles in preschool classrooms may require certain adaptations and developmentally appropriate methods. The integration of play with inquiry-based science learning activities can promote the learning of science in early childhood. The play activities that are embedded within the phases of a learning cycle may promote a child's understanding of science concepts and the use of science process skills. A recent study with preschool children implemented this idea (Miller et al., 2013). Children's understanding of day and night and objects in the sky was examined before and after play-based science instruction to determine the instructional effectiveness. The instructional intervention of the study was based on a play-based 5E learning cycle model for children. The children were able to explore concepts and materials within the phases of the learning cycle while playing. The play materials and settings related to targeted concepts were available to the children during the instructional intervention. The results of the study demonstrated that play-based science instruction assists preschoolers in the development of a scientific understanding of the basic astronomy concepts. Play is also suggested as an alternative resource for early childhood science education in Cambodian schools that mainly serve the children in extensively poor and disadvantaged areas (Reyes & Ebbeck, 2010).

There is a consensus among early childhood educators and researchers that children learn most effectively through play (Bergen, 2009; Bodrova & Leong, 2007, 2010; Broadhead, 2006; Elkind, 2008; Henricks, 2008; Osborne & Brady, 2001; Pelegrini, 2009; Pramling Samuelsson & Johansson, 2006; Schulz & Bonawitz, 2007). However, the evidence that supports the idea of using play as a pedagogical tool is limited. Few studies have examined the context of play activities or play-based science instruction and their influence on childhood science and mathematical concept learning and the development of scientific and mathematical thinking skills (Cook, Goodman, & Schulz, 2011; Bonawitz et al., 2011; Miller et al., 2013; Nayfeld et al., 2011; Sarama & Clements, 2009; Oers, 1996). Additional studies are required to reveal the ways in which children learn within the context of play-based science instruction and whether the inquiry-based science instruction supported by play is effective in young children's understanding of basic science concepts (Cook et al., 2011; Miller et al., 2013; Schulz & Bonawitz, 2007; Trundle & Saçkes, 2012).

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# Chapter 12
# A Modeling-Based Inquiry Framework for Early Childhood Science Learning

**Ala Samarapungavan, Deborah Tippins, and Lynn Bryan**

*Three four-year olds, Zachary, Christopher and Brianna, hunch over a set of colorful wooden blocks. For a silent minute they stare at the pile of blocks. Suddenly, Zachary grabs a block, examining it carefully before placing it in the middle of the floor. Christopher selects another block and carefully places it on top of the first block. Soon Brianna joins in, adding blocks both on top and from side to side. The children's eyes light up as Christopher adds a wooden ramp to the side of the structure. He picks up a small ball and rolls it down the length of the ramp. He then gives the ball to Brianna and watches as she rolls it repeatedly down the ramp. Several minutes later, Zachary reaches over and puts some blocks under the ramp, changing its elevation. By now the children's structure is swaying precariously. Ideas begin to flow simultaneously: "You have to balance it," "Get a smaller block," "Put more blocks on the other side." Then the unthinkable happens with the slow collapse of the children's block tower. Zachary begins to remove the blocks, creating a new fence-like structure with a larger base, explaining, "This is where the cows go." The three children are a bundle of energy as they build up and take apart the blocks, with little concern for creating a lasting structure.*

While Zachary, Christopher and Brianna may not be gathering evidence to revise their block structure in a systematic way, their model changes as they try out new ideas. Like Zachary, Christopher and Brianna, young children never get tired of exploring their world and figuring out how things work. The questions they ask

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of themselves and each other are in essence the beginning of scientific thinking. Kincheloe, Steinberg, and Tippins (1999) described how as a child, the young Albert Einstein spent hours building with prefabricated blocks and cards. As he combined the objects of his play, he learned about spatial relationships, balance and symmetry in unconscious ways. In the process of constructing block and card houses, he rearranged these objects of play in ways that achieved a new synthesis or understanding.

In this chapter, we frame children's engagement in learning about the natural world as a process of model construction and reconstruction, a process that we, following Giere (1988, 2002, 2004), believe recapitulates science itself. Giere describes described science as a process of modeling in which various domains and sub domains of knowledge are embodied in families of models that represent theoretically important features or dimensions of experience. Within Giere's framework, we derive hypotheses from our models that allow us to test similarities between our models and the natural world and to test ideas about how models relate to each other. Additionally, Suppes (1960, 1962) suggests suggested that models of experimentation and of "data" mediate our decision making about how our theoretical or content models fit the world.

For our purposes, a scientific model is a dynamic analog that selectively represents the structure and behavior of some part of the natural world. A model may contain iconic as well as symbolic (linguistic or mathematical) representational elements and may be distributed, existing both in the mind and as an external inscription. Models are dynamic in that they can be "run" to generate explanations of behavior or predictions about future behavior.

Modeling in the early childhood years is about selectively representing salient features of our interactions with our world. As young children engage in activities where they explore and modify their world, they are guided by not only new information constructed through their ongoing interactions, but also their pre-existing models of the physical world, which developmental research suggests appear early in the first months of life, are abstract, can model structural and causal relations, and are malleable through experience (Baillargeon, 2002; Spelke, 1991, 2000). Einstein's example has important implications for early childhood educators. Teachers can protect children from the reductionist principles of rote memory and mechanics that eventually lead to the fragmentation of knowledge by helping them make connections between their daily experiences and what they are learning. The use of models and modeling processes is one way to help children make sense of their natural world.

Engaging children in more mindful, inquiry-driven, modeling activity in the science classroom helps them understand the cultural dimensions of models and modeling. When one considers scientific modeling as a cultural process and models as its products, certain aspects of modeling activity and of the models its produces need to be highlighted in the teaching and learning of science. Although the cognitions of individual scientists who are part of the community of practice contribute to the modeling processes and the models themselves, the modeling enterprise is shaped by the interactions among the members and institutions of the community.

Scientific models serve important intersubjective aims of communicating, replicating, evaluating, and building upon or revising ideas in the context of scientific inquiry. We propose that science education needs to create ways of constructively replicating these cultural practices for science learners at all level. From this perspective, science learning in young children should be viewed as socially negotiated and embodied in specific cultural practices (Boyd & Richerson, 2005; Rogoff, 1990; Roth, 2005).

## Models and Modeling in Science Education Reform

For decades, efforts to reform U.S. K-12 science education have emphasized modeling-based conceptual understanding and reasoning. In *Project 2061 Benchmarks for Scientific Literacy* (American Association for the Advancement of Science & Project, 2061), "models" is one of four common themes deemed essential for K-12 science curriculum. More recent reform documents such as *A Framework for K-12 Science Education: Practices, Cross-cutting Concepts, and Core Ideas* (National Research Council & Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education [NRC], 2012) reflect a view of young children having the capacity to engage in scientific practices, suggesting that children in early grades develop and use models:

> Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system. Young students should be encouraged to devise pictorial and simple graphical representations of the findings of their investigations and to use these models in developing their explanations of what occurred. (p. 58)

*A Framework for K-12 Science Education* highlights modeling as a fundamental scientific and engineering practice that requires children to draw on knowledge constructed in multiple contexts. It also explains how the use of models and modeling at an age-appropriate level can help children build explanations of phenomena that extend beyond their understanding: "Science often involves the construction and use of a wide variety of models and simulations to help develop explanations about natural phenomena. Models make it possible to go beyond observables and imagine a world not yet seen" (NRC 2012, p. 50).

A multiplicity of researchers, incorporating a diversity of perspectives, have proposed structuring science learning as recursive modeling activities in which children are encouraged to continually construct, evaluate and reconstruct models. For example, Lesh & Doern (2003) describe a modeling cycle that begins with introducing children to a model-eliciting problem and evolves through a series of develop-test-revise cycles. These scholars note how children, as they refine their models to achieve more consistency and coherence, often notice unexpected implications of a particular representational choice or an additional feature of their world that the model fails to account for. A similar approach, taken by The Engineering in Elementary program (EiE), developed by the Boston Museum of Science, encourages children to ask, imagine, plan, create, and improve as part of a modeling process (Cunningham & Hester, 2007). Looking across various conceptualizations of modeling, several basic tenets appear to be common to all. There is an inherent emphasis on the potential for modeling to impact children's epistemic goals, such that they learn to pose, evaluate and pursue worthwhile questions of their own, rather than searching for answers to others' questions. Another principle reflected in many of the modeling cycles is the idea of children as producers of knowledge who craft their identities as inventors of models, rather than consumers of knowledge or simply users of existing models. Furthermore, such perspectives do not delineate learning about "content" and "process" as distinct and separable components. Rather the development of content and process is inextricably melded as children construct and reconstruct models.

Indeed, research supports the idea that there are entry points in young children's experiences with the physical world that allow for productive science instruction. For example, research has shown that children from 3 to 7 years of age believe that tiny invisible particles (e.g., particles of sugar or salt) can exist in aqueous solutions even though they are too small to be visible to the naked eye, and that properties of solutions, such as taste or drinkability, may be affected by these particles (Au, Sidle, & Rollins, 1993; Rosen & Rozin, 1993). Macdonald and Bean (2011) have shown that second graders who participate in informal museum-learning programs show an understanding of microscopic material entities that can be studied indirectly. Current perspectives on science learning suggest that students' models of physical phenomena evolve gradually and that productive instruction often facilitates young children's construction of a series of intermediate models that approximate some, though not all features of normative scientific concepts (Mazens & Lautrey, 2003; Wiser & Smith, 2008).

In this chapter, we outline a modeling-based inquiry framework for exploring young children's science learning and share results of a research project in which we are engaged that have yielded important theoretical information about the nature of young children's conceptual development in science. Our research projects explore how the scaffolding of model-centered classroom discourse during inquiry learning helps young children articulate physical science models and develop an understanding of models and modeling.

## A Modeling-Based Inquiry Framework for Early Childhood Science Learning

Our theoretical framework is grounded in a view of science learning as a process of domain-specific knowledge construction (Brown, 1990; Carey & Spelke, 1994; Gelman & Brenneman, 2004). From classic developmental theories, we draw upon the tenet that children are active learners (Bruner, 1996; Piaget, 1955; Vygotsky, 1962). However, the domain-specific view implies that learning in particular conceptual domains such as science entails the development of distinct domain-specific conceptual constructs, reasoning processes, and patterns of activity. In this context, thinking with and about rich content becomes a central concern for learning and for instructional design. Our approach is consistent with the National Research Council report advocating that science instruction should be organized around "big ideas" (Smith, Wiser, Anderson, Krajcik, & Coppola, 2004). A core theoretical assumption of our framework is that science learning is situated in specific cultural contexts and practices and is socially negotiated (Boyd & Richerson, 2005; Brown & Campione, 1994; Rogoff, 1990; Roth, 2005). This assumption is consistent with a vast body of research in science studies on the historical and current practices of science (Giere, 1988; Knorr-Cetina, 1999; Kuhn, 1962, 1977; Laudan, 1990; Thagard, 2003, 2004).

Following Giere (1988, 2004), we conceptualize science as a process of constructing, testing/evaluating, and reconstructing models of the world. Giere suggested that knowledge in various domains and sub domains of science is embodied in families of models that represent theoretically important aspects of the external world. Consistent with recent efforts to bridge cognitive and situated/socio-cultural perspectives on knowing and learning (e.g., Cobb, 1994; Vosniadou, 2007), we do not draw sharp distinctions between models as knowledge internal to the learner (i.e., in the mind) and models as external representations created by the learner with the aid of cultural tools (e.g., drawings, computer simulations, 3-D Models).

## *Modeling-Based Inquiry with Young Children*

We believe that PreK-2 science instruction should be designed to facilitate students' understanding of the relationships among domain models, and their ability to use models generatively (Frederiksen, White, & Gutwill, 1999; Gobert, 2000; Grosslight, Unger, & Smith, 1991; Justi & Gilbert, 2002). The nature of the learning tasks that are assigned to students and the ways of assessing student learning can have a significant impact on the flexible application or transfer of knowledge to varied contexts. Thus in our work, we have employed the instructional approach of guided inquiry (Brown & Campione, 1994; Magnusson & Palincsar, 1995). Our instructional approach follows a set of design principles for inquiry-based pedagogy that include the integration of the cognitive (science concepts and scientific inference processes), epistemic (knowledge validation and evaluation), and social (understanding the sociocultural norms and practices of science) dimensions, as recommended by a national panel of science education experts (summarized in Duschl & Grandy, 2008).

Our goal is to develop instruction through which young students experience science as a set of cultural practices supporting shared norms for co-constructing, evaluating, and revising knowledge (Knorr-Cetina, 1999; Kuhn, 1962, 1977; Laudan, 1990; Samarapungavan, Patrick, & Mantzicopoulos, 2011). The central idea is that early science learning is supported by discourse-rich interactions among students and between students and teachers.

## *Our Framework for Implementing Modeling-Based Inquiry*

Our modeling-based inquiry implementation framework is an adaptation and extension from key features of *Practices of for K-12 Science Classrooms from the Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (*NRC 2012*)*. The dimensions that we focus on are:

1. Engage learners in posing/addressing scientific questions centered on core disciplinary ideas (Aligns with Practice 1 from Framework, 2012).
2. Develop metamodeling awareness by explicitly using the language of models and modeling and drawing learners' attention to the constructive representational aspects of models such as decisions about what features /aspects of the world to model (Aligns with Practice 2 from Framework, 2012).
3. Facilitate learners' ability to plan and carry out investigations (Aligns with Practice 3 from Framework, 2012).
4. Engage learners in analyzing and interpreting evidence to evaluate their models (Aligns with Practice 4 from Framework, 2012).
5. Facilitate learners' articulation of model-based explanations (Aligns with Practice 6 from Framework, 2012).
6. Facilitate the comparison, evaluation, and revision of models based on the outcomes of investigations (Aligns with Practice 7 from Framework, 2012).
7. Engage learners in communicating what they have learned (Aligns with Practice 8 from Framework, 2012).

Our prior research and that of others has shown that the scaffolding of science discourse during inquiry is critical to facilitate students' developing intersubjective understandings of the processes of model articulation, evaluation, revision, and communication (Roth & Welzel, 2001; Samarapungavan, Mantzicopoulos, & Patrick, 2008; 2011; Seymour & Lehrer, 2006; Windschitl, Thompson, & Braaten, 2008a, 2008b). In the following section, we provide an example of how teacher-scaffolded inquiry discourse supports children's inquiry-based modeling in the science classroom—illustrating four of the dimensions of the framework: (a) articulating a model; (b) identifying evidence with which to make a prediction; (c) communicating model, and (d) collecting and analyzing evidence.

## Examples from Science Classroom Discourse

Our example is drawn from a kindergarten science unit in a project called the Science Literacy Project (SLP) (Mantzicopoulos, Patrick, & Samarapungavan, 2005). Detailed descriptions of the SLP curriculum are beyond the scope of this chapter but have been detailed in several prior publications (e.g., Samarapungavan et al., 2008; Samarapungavan et al., 2011). This unit entitled, *What is Science?*, introduced children to the key themes of the SLP curriculum: (a) Science is the study of the natural world; (b) Everyone can do science; and (c) Scientists learn about the world through planned and carefully conducted processes of inquiry. The focus of this unit was to introduce children to scientific inquiry through simple experiments with dissolving, to help them decide which of several substances (salt, sugar, lemonade mix, beans, a plastic paper clip, an iron nail, etc.) will or will not dissolve in water. The lesson starts with the teacher scaffolding children's predictions as they worked in small groups (4–5 students). Each group was seated around its own work table with materials for the experiments and their science notebooks and pencils out. It is important to note that the kindergarten science lesson occurred about three weeks into the start of the school year and was the *first* SLP lesson. The students (5–6 year olds) were novices, both in terms of their experiences of formal schooling in general and of school science learning. The teacher was in her first year of participation in the SLP project and had had no systematic prior experience with inquiry-based science teaching beyond the week of professional development she received through SLP workshops prior to the start of the intervention. She was also new to the school district and to kindergarten teaching. Prior to assuming her current position, she taught 4th graders in an affluent private school in another U.S. state. The examples we use followed from an earlier segment of the lesson in which the teacher explored children's ideas of dissolving with an introductory whole class activity and discussion centered on mixing and stirring lemonade mix in a pitcher of tap water. It is important to keep in mind that the main purpose of this initial unit was to give young children a sense of what it means to engage in scientific inquiry, rather than to build scientific models of dissolving. In the excerpts that follow, the teacher is engaged in several interactions that scaffold young learners' ability to identify, collect, and interpret evidence to evaluate their models.

## *Articulating a Model as a Context for Inquiry*

As the children began to consider whether salt will dissolve in water and started to use the word "dissolve" in their conversations, the teacher encouraged them to articulate their models of what it means to dissolve something (see Excerpt 1). In this process, she focused their attention on what changes they expected to observe when they said something is dissolving. In response, the students started talking about the changes that accompany dissolving, referring to the lemonade activity as they did so:

Excerpt 1

| | |
|---|---|
| *Leticia:* | *Dissolve (pointing to salt)* |
| *Teacher:* | *Dissolve?* |
| *Leticia:* | *Yeah* |
| *Teacher:* | *What's that mean? Tell me your ideas, what do you think? What do you think Jonathan?* |
| *Jonathan:* | *Um* |
| *Teacher:* | *What do you think it means to dissolve? Remember the lemonade? We got the lemonade [[and she's pouring it.* |
| *Marcello:* | *[[Oh yeah]]* |
| *Ethan:* | *(pointing to the lemonade that the teacher is pouring out of the pitcher for each child). It dissolved.* |
| *Matthew:* | *It dissolved to a different color.* |
| *Teacher:* | *What did you say? It dissolved (repeats after Leticia who is inaudible) it dissolved into the water? What does that mean? What did it do?* |
| *Leticia:* | *It changed colors.* |
| *Teacher:* | *It changed colors you said that, that's good.* |
| *Ethan:* | *I changed it.* |
| … | |
| *Teacher:* | *Well let's think of more reasons, I like the way that Eth- Alexa was comparing it to the lemonade mix that's very good. Okay. Boys and girls, if you think, we're gonna go ahead and make our predictions.* |

At this point in the lesson, the children's model of dissolving focuses on the color of the substance and color change. The teacher encourages students' model articulation through non-directive questions. In this initial phase, the teacher's discourse is simply focused on having the students lay out their ideas and explanations without concern for their accuracy. This is appropriate in the early phases of modeling-based inquiry.

## *Identifying Relevant Evidence*

As the children continued the lesson, the teacher helped them identify evidence that they would collect about whether various substances will dissolve in water by scaffolding their predictions about what will happen for each substance (Excerpts 2a and 2b). The children responded by making their predictions about whether or not the salt and the beans will dissolve in water. The teacher also called upon children to explain/justify their predictions:

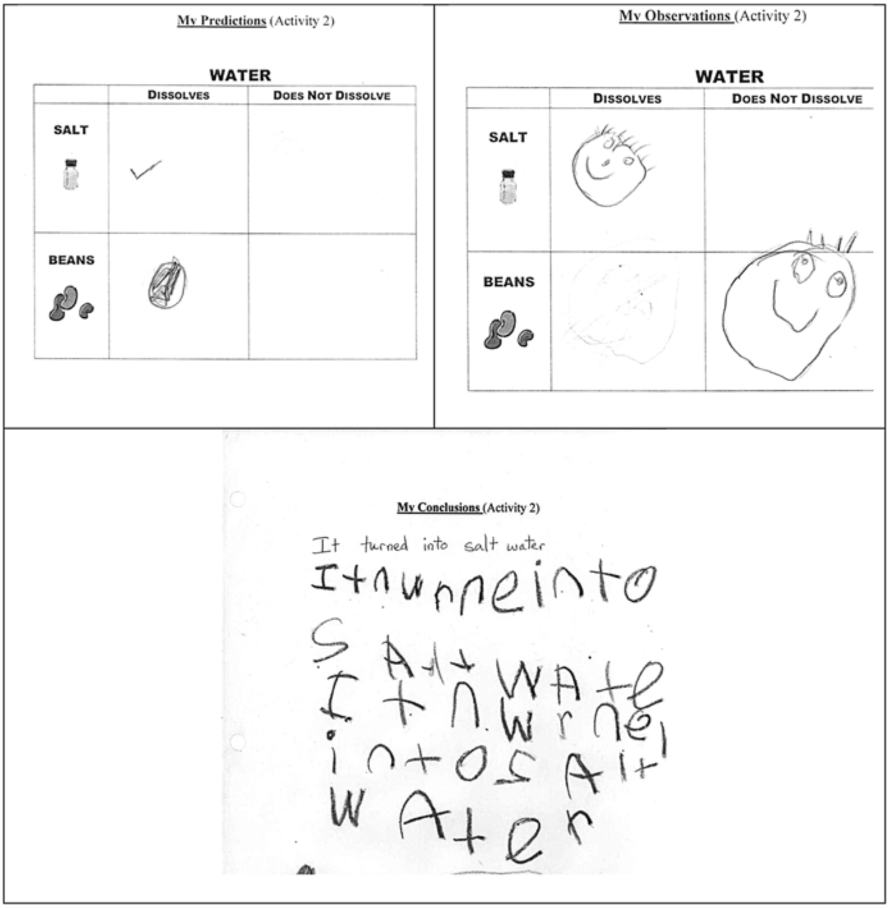
Excerpt 2a

| | | |
|---|---|---|
| 1<br>2<br>3<br>4<br>5 | *Teacher:* | *This, boys and girls look up here (holding up a science notebook). This is the front of your binder, this is the back of your binder, open your binder from the front. Okay, and then you can look through it. Okay. Today we're gonna make some predictions. So each of you at your table will get some salt and some beans (she is showing the salt and bean cups). Okay.* |
| 6 | *Students:* | *[Salt. Bean]s* |
| 7<br>8<br>9<br>10<br>11<br>12 | *Teacher:* | *Good job. Okay right here. Now boys and girls we get to make a prediction. Okay so we get to guess what's going to happen. Sergio, listen up. We're gonna take a guess, we're gonna predict and see if the salt will dissolve. Now I'll pass some salt around, 'cause I want you to take a good look at it. I'll put some on your table. I want you to take a good look at it. Don't put it in your mouth; don't stick your fingers in it; just look at it.* |
| 13 | *Sergio:* | *I can't see* |
| 14<br>15 | *Teacher:* | *And see what it looks like and I want you to guess if it will dissolve in water. Pass it around.* |
| 16 | *Eric:* | *You can't look that long* |
| 17<br>18<br>19<br>20<br>21<br>22<br>23 | *Teacher:* | *Remember we talked about PREDICTIONS. When we do science, we can use what we know, or maybe what we have seen before to make PREDICTIONS – make a guess about what we think will happen to something. What are your predictions about the salt and the beans? Let's share our predictions. Boys and girls raise your hand if you think—if what -tell me what you think about the salt, if you think it will dissolve or not. Adrianna, what do you think?* |
| 24 | *Adrianna:* | *It will.* |
| 25 | *Teacher:* | *You think it (the salt) will dissolve, why do you think it'll dissolve?* |
| 22<br>27 | *Alexa:* | *'Cause that (pointing to the box with lemonade mix used earlier), the powder was kinda white.* |
| 28<br>29 | *Teacher:* | *Yeah, because it -it was maybe the—when, yeah maybe 'cause it's it looks like the powder did (referring to lemonade mix from earlier) didn't it?* |
| 30 | *Eric:* | *(nods) Mmm hmm* |
| 31<br>32<br>33 | *Teacher:* | *So it's a little different from the powder though isn't it? It's a different color. What's everybody else think? ((pause)) Do you guys think it'll dissolve in water? [[If we put it in water?* |
| 34 | *Sergio:* | *Yeah* |

Excerpt 2b

| | | |
|---|---|---|
| 1 | *Students:* | *(taking the beans and looking at them)* |
| | … | |
| 2 | *Teacher:* | *Okay, so what are your predictions?* |
| 3 | *Eric:* | *I think it will.* |
| 4 | *Teacher:* | *You think it will. Eric? (to class) Eric thinks it will dissolve. Why do you think it'll dissolve?* |
| 5 | | |
| 6 | *Eric:* | *I can see white.* |
| 7 | *Teacher (to class):* | *Eric can see white. Do you think that everything's that white will dissolve?* |
| 8 | | |
| 9 | *Eric:* | *Yeah.* |
| 10 | *Teacher:* | *If you put a golf ball, is a golf ball white?* |
| 11 | *Students:* | *Yeah!* |
| 12 | *Teacher:* | *Uh huh. If you put a golf ball in water is it gonna [[is it gonna dissolve?* |
| 13 | | |
| 14 | *Matthew:* | *No!* |
| 15 | *Teacher:* | *Are you still gonna be able to see it?* |
| 16 | *Students:* | *[No, yes.]* |
| 17 | *Teacher:* | *Yeah, but that's good, you're thinking. That's very good. What are your o what's everybody else think?* |
| 18 | | |

Both Alexa and Eric apply their color-focused dissolving model to the prediction—that is, they think the salt and the beans will dissolve because they are white, like the powder they saw dissolve earlier. For example, Alexa (*Excerpt 2a*, lines 22–27) introduces the idea that white powders dissolve in water by drawing an analogy between the salt which she predicts will dissolve and the lemonade mix which she describes as "kinda white" which dissolved in an earlier part of the lesson. In an attempt to move the focus away from color as the relevant evidence for whether or not something would dissolve in water, the teacher responds by saying, "*…So it's a little different from the powder though isn't it? It's a different color.*" *(Excerpt 2a*, lines 31–32). Later, Eric again picks up on the theme of whiteness as a marker for whether or not something will dissolve, (*Excerpt 2b, lines 6–9*). The teacher then introduces a thought experiment by asking the students to imagine a white golf ball and asking whether it would dissolve in water (Excerpt 2b, lines 10–18). We interpret these teacher-student interactions as productive exemplars of moves to identify what counts as relevant evidence in the context of modeling-based inquiry for young science learners. The key aspects of the teacher's discourse here are that she never tells the students that they are wrong or that color is not relevant. Rather, she tries to draw their attention to phenomena that do not fit well with their initial models and in asking them to recognize these discrepancies, she helps them reconsider their initial models.



My Predictions (Activity 2)

WATER

| | DISSOLVES | DOES NOT DISSOLVE |
|---|---|---|
| SALT | ✓ | |
| BEANS | | |

My Observations (Activity 2)

WATER

| | DISSOLVES | DOES NOT DISSOLVE |
|---|---|---|
| SALT | | |
| BEANS | | |

My Conclusions (Activity 2)

It turned into salt water

Itnwrneinto

SAlt wAte

Itnwrne

into SAlt

wAter

Fig. 12.1 Entries from Eric's science notebook for unit 1

## *Using Inscriptional Tools to Support Inquiry*

Another key feature of modeling-based inquiry is the use of inscriptional tools to scaffold children's model articulation, evaluation, and revision. *Excerpt 3* illustrates how the teacher used inscriptional tools, in this case science notebooks, to facilitate learners' ability to identify, collect, and interpret evidence to evaluate their models. Figure 12.1 provides an example of the science notebook entries that children made as they engaged in the processes of inquiry. The notebook contains Eric's records of his initial predictions that both the salt and the beans would dissolve in water, his observations that the salt dissolved but the beans did not, and his conclusions (e.g., dissolving the salt in the water made it "turn into salt water").

Excerpt 3

| | |
|---|---|
| *Teacher:* | Look here, look what it looks like (shows page of science notebook in Fig. 12.1). Do you think that's gonna dissolve? You think that's gonna dissolve or not dissolve? If you think it's gonna dissolve put a mark. What do you think, do you think it's gonna dissolve or does not dissolve? Okay, do you think it'll dissolve? So then put a smiley face right here. If you think it'll dissolve, put a smiley face right there. Great job with your predictions (said to the whole class). Very good, I see smiley faces all over. Very good, Logan's even writing his name on the paper. |

In order to understand the significance of Fig. 12.1 and Excerpt 3, it is important to note that this is the first lesson of the year's science curriculum for the kindergarteners and takes place within three weeks of the start of the school year. The young students have just begun formal instruction on reading and writing at school but the teacher is already engaging them in practices of scientific literacy as they record and communicate their predictions, observations, and conclusions through modeling-based inquiry. For example, Fig. 12.1 shows that Eric initially predicts that both the salt and the beans will dissolve in water, but then records his observations that the salt did dissolve but the beans did not and concludes that the salt turned "into salt water" but the beans remained whole in the water (drawing). The children are given the freedom to use a combination of words and drawings to articulate their ideas throughout inquiry.

## *Collecting and Interpreting Evidence*

*Excerpt 4a* and *Excerpt 4b* illustrate how the teacher engaged in children in collecting and interpreting evidence as they continued their investigations of dissolving. The teacher started out by explaining the procedure for mixing the salt in the water. She and the teaching assistant continued to scaffold the students as they mixed the salt and beans in the water with hints and prompts (see exchanges in *Excerpt 4a*, lines 1–12). The teacher supported the children as they engaged in collecting and interpreting their evidence by asking them to describe what they were observing and to explain their observations. For example, in *Excerpt 4a* (lines 4–12), the teacher engaged the children in describing and interpreting their observations of what happened to the beans, once they were mixed in the water and whether they dissolved on the water. Riley and Rose indicated that the beans did not dissolve, with Rose explaining that she could still see the beans after they had been mixed in the water (*Excerpt 4a*, line 9). In contrast, John said the beans would eventually dissolve but they just needed more time to get wet (*Excerpt 4a*, line 13). The teacher scaffolded a similar conversation about evidence with another group (see *Excerpt 4b*, lines 1–17). In that exchange, Matthew observed that the salt dissolved right away (*Excerpt 4b*, line 2) while Ethan notes that the beans are not dissolving (*Excerpt 4b,* lines 5–11). The teacher then asked the children if the beans were changing in any way (*Excerpt 4b,* line 12). Leticia and Matthew responded by saying the beans were changing colors (*Excerpt 4b,* lines 13–14). At this point Alexa, who was in a different group (Group 2) but listening in to Group 3, told Mathew that she thought the beans would eventually dissolve if they just kept stirring (*Excerpt 4b,* lines 17). Although, the complete lesson transcript is not presented here because of length, the teacher did allow the children more time to stir the beans until they eventually concluded that the beans will not dissolve in the water. These examples illustrate how our instructional approach helps teachers to scaffold children's sense making in the context of modeling-based inquiry.

Excerpt 4a

| | | |
|---|---|---|
| 1 | *Teacher:* | *And then stir it. Good job. (to Riley) What do you think? They (points to the beans in the water) dissolve? (Riley shakes her head to indicate no.) They're not?* |
| 2 | | |
| 3 | | |
| 4 | *Teacher's Assistant:* | *What do you (John) think? Does it look like they're dissolving? Do you observe them dissolving? (no response from John)* |
| 5 | | |
| 6 | *Riley:* | *(Shakes her head to indicate no.)* |
| 7 | *Teacher's Assistant:* | *No? Why not?* |
| 8 | | |
| 9 | *Rose:* | *I can still see [[them* |
| 10 | *John:* | *It will. It will.* |
| 11 | *Teacher's Assistant:* | *You think so still?* |
| 12 | | |
| 13 | *John:* | *Yeah, [[it (the beans) just it just has to get wet.* |

Excerpt 4b

| | | |
|---|---|---|
| 1 | *Teacher:* | *Okay, what do you guys notice, what are you observing?* |
| 2 | *Matthew:* | *[[The salt, the salt dissolved right away.]]* |
| 3 | *Ethan:* | *[[The beans]]* |
| 4 | *Teacher:* | *The beans? What about the beans Ethan?* |
| 5 | *Ethan:* | *They ain't.* |
| 6 | *Teacher:* | *They what?* |
| 7 | *Ethan:* | *They ain't.* |
| 8 | *Teacher:* | *They aren't what?* |
| 9 | *Ethan:* | *Disserving* |
| 10 | *Teacher:* | *They're not dissolving?* |
| 11 | *Ethan:* | *No* |
| 12 | *Teacher:* | *Are they changing?* |
| 13 | *Leticia:* | *Changing colors, yeah.* |
| 14 | *Matthew:* | *Changing colors!* |
| 15 | *Teacher:* | *They're changing colors?* |
| 16 | *Matthew:* | *Yeah! A little, but they're not but it's change colors.* |
| 17 | *Alexa:* | (from another group, to Mathew) I think they will solve (dissolve) |
| 18 | *Teacher's Assistant:* | You still think they might. I don't know, the salt didn't take that long to dissolve, though did it? |
| 19 | *Leticia:* | *Yeah!* |
| 20 | *Alexa:* | [[Just keep stirring, see if that will ((inaudible))*]]* |

One important feature of the lesson was that the children's inquiry did not follow a proscribed linear path from posing questions, to planning, to collecting and interpreting evidence etc. Rather, children cycled back and forth fluidly between posing questions, making predictions, engaging in explanation, and collecting and interpreting evidence. This is illustrated towards the end of *Excerpts 4a and 4b*, where the children were engaged in *c*ollecting and interpreting data on whether or not the salt and the beans dissolve when mixed in water. Both John (*Excerpt 4a*, lines 10–13) and Alexa (*Excerpt 4b,* lines 17, 20) thought that the beans had not had sufficient time to dissolve in the water. Alexa introduced the prediction that if the beans are stirred some more, they will dissolve. This kind of fluidity in inquiry is consistent with our view of modeling-based inquiry as complex and non-linear.

The results of the SLP project (Samarapungavan et al., 2011) provide support for the integration of modeling-based inquiry in science instruction with young children. Samarapungavan et al. (2011) showed that children engaged in modeling-based inquiry as part of the SLP intervention developed richer and more sophisticated science knowledge and also developed a better understanding of the processes of scientific inquiry than their comparison peers in demographically similar comparison classrooms which implemented routine (non-modeling-based) science instruction. Children in comparison classrooms typically learned science by reading fictional and informational text that incorporated science (usually stories about dinosaurs or farm animals) or sometimes by watching television shows or movies with science content. Learning was typically focused on vocabulary acquisition rather than developing conceptual models (see Samarapungavan et al., 2011, for a more detailed description). For example, the children in the SLP intervention outperformed their comparison peers on the end-of year Science Learning Assessment (SLA). The group differences were statistically significant ($p<.01$) and the effect size as measured by Cohen's D (ES = 2.25) was large.

## Discussion and Implications

As our own example presented above and the research of others we have cited shows, young children indeed are capable of engaging in modeling-based science learning through inquiry. They can articulate, evaluate and revise their models and communicate with and about their models as they participate in scientific inquiry. While research on models and modeling-based science teaching and learning in early childhood settings is still in its infancy, in recent years researchers have emphasized that when young children engage in modeling-based science inquiry, they not only better understand important aspects of the activity of scientists at an early age, but they also develop more sophisticated and robust science knowledge. Collectively, the current body of empirical work on young children's learning through modeling confirms the promise of the recommendations embodied in the current science education reform documents including the A *Framework for K-12 Science Education* (2012) for the *Next Generation Science Standards* (Achieve, Inc, 2013).

## *Implications for Classroom Practice*

That said, the successful implementation of modeling-based inquiry instruction with young children requires activities that find entry points in children's phenomenological experience and prior knowledge for model articulation, elaboration, and revision. As noted in the introduction to this chapter, the cognitive research on the development of young children's knowledge of the natural world in infancy and the preschool years is a rich source of information on such entry points. The processes of modeling in young children develop in tandem with other key domains of skill and knowledge including literacy and numeracy as these skills are actively engaged in the processes of modeling science phenomena. This requires the refinement of teachers' existing pedagogical content knowledge to develop a repertoire of productive strategies for facilitating student science discourse. For example, teachers need to be able to "see" the emerging science in children's classroom discourse (Hammer & van Zee, 2006). Developing a more fine grain-grained understanding of productive discourse strategies and how these may be supported during instruction is vital to effective preservice teacher education as well as inservice teacher professional development in the primary grades.

Another implication for implementing early childhood modeling-based science inquiry instruction involves assessment. Modeling experiences offer opportunities for children to ask unique questions and see connections between concepts. Yet high stakes assessments and evaluation procedures typically discourage the kind of conceptual thinking that is the centerpiece of modeling-based inquiry. In many cases, the continued emphasis on memorization of isolated pieces of information, starting at an early age, trivializes learning. It is an educational imperative for assessment to be viewed as an extension of the process of learning, rather than something that isolates children from knowledge.

Finally, the cultivation of a vision of the role that modeling might play in early childhood science contexts, must necessarily include a discussion of how teachers can be supported as learners. In an educational climate where the deskilling of teachers often results from test-driven or pre-packaged (teacher proof) curriculum materials, modeling-based inquiry approaches must first be viewed as valuable and worthwhile. Kenyon, Davis & Hug (2011) note that both prospective and practicing teachers have limited experience in scientific modeling practice, and particularly its application in early childhood settings. In this regard, teachers may not understand the purpose of models, how to engage young children in modeling experiences, or the role of discourse in communicating children's understandings of everyday phenomena. Windschitl and Thompson (2006) link the use of modeling to teachers' understanding of the nature of science, suggesting that their use of modeling-based inquiry may be constrained by the extent to which they hold to a belief in the scientific method. As schools attempt to solve the educational problems that confront them in the twenty-first century, there is an urgent need for transcending concrete and formal ways of thinking—modeling-based inquiry has the potential to draw inspiration from children's lifeworlds in building curricula that unlocks relationships between everyday phenomena.

## *Implications for Future Research*

As we reflect on the implications of modeling-based science instruction for research, we return to Albert Einstein. At an early age, Einstein's sense of wonder was engaged when his experiences with everyday phenomena conflicted with what was already established in his mind. Anyone who has had the opportunity to observe and interact with young children will have quickly noticed how they spend much of their time asking questions about their world. Yet far too often children quickly learn how to answer questions without inquiring further. Modeling-based inquiry science teaching and learning has the potential to support dynamic rather than static science education practices that recognize the inherent value in children's questions. In this sense, it requires teachers to build on children's abilities to ask questions before being asked. The use of models and modeling in early childhood settings clearly presents a unique combination of benefits and challenges for practitioners, giving rise to many questions for further study: How do teachers create classroom learning environments that position children at an early age to think about their own thinking? What patterns of argumentation are evident in young children's classroom discourse about modeling? What are the scope and limitations of various types of models in early childhood science learning contexts? How do young children's modeling practices develop and change over time? How do teachers understand modeling-based inquiry science instruction for early childhood learners? How do teachers' understandings of the processes of model-based inquiry influence their instructional practices and discourse strategies? As Crawford and Jordan (2013) pointed out, questions range from considerations of modeling as a practice to the notion of "how we test ideas using models in our own research" (p. 120). In the midst of our consideration of some of the implications of models and modeling for research and practice, we emphasize the importance of ultimately using contextualized approaches to better understand the impact on student learning.

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# Chapter 13
# Connecting Young Children with the Natural World: Past, Present and Future Landscapes

**Deborah J. Tippins, Stacey Neuharth-Pritchett, and Debra Mitchell**

## Connecting Young Children with the Natural World: Past, Present and Future Landscapes

The Earth is the only planet within our solar system that presently supports life as we know it. It is undeniable that as humans we have come to be because of our relationship with the Earth. Wilson's (1984) biophilia hypothesis suggests that because humans are connected to all living things, they are predisposed to interact with other living beings in the natural world along with the elements that support life. The natural world consists of complex connections between animals, plants, humans, rocks, pebbles, rain and many more living and nonliving elements. Opportunities for young children to know the Earth and learn to live with and respect the plants and animals that comprise it, may ultimately be necessary for human survival in the future.

Despite the importance of connecting with the natural world, many young children may be growing up without ever experiencing the sensation of soil on their hands or the breeze on their face. They may have limited experience with the uncertainty of the outdoors which cannot be regulated by human control—the unexpected dawn chorus of birds, squirrels darting across the path, or the sense of wonder in nature about which Rachel Carson (1965) writes so eloquently. Bowers and Martusewicz (2006) argue that lack of these relationships with nature "are a major reason for the rapid degradation of the environment—and to the undermining of the

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traditions of self-sufficiency in other cultures (p. 3)." Children at a young age are often encouraged to "save" the environment through personal choices or political activism. Yet, as Sanera (2008) points out, these early childhood curricular activities may not necessarily transfer to long-term care for the environment if children have neither had the experiences nor the opportunities to establish relationships with the natural world. Additionally, Santostefano (2008) notes that without relationships with nature, young children may be less able to establish a sense of self—an ideal that is at the heart of early childhood education.

Richard Louv (2005), in his nationwide collection of interviews regarding people's relationships with nature, coined the idea of "nature-deficit disorder" to argue for the transformative power of nature for today's youth. In his book "Last Child in the Woods: Saving our Children from Nature-Deficit Disorder," Louv cites groundbreaking research, anecdotal stories and compelling narratives to make the case that in a time of rapid economic, social, and technological growth the "future will belong to the nature smart" (p. 14)—those children (and parents) who develop deep and long-lasting bonds with nature. Louv discusses the "culture of fear" and other factors that limit young children's interactions with nature and ultimately influence changing perceptions of childhood. Building on his initial work, Louv (2011) offers precepts to guide adults in reconnecting with the nature of their childhood in his book "The Nature Principle: Human Restoration and the End of Nature-Deficit Disorder." We are living in times of escalating health crises among children that are linked to poor nutrition and lack of experience and diminished time in the natural world.

In the past decade, numerous studies have examined the consequences of changing perceptions of early childhood, and by extension, changes in the way young children experience the natural world. Many of these studies make recommendations that are not grounded in empirical research, but rather stem from a conceptual review of the literature. Among the empirical studies, findings critical for young children suggest that direct experience with nature is diminishing (Kellert, 2008). Wridt (2004) documents how children's access to public play space is declining. Rideout and Hamel (2006) report that young children spend increased time with multimedia such as television and videogames and Sallis et al. (1993) suggest that the prevalence of childhood obesity may be connected to the lack of outdoor play.

Despite these highlighted concerns, activities and curricula situated in outdoor places such as school gardens have been shown to encourage better eating habits (Allen, Alaimo, Elam, & Perry, 2008), willingness to try different vegetables, and behavioral changes in food choice by increasing students' knowledge of fruits, vegetables and plants in general (Ratcliffe, Merrigan, Rogers, & Goldberg, 2011). Some researchers (Bell, Wilson, & Liu, 2008) posit that the presence or lack of green space may be an important factor related to the overall health of today's youth. Several studies shed light on how children DO interact with the natural world. In Anggard's (2010) study of Swedish preschools, the author studied 32 children between 1½ and 6 years old and their teachers over a 1-year period. Anggard used ethnographic data collection techniques such as video observations, interviews, and local documents to study how children interacted with nature in everyday activities, with a particular outdoor focus. The analysis revealed three primary ways in which young children used nature: as a classroom where children learn about nature, as a home—a peaceful place for eating, sleeping and playing, and as an enchanted world—a type of fairyland. Fjortoft (2001) compared how two groups of kindergarten children in Norway engaged in outdoor play. The 46 kindergarteners in this study consisted of two groups. One group of children used the school playground for daily playtime of 1–2 h with occasional nature trips. While the other group had access to the same playground facilities, they could also play in the forest adjacent to the school. A physical fitness pre-test and post-test was given to both groups. Post-tests showed that the children who played in the forest environment performed better on motor skill tests than the children who played solely on the traditional playground. Educators today are asking many questions about children's relationship with the natural world and with each other. Many of these questions are not new to science or early childhood education; rather, they are rooted in a long history of ideas such as the Nature Study Movement and John Dewey's pragmatism as it applies to science education.

The goal of this chapter is to start a conversation about children and nature in relation to twenty-first century early childhood science education. We do so by first examining the historical context regarding nature education by using school gardens and gardening as an example. We then situate the conversation in the context of current rhetoric and reform specific to early childhood education. We discuss several emergent trends in early childhood science with relevance to childhood and nature, and the tensions or challenges that surround them. We speak of tensions as productive moments of change that have the potential to move forward our understandings. Finally, we conclude with a vision and discussion of possibilities that the future may hold for strengthening the young child's connection with the natural world. For the purpose of this chapter we define early childhood in accordance with the National Association for Education of Young Children as spanning the range from birth to eight. A thorough review of all of the environmental and outdoor education literature as it pertains to young children is beyond the scope of this chapter.

## Children and Nature: The Historical Landscape

The incorporation of the outdoors and natural world into early childhood education, and school gardens in particular, is not new—it has deep roots in America's historical connections with the land. The strong history of school gardens in the United States, as a centerpiece for the learning of science, is one which mirrors the waxing and waning of the progressive movement in education. The American education system, particularly in science, has shifted from a traditional focus to a progressive one and back again several times (Bracey, 2007). When the pendulum is swinging toward progressivism, gardening and other ways of knowing the natural world are seen as highly appropriate and useful in education. When the swing is toward traditionalism, technological advances aimed at placing the U.S. in a higher globally competitive position come to be viewed as the primary goal for fostering scientific literacy.

**Gardening** Gardening, meaning the intentional cultivation and management of plants, has different purposes—for food, medicine, wildlife, education, or ornament. For young children, gardens foster an authentic context for questions to emerge through first-hand experience: How many seeds are planted in this row? How many seeds will germinate? What does the soil feel like? What happens when seeds are given different amounts of water? How tall is the tallest flower? In terms of educational practice, gardening is an important part of the history of early childhood education and schooling in general. In Europe, the idea of school gardens dates back to the 16th and 17th centuries in Italy where botanical gardens, common in cities, were extended to schools (Subramaniam, 2002). In the eighteenth century France, Rousseau (1762/1979) developed his philosophy on social reform and recommended school gardens for young children to support his theory of learning of education through nature. In 1869, Austrian law mandated a garden in every school leading to a count of over 100,000 school gardens in Europe by 1905 (Dunnigan, 1999). In the mid nineteenth century in Switzerland, Fröebel coined the term kindergarten, literally meaning "children's garden" in reference to the methods he had developed for the education of young children, which included singing, dancing, and gardening along with "free work" (Liebschner, 1992). A similar concept of "work," or purposeful child-driven activity that enables a closeness with nature, is central to the Montessori pedagogy that was also developed in the early twentieth century in Italy (Standing, 1957). There is no doubt that these roots of European school gardening helped to establish a garden movement in early childhood and elementary education settings among schools in the United States.

**Nature Study and School Gardening for Young Children** Benjamin Franklin, founder of the American Association for the Advancement of Science and early American elementary science education, established some of the first schools in the U.S. that included gardening (Franklin, 1749). Later, with the advent of the American Industrial Revolution (1820–1870) and Civil War recovery efforts, there was an increased movement from rural, agricultural communities to cities. Spurred by the search for work, people were increasingly separated from nature. The introduction of Nature Study (McComas, 2008) came at a time when the observed loss of "practical knowledge" and experience with nature and agriculture triggered President Theodore Roosevelt's establishment of the Commission on Country Life, lead by Cornell professor Liberty Hyde Bailey (1915), which sought to revitalize country life and connections to nature (Kohlstedt, 2005; McComas, 2008). Bailey's colleague, Anna Comstock, developed a curriculum for nature study, dubbed *Handbook of Nature Study* (1911), and led professional development for teachers of young children. The goal of the Nature Study curriculum was to promote learning about nature while in the environment. Other curricular materials, such as Annie Engell's *Outlines in Nature Study and History: A Textbook for Pupils in Elementary School* (1900) assisted teachers in guiding young children's learning in the garden. Nature study was put into practice in schools around the country, including Dewey's Laboratory School at the University of Chicago (Harms & DePencier, 1996).

**Gardening at Dewey's Laboratory School** Dewey was the founder and director of the University of Chicago Laboratory School between the years of 1896 and 1904. The school served as a place for testing philosophical ideas in a joint venture among students, parents, and teachers (Mayhew & Edwards, 1936). The Laboratory School also served as a context for educational research and opportunities for putting Dewey's educational theory into practice. The school emphasized communication and problem solving such that children, who were seen as ever-changing beings in an ever-changing world, would be prepared to make their own way through life; that is, not to fill a pre-determined slot in society. Dewey was adamant about the placement of the child at the center of the educative process. The child-centered focus differed from that of the other school founder, Francis Parkman, who wanted the school to center on nature itself. Dewey and Parkman were able to merge their intentions for the school by integrating the study of nature into a child-centered program (Harms & DePencier, 1996). The school integrated disciplines with community and family life, blurring the boundaries of traditional subject domains. Children were guided in activities that incorporated inquiry and analysis around such topics as storytelling, cooking, woodworking and gardening, in a manner consistent with understanding the properties of materials, history, and usefulness in everyday life of society (Dewey, 1900). Gardening was embedded in the curriculum in a way that mirrored Dewey's child-centered approach. His metaphor of "growth" was carried out in the garden where young children were taught to nurture plants (and people) with care (Pudup, 2008). In other words, for the children at Dewey's Laboratory School, the content was not separate from reasoning and decision-making, and not separate from moral development associated with gardens. His garden-science-education approach was a pedagogy process always-in-the-making which continues to influence early childhood science education today.

The involvement of young children in school gardening was also emphasized during the years of the Great Depression and throughout World War II. In Marye's (1933) account of school gardening in the Atlanta area she notes that science learning was not the sole or even main purpose of engaging young children in the garden. She writes, "the school gardens are laboratories. Here children experiment, test soils, learn the needs of different plants—all with the basic idea of having each child carry back to his home the desire to build a garden" (p. 433). During the depression years, young children in Atlanta planted seedlings in school gardens that were transplanted to more than 150,000 home gardens. Widespread school gardening continued throughout World War II with adults, community members and students in secondary schools joining young children in the development of what became known as Victory Gardens—a nationwide effort to support the national food supply during a time of war (Lawson, 2005). Victory Gardens grew nationwide into an enormous collective effort, numbering 20 million in 1944, led by the inspiration of First Lady Eleanor Roosevelt (Lawson, 2005). The Victory Garden movement proved to be empowering for both youth and adults, providing a sense of solidarity in the cultivation of food during the national unrest of wartime. School gardens, as a context for early childhood learning, gradually waned in the years following World War II due to increased pressures of suburbanization, together with a shift in attention to technological developments and materialism. Despite the renaissance of gardens nationally, the movement hinged on war, and when the war ended so did the excitement around Victory Gardens. Public interest in gardening also declined with the Korean War of the 1950s following in close proximity to WWII. However, as Lawson (2005) points out, the 1960s and 70s brought a resurgence of gardening in the form of community and urban gardens as counter-culture response to the unrest associated with the Vietnam War and the Civil Rights movements. This renewed interest in gardening was short-lived as the relocation of people and jobs from cities to suburbs increased exponentially during the 1980s and 90s. In the past decade, there has been a renewed interest in the role that school gardens can play in early childhood science. Today, the White House lawn again models support of school gardening nationwide with a community-sized kitchen garden and bee hives, driven by First Lady Michelle Obama's focus on the need for improved nutrition and fitness among America's youth (Obama, 2012). Nevertheless, school gardening requires work, an investment of self, time and energy. It requires collaboration and organization of teachers and community members. It requires that caregivers of students also agree to become caregivers of gardens, not only during the school year, but also during the summer. These hurdles are more likely to be overcome when educators become informed of the academic benefits of school gardening. Klemmer, Waliczek, and Zajcek (2005) noted significantly higher scores on achievement tests when gardening activities were integrated simultaneously with or reinforced objectives. Eick (2011) found that gardening is associated with demonstrated improvements in literacy achievement, which is a significant metric in light of the Common Core Standards approach to integrating literacy with science. Blair (2009) reported an overall enhancement of achievement through gardening due to enhanced relationships among teachers and students.

## Moving from a Historical Perspective to the Current Context of Children and Nature Within Early Childhood Education

Despite a rich tradition of connecting young children to nature, the proliferation of large-scale early childhood education programs across the United States suggests a need to re-examine the role of science education and children's experience with nature. While almost every state with such programs has early childhood education standards for science (Brenneman, Stevenson-Boyd, & Frede, 2009), it appears that, for the most part, early childhood teacher preparation programs do not emphasize standards-based teaching and learning in the context of education for young children (Appleton, 2003) and that there is relatively limited empirical evidence on the effectiveness of early childhood science teaching and its influence on young children's development (Klein, Hammrich, Bloom, & Ragins, 2000; Sackes, Trundle, Bell, & O'Connell, 2011). Patrick, Mantzicopoulos, and Samarapungavan (2009) note that focused experiences with science in kindergarten classrooms have the potential to promote motivation for science learning, a natural disposition of young children (Eshach & Fried, 2005). However, these early childhood science experiences are relatively limited in the overall early childhood curriculum (Early et al., 2010; Lanahan, Prinicotta, & Enyeart, 2006; NAEYC, 2002).

Other contemporary reforms in education such as the introduction of the Common Core State Standards are critiqued for their developmental appropriateness as well as their failure to explicitly focus on science as a distinct area of knowledge (National Association for the Education of Young Children (NAEYC), 2011). Educators such as Gruenewald (2003), Louv (2005), and Orr (2004) argue that decontextualized curriculum standards and high-stakes testing actually contribute to the estrangement of children from nature. In addition, teachers often feel pressure to minimize science instruction, particularly in outdoor settings, in favor of other curricular areas such as literacy (Greenfield et al., 2009). Research also points to the role of teacher support for learning in science; children who are highly motivated to learn science, in spite of lower academic achievement, report less teacher support for learning (Mantzicopoulos, Samarapungavan & French (2008)).

Another trend in early childhood education involves reconceptualizing practice with a focus on learning rather than on just cognitive outcomes (Hatch, 2010). For example, Segal (1996) notes that it is important for early childhood educators to establish a combination of appropriate instructional support coupled with exploration, free play, and discovery. Siry and Lang (2010) extend this thought by focusing on teacher-child relationships and exploration of the natural world through teacher-child interactions. According to Siry and Lang, these interactions should center on dialogues and conversations where young children can explain their ways of knowing in nature. Although contemporary practices in early childhood education on the whole may be focusing attention away from children's connections with the natural world, there are a number of modern practices from which we may draw hope for facilitating these connections.

## Engaging Young Children with Nature: Trends in the Twenty-First Century Landscape

**Citizen Science for Early Childhood Youth** Citizen Science is an emerging pedagogy in science education which seeks to bridge the growing chasm between professional science and science education. Some of the early examples of citizen science can be traced back to Benjamin Franklin's efforts to engage people in collecting weather data and attempts to document the number of birds that flew into lighthouses during the 1800s (Mueller & Tippins, 2012). Perhaps the most famous citizen science project is the Audubon Christmas Bird Count which has involved thousands of citizen scientists since the early 1900s in counting and documenting early winter bird populations (this project continues today). Youth of today are involved in a wide range of citizen science projects such as butterfly migration monitoring, worm and weed watches, pollinator counts, water quality monitoring, ant surveys, and many more. More than 200 citizen science projects worldwide can be found on the Citizen Science Toolkit (2009) website (www.citzienscience.org), many of them related to biodiversity and climate change.

Traditionally, approaches to citizen science were top-down in nature, with local youth collecting data for scientists' projects. There were few opportunities for youth to formulate questions or analyze data with relevance to local issues in these projects. More recently, there has been a movement to re-define citizen science such that youth, including young children, are repositioned as producers of scientific knowledge and members of the scientific community. One assumption behind this movement is that young children are citizens who can make decisions which impact their everyday world.

Examples of citizen science projects created specifically with early childhood youth in mind are *Project Budburst*, *Classroom Feeder Watch*, *Project Squirrel* and *Project Pigeonwatch*. While these projects still reflect, for the most part, characteristics of a top—down approach, they are designed more clearly with young children's interests in mind. In *Project Squirrel* young children observe the squirrels in their neighborhoods and share information about them by submitting photos. *Project Pigeonwatch* provides opportunities for children living in urban areas to record and share their observations of pigeons and other city-dwelling birds. *Project Budburst* is one of the more well-known citizen science projects for young children. In this citizen science project young children select a plant and make regular observations of it throughout the year. They monitor their plant and observe how it changes across seasons. They can submit ecological data about their plant, including information about the first leaves, flowers or fruits to be observed on their plant. Similar to the projects described above, *Lost Ladybug* is a citizen science project in which children identify ladybugs and submit photos to a national database. This project is a response to the declining numbers of native ladybug species with a corresponding increase in the number of invasive species that can be found in the United States. In this project, young children use sweep nets to capture ladybugs living in fields or grasses in the late spring or early summer months. The ladybugs are placed in a cooler for about five min, slowing their metabolism so that children can easily photograph them. At the same time, children learn not to harm these insects and the importance of releasing them back into the wild. The school garden can also serve as a context for young children to be citizen scientists. *Bee Hunt*, for example, is a citizen science project that involves children with counting the number and kinds of pollinators that visit their school garden. Children can explore questions such as: Are some plants visited more often by certain pollinators? How does the weather affect the number of pollinators visiting the garden? Children photograph the pollinators in the garden and submit them to a national data base, and even compare their findings with data collected at other school sites. One of the tensions surrounding the citizen science movement is the legitimacy of the data children collect. Some scientists question whether the data generated by children can really be trusted in terms of its accuracy. In contrast to this deficit view of knowledge, we would argue that young children's knowledge, though different than that of scientists, still has the potential to enrich our understandings of the natural world. We emphasize that everyone, even young children, can offer something to today's conversations about the environment.

There are numerous citizen science projects worldwide which provide a context for young children to enact environmental concerns in their immediate world. Anecdotal evidence suggests that in the process they may come to feel that they can make a difference when they know that other youth and adults take their data seriously (Cohn, 2008; Jenkins, 1999; Mueller, Tippins, & Bryan, 2011; Schibsted, 2007). Additionally, anecdotal evidence suggests that citizen science projects encourage children to spend more time outside where they can begin to know and develop an ethic of care for the natural world. The inherent benefits of children's participation in such projects at an early age is widely discussed throughout the citizen science literature. However, much of the empirical research surrounding the perceived benefits of citizen science has focused on middle and secondary classrooms or the public at large (i.e., Trumbull, Bonney, Bascom, & Cabal, 2000; Trumbull, Bonney, & Grudens-Schuck, 2005). As a focus of research, Gaydos and Squire (2012) have even inquired into what students learn about the practice of citizen science in digital worlds. Yet with one exception, few empirical studies have looked at the impact of citizen science participation on young children, clearly pointing to the need for additional research.

Alexander and Russo (2010) conducted a study to shed light on citizen science as an educational context for early childhood education. They investigated how teachers' and children's ideas about the environment were influenced by their participation in the citizen science project, Operation Magpie. Operation Magpie is a citizen science project originating from the University of Southern Australia which engages children in observing, gathering and sharing data about magpies and other birds within the school grounds. The study participants included 22, 6 and 7 year old children and five teachers who were observed and interviewed over a ten week period as they engaged in citizen science activities. Not surprisingly, all of the children demonstrated an awareness of the world around them and an eagerness to engage with it, but demonstrated only limited understanding of relevant science concepts. Children cited outdoor observation and recording of birds and learning about the preservation of birds as some of their favorite activities. The teachers noted that their motivation to teach science was enhanced by their participation in Project Magpie. Further evidence of the success of this citizen science project was documented through records of children using what they had learned in Project Magpie at home with their families.

**Place-Based Science Education** Much of science learning for young children is grounded in their natural curiosity and explorations of the immediate environment. In our experiences in early childhood settings, we are sometimes surprised to find young children participating in activities focused on rainforests and jungles far removed from their everyday lifeworlds. Some of us have been guilty, ourselves, of framing children's experiences with the natural world in terms of a "tourist" approach, focusing on the exotic, the next scenic overlook, or the highest mountain to be climbed. By contrast, place-based (science) education is considered to be an approach that supports the development of the whole child, a goal consistent with early childhood philosophy. Place-based (science) education typically emphasizes learning situated in the local community, neighborhood or schoolyard and connected to students' lives and interests, or as Smith and Sobel (2010) describe: "an approach to teaching and learning that connects learning to the local (p. viii)." Gruenewald (2003) adds that "place-based educators advocate for a pedagogy that relates directly to experience of the world (p. 7)." van Eijck (2010) points out that children may never develop or may lose a sense of place if their early education experiences focus primarily on abstract, global ideas and issues. Karrow and Fazzio (2010) add to the complexity of meanings associated with place-based education by describing three different conceptualizations of "place" in education: place- as- land or natural environment, place-as-community, and place-as-being. In the first two conceptualizations, place is objectified, and viewed from the perspective of a subject. It is the last meaning, with its emphasis on nurturing an ecological relationship between children and their world, we find particularly appealing in the context of early childhood science education, as it conveys a sense of dynamic and ongoing learning *within* a place. In Karrow & Fazzio's work with Project WormWatch, for example, children forge relationships with worms in their local schoolyard environment.

In the *Geography of Childhood: Why Children Need Wild Places*, Nabhan and Timble (1994) suggest that young children have a primordial connection to the Earth, evidenced in their preference for playing outdoors in small spaces that reflect a sense of animal-comfort. Their perspective is supported by the research of Kirkby (1989) who mapped outdoor behavior of 26 preschool children as they "played" on a half-acre schoolyard. Kirkby observed how children, rather than using the large schoolyard available to them, established three small refuges or "nesting" areas on the densely vegetated margins of the playground, where they engaged in dramatic role play. Sobel (2002) sheds additional light on the processes by which children create place meanings and attachments, noting how their preference for playing with stones, stumps, sand, and other natural materials and for building forts, dens, bush houses, and other special places contribute to the development of persistent emotional ties or place attachments essential to the development of a sense of place.

Place-based education is at the heart of two early childhood movements that offer alternatives to decontextualized teaching and learning—what has become known as Forest Preschools/Kindergartens and Adventure Playgrounds. The Forest Preschools/Kindergartens first became popular in Denmark and Germany. These outdoor place-based schools situate learning in the context of children's interactions with nature. Virtually all of the daily educational experience of Forest Schools occurs outside, as children interact and play with each other and their surroundings. The Forest School movement, with its emphasis on fostering children's awareness of and relationships with nature at an early age, has spread rapidly throughout Europe, Australia, England, and the Middle East. Robertson, Borradaile, and Martin (2006), in their study of Forest Schools, found that children who attended these schools had higher attendance rates, greater concentration, better motor skills and played more imaginatively than those who attended more traditional preschools and kindergartens. The Forest School movement, although slow to reach the U.S., began with the establishment of Cedarsong, a Forest Preschool and Kindergarten on Vashon Island in Washington State. Cedarsong's web-site (retrieved, 2013) describes the curriculum as interest-led, place-based, experiential, and seasonal, reflecting a motto of "children cannot bounce off the walls if we take away the walls." Concerns for safety and health may be partial reasons why Forest Schools were initially slow to catch on in the U.S.; however, the Forest School philosophy is premised on a belief that children grow through reasonable and manageable risks, and that there is no such thing as "bad" weather (Knight, 2009). Similar to the Forest Schools, Adventure Playgrounds (Web Urbanist, 2007) are designed to provide young children with a natural form of play that enhances their sense of place and awareness for local knowledge. These playgrounds, which are free of the mechanical equipment typically found in outdoor play areas, are based on the assumption that children, even at a young age, should have a voice and ownership in the design of outdoor environments. Valuable knowledge for young children is directly related to their everyday reality. However, local, place-based knowledge can also lead to global awareness when children understand how the choices they make can have an effect around the world. For example, by tracing the origins of their food, clothes or toys children can experience how their world is connected to other people and places. Sociologist Roland Robertson (2012) explains how the boundaries between the local and global are becoming more blurred, with local knowledge and process giving meaning to global influences and vice versa. He recently coined the term *glocalization* to describe how local, place-based understandings are one aspect of the global.

There is a growing body of research that analyzes place-based education and "pedagogies of place" in the context of early childhood education. For the most part, the early childhood literature reflects an uncritical perspective of the nature/child relationship. Gruenwald (2003) was one of the first scholars to theorize a more critical pedagogy of place. Ritchie, Duhn, Rau, and Craw (2010) bring a critical perspective to their examination of the child/nature intersection. Their 2 year qualitative case study, which took place in ten early childhood centers and kindergartens across New Zealand, focused on early childhood teachers' efforts to make ecological sustainability and sense of place a centerpiece of their pedagogy and curriculum. Their study was framed from a bicultural perspective which integrated both Western and Maori indigenous perspectives. Ritchie, Duhn, Rau & Craw found that teachers in the study were initially uncomfortable with addressing sustainability from the perspective of large issues such as climate change, preferring to focus on "developing a sense of place" with young children. Teachers in their study struggled with issues concerning the relationship between local and global knowledge which are integral to education for sustainability. Duhn (2012) suggests that teachers were challenged to think about sense of place and sustainability in ways that disrupt the dominant discourse of early childhood centers as "special places" and teachers as "protectors" of young children. The authors noted that in many of the centers there was a natural fit between indigenous knowledges and issues of sustainability and place. A central theme that emerged through their work highlights the importance of "place-making as a democratic practice." They share the example of one center with an emphasis on recycling of plastics and consumption in the local community. Duhn explains how, for teachers and children at this center, "developing a pedagogy of place meant becoming more vocal and visible within their wider community to further align their practices and existing local knowledge and ways of doing" (p. 26).

In Kalvaitis and Monhardt's (2012) phenomenographic study of young children's relationship with nature and their developing sense of place, students' drawings and narratives were methods central to the research. In this study, 176 children, ages six to eleven, were asked to draw and write about their relationship with nature. These drawings were analyzed using quantitative visual content analysis procedures. Young children in the study (grade 1 and 2) demonstrated a positive relationship with nature, including insects, animals and friends in their drawings. The drawings of older children in the study also reflected a positive relationship with nature, but focused more on natural areas and activities such as hiking that take place in these areas. The authors emphasize the importance of understanding children's evolving relationships with nature and place.

Karrow and Fazzio's series of case studies (2010) used sense of place as a framework for analyzing young children's participation in the Worm Watch project mentioned earlier in this chapter. The Worm Watch project engages children in exploring the ecology of worms through such experiences as identifying juveniles and adults, observing weather and soil conditions, and locating and indentifying worms in a variety of settings. Karrow and Fazzio, drawing on hermeneutic phenomenology, theorize place-as-being, arguing for educating within place because place and being are inextricably linked. Through their Worm Watch studies, these scholars observed how young children participated in the detached, objective and impartial manner of a young scientist (as they roved around searching for worms), which provided little opportunity for them to develop a meaningful relationship with their local environment. In this context, Karrow and Fazzio theorize place-as-difference, and point to the need for developing a more embodied sense of place in young children.

Research demonstrates that place-based education has the potential to foster a life-long ethic of care for the environment, beginning with the early years of a child's life (Hacking & Barratt, 2007; Nespor, 2008). The challenges and possibilities of place-based education for early childhood ultimately rests in educators' ability to analyze deeply held assumptions of early childhood as a time of "innocence that should be kept free of complex knowledge" (Lenik-Oberstein, 1994) or discourses of materialism (Ailwood, 2008) that strongly influence approaches to teaching young children.

**The Young Child and Mindfulness** Kabat-Zinn (1994) defines mindfulness as "paying attention in a particular way: on purpose, in the present moment, and non-judgmentally" (p. 4), while Langer (1989) operationalizes the construct as a conscious state in which a learner is aware of both context and content of information. This extension of awareness of context and the content of information is particularly informative when thinking about young children in the natural world. Mindfulness can unfold through young children's science education by involving children with their surroundings and encouraging dialogue that enables knowledge to develop through the experiences of the communal whole. This realization is found in the two areas of attention and awareness. Brown and Ryan (2003) suggest that attention is the focus on a particular object or experience while awareness is the orientation of the mind and senses. Perhaps in early childhood education we foreclose on these attentive experiences with young children by restricting their interactions with the natural world and failing to include such opportunities in the instructional experiences of young children (Frauman, 2010).

In reorienting experiences for young children and the natural world to practices that were advanced in the 1900s, we can encourage opportunities for mindfulness among young children. Through such experiences, we alter the nature-deficit orientation to young children's knowledge of the natural world. Instead, we begin a lifelong attentiveness to the world ultimately resulting in awareness of the contributions of that natural world to young children's adoption of a curious and accepting perspective on all that is observed through a heightened sense of attention. Early childhood science educators can also facilitate children's mindful connections to the natural world by providing realistic experiences that help children become part of the natural life cycle as they interact with nature and become problem solvers in those environments. Many children merely experience natural world phenomenon by having their teachers explain what will happen in a series of scientific events rather than experiencing those events for themselves. Consider, for example, the common event of a tree fallen in a wooded area near a playground. Children may observe that the tree contains a bird's nest with two newborn birds. Some teachers would note to the children that the baby birds are now in much more danger as the nest is closer to the ground, explaining how other predatory animals may take advantage of the baby birds' precarious position. A teacher might further note that this is part of the life cycle and that the children should not intervene. A teacher who engages in mindfulness practices with his or her early childhood students, however, would pose a series of "What If" questions to help children engage in potential decisions regarding their actions and how their thoughts and actions will influence the outcomes of nature. Questions such as "what if we add water to the clay?," "what if we plant our vegetables in a shady area?," or "what if we bury our pumpkins and dig them up later?" help children foster relationships with the environment as they consider how their own local actions influence the natural world. While there is limited empirical evidence regarding the use of mindfulness practices with very young children, coupled with place-based science education and citizen science approaches, there may be great potential in their use to assist children in making connections with the natural world.

## Looking to the Future: Teaching Children to Value Nature

**Returning to Our Roots** In sharing our vision of connecting children with nature, we return to our roots through the earlier example of the school garden. The school garden can provide a place for teaching and learning science outside of its typical boundaries, in a manner that is integrated with other disciplines. For example, plants in the garden can provide living examples of scientific concepts; they can serve as sources of data for phenological citizen science projects; they can be providers of nutrition and keepers of genetic material. These plants, however, also can provide their own stories—their geographic origins, their histories of how they have moved around the globe, how they came to have the names they do, their uses, and folklore surrounding these. The plants can contribute to art lessons with beauty and textural material, such as those used in collage. They can inspire literary works as they have for ages for poets like Emily Dickinson. They can serve as conversation pieces among children. And they can be teachers.

The school garden can also be a central meeting place for children, friends, and neighbors who may gather there to make plans for action. As places of shared work, the garden and surrounding green space can be cared for by children, who share in the produce grown and contribute excess to a local shelter. For children, many lessons can be learned along the way, as their development is nurtured, and connections made with nature and the larger community through caring and sharing in the garden.

The garden of our future landscape has a design that is integrated into that of the school building, with doorways and windows opening directly to its central location for easy access and lighting. The materials of the garden and school building reflect each other to promote a sense of integration even subconsciously. Buildings and other human-built structures can reflect the manner in which a society or culture views its natural resources in a form of interpretation on a large scale. Depending on the building, it can either connect children to the surrounding environment and a particular place, or do the opposite by working against establishing connections to the environment and community. Kellert (2004) writes of how interconnectedness of humans and the rest of nature are overlooked in architecture. Similarly, Orr (1994) writes of institutional architecture as "crystallized pedagogy," serving as a hidden curriculum that conveys concepts to children just as curriculum that is explicit does, but concepts of human domination, passivity, and artificiality. The school garden is monitored and maintained by children, with the help of the parents, teachers and other community members. It runs on solar energy, incorporates materials and structure that allow for optimal passive heating and cooling, and recycles 90 % of annual wastewater through natural processes, such as phytoremediative plants in a pond that doubles as an irrigation reservoir. Its water catchment system collects rain from the roof and stores it in a cistern. For rural and urban areas alike, this scenario takes place on public lands where schools are built. School grounds are often adjacent to other public lands, such as other schools, libraries, housing projects and parks. These are connected, unifying the tract of land, dissolving imaginary boundaries, while establishing green corridors for wildlife and nature trails—no matter how small the tract of land (it is amazing how, for example, birds find places for their nests amidst skyscrapers and how pollinators find flowers for nectar wherever they are planted). The access that is opened between previously separate land tracts (i.e., between preschool, elementary, middle- and high-schools) allows for older students to become mentors for younger children.

The natural world is ripe with opportunities for innovative and interdisciplinary learning, although at an early age children may not have an explicit awareness of the connections between themselves and all other aspects of the natural environment. In spite of the documented benefits that a profound relationship with nature has to offer children, education in the natural environment in more than a novel manner is rare. How can we reclaim the power of nature for young children? Sobel (2004) emphasizes the need for children to be allowed to love their environment before being asked to save it. Accordingly, the knowledge needed to look after local places begins with a love and attachment to the natural world. We must recognize that without this sense of connection to the environment, children may lose connection to the most immediate natural place in which they live. This immediate connection is the foundation to extending their care and concern for the larger global community. In a study of 357 early childhood educators' perceptions of nature, science and environmental education, Torquati, Cutler, Gilkerson, and Sarver (2013) found that the majority rated nature/environmental experiences as the least important for young children in terms of learning outcomes, when compared with other curricular areas. These researchers also found that the early childhood educators in their study did not feel confident with respect to implementing nature/science activities and were unclear about what they needed to "know and be able to do in order to be effective nature educators" (p. 721). This study highlights the importance of including relevant science and environmental content in teacher preparation courses, providing opportunities for early childhood educators to explore place-based education as a curriculum theme and engaging them in first-hand experiences with nature. In this sense, both children and teachers can build meaningful relationships by participating in, and not just observing nature. The importance of spontaneous learning situations—chasing after butterflies, exploring evaporating rain puddles—cannot be overlooked.

Children's explorations of the local environment should also be grounded in an ethic of respect and care for all life and its diversity. Early childhood teachers can play an important role in fostering care and passion for the environment in a sustainable way. Yet, as Adams, Ibrahim, and Lim (2010) point out, educators must first "make sense of their own relationship with and in a place and experience the tools to bring this place-consciousness into their teaching (p. 227)."

Young children today face an increasingly uncertain future. As we reach the limit of Earth's natural resources, we are faced with melting ice caps, rising sea levels, increased instances of disease, and changes in our abilities to produce food and clean water for a population on a shrinking land mass. If many of our issues lie in the natural environment, should that not be where we concentrate our early childhood education?

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# Chapter 14
# Teaching Science to Young Children with Special Needs

**Sheila R. Alber-Morgan, Mary R. Sawyer, and Heather Lynnine Miller**

In its vision of a well-prepared twenty-first century workforce, the U.S. government has prioritized STEM (science, technology, engineering, and mathematics) education as a primary objective. The 2013 Budget allocates $3.0 billion for STEM education programs, with the goal of improving teaching, engagement, and learning in STEM fields beginning with young children, in order to increase the number of college graduates and career professionals with STEM degrees (White House Office of Science and Technology Policy, 2012). Science is the first pillar in a STEM paradigm of education. Advancement in STEM fields requires a rich foundation in science, and establishing such a conceptual framework in preschool can lead to its expansion and enhancement throughout a child's education, resulting ultimately in great personal and societal economic success (Ludlow, 2013). One aim of the Federal investment in K-12 STEM education is to increase expectations for all students and use evidence-based practices to improve outcomes (White House Office of Science and Technology Policy, 2012).

## Students with Special Needs and Science Education Legislation

Students with special needs belong in the educational pursuit of excellence in STEM fields, as they stand to reap the same benefits as their typically developing peers. Indeed, individuals such as Stephen Hawking, Albert Einstein, Temple Grandin,

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Thomas Edison, and Louis Pasteur have demonstrated that individuals with special needs are capable of succeeding and making meaningful and substantial contributions in the field of science (Ludlow, 2013; Melber, 2004). The Foundation for Science and Disability (FSD) is a professional organization comprised of accomplished scientists and engineers with and without disabilities who are dedicated to overcoming barriers and promoting science endeavors of persons with disabilities (Foundation for Science and Disability [FSD], 2013).

Despite the success of such individuals and groups, however, people with special needs are underemployed in STEM fields; less than 7 % of American scientists have disabilities (Leddy, 2010; National Science Foundation [NSF]. 2013). It is possible that individuals with special needs remain an untapped resource in science professions because, as students, they are not provided with an adequate knowledge base upon which to build further science understanding and skills. In addition, elementary school science teachers report a lack of opportunity to receive professional development that emphasizes the skills necessary for teaching science to learners with special needs (2000 National Survey of Science and Mathematics Education, 2002). A quality science curriculum at the K-12 level and the integration of informal science education are critical components of an authentic understanding of science, and without early exposure to these elements, it is unlikely that students with special needs will pursue careers in science (Melber & Brown, 2008; White House Office of Science and Technology Policy, 2012).

The No Child Left Behind Act of 2001 requires that students with special needs have access to the same high-quality curriculum and instruction as their peers (Irving, Nti, & Johnson, 2007). Central values of special education such as equal access to an appropriate education are violated, however, by the perpetuation of the myth that science is an elitist subject for the brightest students. Unfortunately, this myth is endorsed when educators fail to intentionally provide science instruction that is accessible to all students (Melber, 2004). On the contrary, science is a subject accessible for students at all levels of ability, as it is amenable to modifications and accommodations based on individual learner needs.

Learners with special needs comprise approximately 13 % of the student population, and the majority of these students spend the bulk of their time in general education classrooms (National Center for Education Statistics [NCES], 2012). Further, the number of students with special needs is increasing (Perrault, 2010). In addition to the push for STEM education, federal legislation such as No Child Left Behind also stipulates that standardized state tests include a science component. Students with special needs are likely to receive science instruction from classroom teachers, and these students as well as their teachers will be held accountable on the same tests as students without special needs (Perrault; Steele, 2007). Therefore, it is imperative teachers possess a repertoire of effective strategies suitable to the diversity of their student populations, and that they provide meaningful learning experiences for students with special needs in all subject matter, including science.

Although children with special needs are included in the "Science for All Americans" goal of Project 2061, a program of the American Association for the Advancement of Science (AAAS), they can present a challenge to early childhood and elementary teachers. There is a well-documented lack of scientific background knowledge on the part of teachers of young children (2000 National Survey of Science and Mathematics Education, 2002; Appleton, 2003; Howes, 2002), which can hinder their ability to successfully include science as part of *every* student's well-rounded curriculum. Research into early childhood play has identified the "early childhood error" (Bredekamp & Rosegrant, 1992), where teachers provide a wealth of materials but neglect to give children guidance, support, and explicit content instruction necessary to provide context-specific information. The dual challenges of incomplete content knowledge and the impairments of students with special needs would seem to pose a huge barrier for teachers in their mandated quest to provide developmentally appropriate instruction in all subject areas. Developmentally appropriate practice is fostering learning experiences that are age appropriate, individually appropriate, and culturally appropriate (Copple & Bredekamp, 2009).

## Evidence-Based Science Education

When educators are knowledgeable and skillful in teaching subject matter to all students, including those with special needs, high academic standards are achievable, and such success carries over into adulthood (Irving et al., 2007). As adults, these individuals are then able to interact more effectively with everyday scientific phenomena in their environments and thus live richer and more independent lives (Melber, 2004).

Historically, a gap between research and practice exists in special education, as students with special needs are often exposed to ineffective teaching practices, rather than scientifically effective, research-based methods (Cook, Tankersley, & Landrum, 2009). Additionally, an achievement gap exists in special education in which children with special needs fall further behind their typically developing peers as they progress through each grade. For this reason, it is critical that teachers select efficient teaching practices that have been proven to be effective through controlled research. Requiring teachers to consider evidence based practices when making instructional decisions is also mandated by No Child Left Behind Act of 2001 and the Individuals with Disabilities Education Act of 2004.

With the mission of establishing an empirical foundation of effective practices in education through rigorous scientific research, the U.S. Department of Education created the Institute of Education Sciences (IES; Gersten & Hitchcock, 2009). Subsequently, in 2002, the IES developed the What Works Clearinghouse (WWC) with the intent of creating an authoritative database on scientific, evidence based programs, policies, and practices in education (http://whatworks.ed.gov). The WWC provides the public with access to high-quality evidence on interventions so that instructional decisions can be based on scientific findings and so that researchers can conduct empirically sound evaluations of interventions (Gersten & Hitchcock).

One preliminary screening criterion for the WWC is that the research study must use an eligible design (i.e., randomized controlled trial, quasi-experimental, regression discontinuity, or single subject). In an effort to identify evidence based practices, this literature review examined experimental research that included both control group and single subject designs. Previous literature reviews on teaching science to students with special needs have only included control group experimental designs. In single subject research designs, the experimenter manipulates the independent variable using a design that controls for confounding variables (e.g., reversal, multiple baseline), and determines whether or not a functional relation exists by comparing each participant's intervention data to his or her baseline data. Most of the intervention research for individuals with the most severe learning needs has employed single subject designs, including the research on science instruction.

## Literature on Science Instruction

In previous literature reviews, Mastropieri and Scruggs (1992) and Scruggs, Mastropieri, and Boon (1998) examined science instruction for students with disabilities in elementary through high school grades. The participants in these studies included students diagnosed with learning disabilities, behavioral disorders, developmental disabilities, physical disabilities, visual impairments, and hearing impairments. Mastropieri and Scruggs (1992) identified positive effects for students with disabilities in studies which used mnemonic devices, adaptive texts, structured instructional strategies, concrete experiences, and hands-on materials. In many studies, existing curricula were adapted, with most adaptations being related to a decrease in reading demands and an increase in opportunities for review and practice. They noted that using hands-on materials and focusing on conceptual understanding rather than memorization of vocabulary and text-heavy instruction is consistent with current reforms in science education. The subsequent literature review by Scruggs et al. (1998) supported these findings and concluded that students with disabilities can improve their science achievement with inquiry based activities that provide for necessary amounts and types of structure and teacher support.

Therrien, Taylor, Hosp, Kaldenberg, and Gorsh (2011) conducted a meta-analysis on science instruction specifically for students diagnosed with learning disabilities. Similar to the two previous literature reviews, their review included students in elementary, middle, and high school. Twelve experimental and quasi-experimental research studies published across 30 years (1980–2010) were included in the analysis, and the researchers categorized interventions as structured inquiry, supplemental mnemonics instruction, and supplemental nonmnemonics instruction. Results indicated students with learning disabilities can achieve in science within an inquiry framework; however, in line with the findings of Mastropieri and Scruggs (1992) and Scruggs et al. (1998), students with special needs require structure such as explicit review of key vocabulary and concepts, systematic feedback, and additional hands-on practice to be successful (Therrien et al.).

## Purpose

This literature review extends previous reviews on science instruction for children with disabilities by focusing specifically on teaching science to young children with special learning needs (preschool through fourth grade). Aligned with the What Works Clearinghouse inclusion criteria for evidence based practices, this literature review includes only research studies which used designs that produced quantitative results and demonstrated experimental control (i.e., control group designs and single subject designs). The purpose of this literature review is to identify evidence based practices for teaching science content and skills to young children with special needs, identify directions for future research, and provide recommendations for practitioners.

### *Method*

Before beginning the process of identifying relevant literature for this review, the authors established the inclusion criteria. The inclusion criteria consisted of studies that (a) examined instruction of science content as an independent variable, (b) examined student outcome measures related to science content, (c) included participants with disabilities (learning disabilities, intellectual disabilities, behavior disorders, autism, multiple disabilities, and other health impairments) in pre-K to fourth grade including pre-K participants considered to be at risk, (d) used true experimental, quasi-experimental, or single-subject experimental designs in which the effects of manipulating an independent variable were examined on student outcomes, and (e) were published in peer-reviewed journals between 1992 and 2013.

The authors then searched for articles meeting these criteria by using data based websites including EBSCO-HOST, Education Research Complete, ERIC, PsychInfo, Psychology and Behavioral Sciences Collection, Education Abstracts, and Google Scholar. In order to capture as many articles as possible that met the inclusion criteria, we used the following search terms: science *plus* content, instruction, inquiry, comprehension, vocabulary, or hands on; and disabilities, at risk, elementary, early intervention, young children, or preschool. After the initial search was complete, we conducted an ancestral search that involved reviewing the pertinent studies cited in the articles.

Following the searches, the authors met and conducted a screening based on titles and abstracts. Next, the authors examined the articles more closely to determine if they met the inclusion criteria. The second and third author read each study that met the criteria and recorded detailed descriptions of participant variables (gender, age, disability, and ethnicity), settings, research designs, dependent variables, independent variables, and results. These descriptions were then given to the first author who independently reviewed the studies and made additions and corrections to the original descriptions. The second and third authors then examined the revised descriptions and came to agreement on content to be included in a final table. This review is based on the 12 research studies that met the inclusion criteria. These studies are delineated in Table 14.1.

**Table 14.1** Research studies on teaching science to young children with special needs

| Authors/year | Participants | Design | Independent variable | Dependent variables | Results |
|---|---|---|---|---|---|
| Aydeniz et al. (2012) | Two fourth grade boys with LD | Single subject: (multiple probe design across skills) | Electric Circuit Kitbook | Percent correct on immediate conceptual and application tests | A functional relation for acquisition and maintenance was demonstrated for all participants |
| Bay et al. (1992) | Four male fourth graders (two with LD and two with BD) | Control Groups Comparison (experimental) | Compared discovery teaching to direct instruction using SAVVSELPH materials | Percent correct on immediate post test, two-week maintenance test, and a performance based generalization measure | Students with LD in the discovery teaching condition achieved higher scores on maintenance and generalization tests. No difference for immediate tests |
| Dalton et al. (1997) | 33 fourth graders with LD (14 male, 19 female) | Control Groups Comparison (quasi-experimental) | Compared Supported Inquiry Science (SIS) to Activity Based Science (ABS) | Pre and post test scores on a short answer test and a diagram test | Students with LD in the SIS condition scored higher on both measures |
| Gonzalez et al. (2011) | 148 low income preschoolers at risk for reading disabilities (68 male, 80 female) | Control Groups Comparison (experimental) | Shared book reading | Pre and post test scores on receptive (PPVT-III and experimenter developed) and expressive vocabulary (EOWPVT and experimenter developed) | Preschoolers in the shared book reading condition made gains on expressive vocabulary measures. No significant different in receptive vocabulary measures |
| Greenfield et al. (2009) | 168 low income preschoolers (84 male and 84 female) | Control Groups Comparison (quasi-experimental) | Early Childhood Hands-On Science (ECHOS) | Scores on head start readiness domains | Significant treatment effects were found for four of the eight readiness domains |
| Knight et al. (2011) | Three male first graders with autism | Single subject: (multiple probe design across sets) | Explicit Instruction (model-lead-test) | Correct responses on immediate and delayed probes | A functional relation was demonstrated for all participants |

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|---|---|---|---|---|---|
| Martinez-Alvarez et al. (2012) | Eight fourth grade ELLs with disabilities (six with LD, one with ED, and one with OHI), gender not specified | Control Groups Comparison (quasi-experimental) | InSciRead curriculum | Scores on a pre and post test using the detecting incongruities measure | Moderate effects for ELL students with disabilities |
| Mastropieri et al. (1998) | Five fourth graders with disabilities (four male and one female; two with LD, one with mild intellectual, one with ED, and one with multiple disabilities) | Control Groups Comparison (quasi- experimental) | Compared an activities based approach to a textbook approach | Scores on a pre and post recognition and recall tests | Students with disabilities in the inclusive classroom achieved higher scores on both measures in the activities based approach |
| Nelson et al. (1992) | Two male fourth graders with LD | Single Subject (multiple baseline across settings) | Summary strategy | Comprehension test scores and percent of important information included in the summary | A functional relation was demonstrated for each participant on both outcome measures |
| Smith et al. (2013) | Three second graders with severe intellectual disabilities (one male, two female) | Single Subject (multiple baseline across skills) | Early science curriculum (inquiry based) | Scores on immediate post tests of items answered correctly | A functional relation was demonstrated for all three participants |
| Scruggs et al. (1994) | 14 fourth graders with mild disabilities, gender not specified | Control Groups Comparison (experimental) | Elaborative interrogation | Scores on immediate post tests each session and two-week maintenance tests | Participants with LD in the elaborative interrogation condition scored higher on both immediate and delayed measures |
| Utley et al. (2001) | Five second graders with developmental disabilities (two male and three female) | Single subject (reversal design) | Classwide peer tutoring | Percent correct on topic items on daily post tests | A functional relation was demonstrated for all participants |

## Results

### Participants

The total number of participants (pre-k through fourth grade) in the 12 studies was 395. Out of the 395 participants, 184 (46.5 %) were male, 189 (47.8 %) were female, and, for 22 participants (5.5 %), gender was not specified. These studies included 316 (80 %) preschoolers and 79 (20 %) school age students in grades K through 4. The 316 preschool participants were enrolled in Head Start programs and determined to be at risk, specific disabilities were not identified for these participants. Of the 79 school age participants (6 first graders, 5 s graders, and 68 fourth graders), 61 (77 %) had learning disabilities, eight (10 %) had severe intellectual disabilities, four (5 %) had behavior disorders, three (4 %) had autism, one had a mild intellectual disability, one had multiple disabilities, and one was identified with an Other Health Impairment (OHI). Ethnicity was reported for 93 % of the participants, 192 (49 %) were African American, 89 (23 %) were Latino, 51 (13 %) were Caucasian, 14 (4 %) were Haitian, one (.03 %) was Asian, and 20 (5 %) were reported as "other." For 28 (7 %) of the participants, ethnicity was not reported.

### Setting and Instructional Arrangement

Of the 12 studies, 10 were conducted in public school general education and special education classrooms (one of those 10 was conducted during a summer school program), and two were conducted in public preschool programs for at risk children from low income families (i.e., Head Start). Four of the studies were conducted in urban school districts, three studies were conducted in suburban and rural school districts, and one study was conducted in urban and suburban school districts. The other four studies did not report the type of community setting where the study was conducted.

In terms of instructional arrangement, three of the studies were implemented using large group instruction in a general education classroom (Dalton, Morocco, Tivnan, & Mead, 1997; Martinez-Alvarez, Bannan, & Peters-Burton, 2012; Mastropieri et al., 1998), two were implemented with small groups in a resource room (Aydeniz, Cihak, Graham, & Retinger, 2012; Bay, Staver, Bryan, & Hale, 1992), two were implemented in small groups within a special education self-contained classroom (Smith, Spooner, Jimenez, & Browder, 2013; Utley et al., 2001), two were implemented in small groups within a preschool Head Start program (Gonzalez et al., 2011; Greenfield et al., 2009), two were conducted using one-on-one teaching arrangements (Knight, Smith, Spooner, & Browder, 2011; Scruggs, Mastropieri, & Sullivan, 1994) and one study used both small group and one-on-one teaching arrangements in a summer remedial program (Nelson, Smith, & Dodd, 1992).

## Research Design

All 12 of the studies reported the type of research design. Seven used control group experimental or quasi-experimental designs and five used single subject experimental designs. Of the seven control group designs, five of the studies used quasi-experimental designs and two studies used true experimental designs. Of the five single subject designs, two were multiple baseline designs, two were multiple probe designs, and one was a reversal design.

## Dependent Variables

A variety of dependent variables were examined across studies. Seven studies measured student outcomes using daily assessments, one study used weekly assessments, and five studies used a pre-test before the intervention and a post-test after the intervention. The dependent variables included assessments of science content, vocabulary, and reading comprehension, and one study assessed developmental readiness across eight domains.

The assessments of science content included written quizzes covering conceptual and application-based science problems, processes, and vocabulary (Aydeniz et al., 2012; Bay et al., 1992; Dalton et al., 1997; Mastropieri et al., 1998; Utley et al., 2001). Dalton et al. and Mastropieri et al. also included tests that required students to either draw a diagram or write the answers to questions based on their examination of a diagram. In addition to a multiple choice test, Mastropieri et al. also included a comprehension performance test with open ended response prompts (e.g., “Tell me everything you can about an ecosystem.”). This test was scored using a rubric. Scruggs et al. required students to orally state a new fact they learned about an animal (e.g., “The hummingbird can flap its wings in circles.”), and state why that fact makes sense (e.g., “It has to hover like a helicopter when it eats.”). The science content assessments used for students with more intensive learning needs required students to identify the correct answer by touching or manipulating an item from an array of objects (Knight et al., 2011) or pictures (Smith et al., 2013). For example, the student was required to touch the correct picture from three choices when asked, “Show me the moon.”

Measures of reading comprehension included 10-item multiple choice tests and completeness of text summary measures (Nelson et al., 1992). After reading a science passage and writing a summary, the students’ summaries were assessed by calculating the percentage of important information included (Nelson et al.). Martinez-Alvarez et al. (2012) also used a reading comprehension assessment. This assessment, adapted from Palincsar and Brown (1984), is called detecting incongruities. Specifically, students were provided with science reading passages and asked to indicate whether or not each statement in the passage made sense. If a statement did not make sense, the student was asked to specify the reason.

The dependent variables used for the preschoolers included receptive and expressive vocabulary measures (Gonzalez et al., 2011) and preschool readiness domains measures (Greenfield et al., 2009). Expressive and receptive vocabulary was measured using the Peabody Picture Vocabulary Test (PPVT–III; Dunn & Dunn, 1997) and the Expressive One-Word Picture Vocabulary Test (EOWPVT; Brownell, 2000). The experimenters also developed and administered their own versions of these two standardized tests that specifically assessed receptive and expressive science vocabulary that was taught during the intervention. For the preschool readiness domains assessment used by Greenfield et al., teachers observed children on an ongoing basis throughout the school year and recorded each child's attainment of specific skills within each of the eight domain areas using a Web-based system (Galileo). In addition to acquisition measures, three studies assessed maintenance (Aydeniz et al., 2012; Scruggs et al., 1994; Smith et al., 2013), and three studies assessed both generalization and maintenance (Bay et al., 1992; Knight et al., 2011; Nelson et al., 1992). Six of the 12 studies did not include any maintenance or generalization measures.

Six studies also assessed social validity. For example, Aydeniz et al. (2012) obtained social validity data by administering the Scientific Attitudes Inventory (SAI-II; Moore & Foy, 1997) to the students before and after the intervention. Five studies examined social validity for both the students and the teachers by obtaining their opinions about the procedures and outcomes of the intervention through a questionnaire or interview (Knight et al., 2011; Mastropieri et al., 1998; Nelson et al., 1992; Smith et al., 2013; Utley et al., 2001).

## Independent Variables

The independent variables examined in the 12 studies consisted of the following types of interventions: inquiry and activity based science curricula, comprehension strategies for reading science text, and science vocabulary instruction. Seven studies examined science curricula that featured hands on inquiry based learning activities. For example, Aydeniz et al. (2012) taught science to students with learning disabilities using the *Electric Circuit Kit Book*. After the teacher reviewed vocabulary and activated prior knowledge by questioning and connecting the lesson to the students' experiences, the students worked in pairs to perform experiments. Using the same science topic, Dalton et al. (1997) examined the comparative effects of a Supported Inquiry Science (SIS) curriculum and an Activities Based Science (ABS) curriculum. Both curricula used a hands-on approach with frequent opportunities to explore and manipulate materials (e.g., batteries, wires, bulbs). However, the SIS curriculum emphasized the role of misconceptions in learning by directing attention to possible misconceptions and allowing students an opportunity to discuss and revise their conceptions based on experimentation. Additionally, in the SIS condition, the students illustrated their understanding of the concepts by drawing diagrams.

Bay et al. (1992) also examined the comparative effects of two approaches to teaching science inquiry lessons. The researchers compared a discovery teaching condition to a direct instruction condition using *Science Activities for the Visually Impaired/Science Enrichment for Learners with Physical Handicaps* (SAVI/

SELPH; Malone, De, Thier, & Center for Multisensory Learning, 1984). The discovery teaching approach included making predictions and doing hands on experimentation. The direct instruction condition required students to observe the teacher demonstrating an experiment and complete worksheets.

Other inquiry based science curricula included *Early Childhood Hands-On Science* (ECHOS; Greenfield et al., 2009), *Early Science Curriculum* (Smith et al., 2013), and *InSciRead* (Martinez-Alvarez et al., 2012). *InSciRead* is a curriculum used for English Language Learners that incorporates a substantial reading comprehension strategy component. The sequence of instruction is 3 days focused on science inquiry and 3 days focused on strategies for comprehending science text. ECHOS and *Early Science Curriculum* are designed for young children. Both curricula combine explicit instruction with guided inquiry based science exploration. The components of explicit instruction used in these studies include modeling, guided practice, frequent active student responding with immediate feedback, and systematic error correction.

Five of the studies did not examine a specific science curriculum. Instead, they examined the effects of an instructional procedure used to teach science content. For example, Scruggs et al. (1994) examined the effects of elaborative interrogation, a structured questioning procedure that leads the student to the correct answer. Three of these studies examined the effects of the following instructional procedures on science vocabulary outcomes: classwide peer tutoring (Utley et al., 2001), explicit instruction with application of concepts (Knight et al., 2011), and shared book reading (Gonzalez et al., 2011). Finally, one study examined the effects of a summary writing strategy intervention on reading comprehension of science text (Nelson et al., 1992).

## Effects

The effects of the studies using single subject research designs and control groups comparison designs are reported separately. In single subject research designs, each student's own baseline (pre-intervention) performance serves as the basis for comparison to determine the extent to which an intervention is effective. In a multiple baseline (or multiple probe) design, baseline data are collected until student responding is stable and then the intervention is administered in a staggered format to each student (or for each skill). If the behavior changes only upon introduction of the intervention for each child or behavior, a functional relation is demonstrated. Minimal overlap of data points between the baseline and intervention conditions is indicative of more robust effects.

In this review, four of the five studies used multiple baseline or multiple probe designs. For example, in a multiple baseline design across science topics, Aydeniz et al. (2012) demonstrated a functional relation of inquiry based learning on the percent of application and conceptual science problems answered correctly for all participants. All students demonstrated low and stable baseline responding with an immediate upward trend of correct responding upon the introduction of each new science lesson. All students achieved and maintained 100 % correct responding during the intervention phase.

The participants in the Knight et al. (2011) direct instruction study and the Smith et al. (2013) *Early Science Curriculum* study demonstrated similar patterns of responding. The participants demonstrated low and stable patterns of baseline responding followed by an immediate upward trend upon each introduction of the intervention. Nelson et al. (1992) also used a multiple baseline design and demonstrated a functional relation of the independent variable. Instead of upward trends, however, all of the participants demonstrated an immediate and substantial increase in performance upon the introduction of the intervention. Specifically, the summary writing strategy was effective for increasing comprehension test scores. During baseline, most of the students scored about 40–60 % correct. Upon introduction of the intervention, most students immediately attained 80–100 % correct. Instead of a multiple baseline design, Utley et al. (2001) used a reversal design to demonstrate a functional relation of classwide peer tutoring on the acquisition of science vocabulary and concepts. During all baseline sessions, the students scored less than 20 % correct on post quizzes. Upon introduction of the classwide peer tutoring intervention, they consistently scored 80–100 % across all intervention sessions.

The seven control group designs examined the effects of inquiry based science curricula (Bay et al., 1992; Dalton et al., 1997; Greenfield et al., 2009; Martinez-Alvarez et al., 2012; Mastropieri et al., 1998) or an instructional method (Gonzalez et al., 2011; Scruggs et al., 1994). Mastropieri et al. compared an activities based approach to a textbook based approach, and found significant differences in favor of the activities based approach on a multiple choice post-test, a comprehension/performance test, and an elaboration test. The participants with special needs made the highest gains in pre–posttest scores (mean gain score = 9.4) compared to the general education students in the inclusive classroom (mean gain score = 7.5) and the general education students in comparison classrooms (mean gain score = 6.6). Bay et al. (1992) also found differential effects for students with learning disabilities when comparing a discovery teaching approach to a direct instruction approach. Specifically, there were no differences between groups for acquisition of concepts, but students with learning disabilities in the discovery teaching condition outperformed students with learning disabilities in the direct instruction condition on generalization measures. In contrast to these studies, Dalton et al. (1997) actually compared two different hands on approaches, Activities Based Science (ABS) and Supported Inquiry Science (SIS). The difference was that the SIS condition emphasized the role of misconceptions. Similar to Mastropieri et al. and Bay et al., students with learning disabilities demonstrated significant differences between conditions. The students in the SIS condition outperformed the students in the ABS condition, with average gain scores of 18.0 (SIS) and 9.41 (ABS).

Instead of a specific curriculum, Scruggs et al. (1994) used a control group comparison design to examine the effects of elaborative interrogation on the acquisition and maintenance of animal facts. Students with special needs in the elaborative interrogation group scored significantly higher on immediate and delayed factual recall (i.e., stating a fact about an animal), and immediate and delayed explanation scores (i.e., explaining why that fact makes sense). In another control group comparison design, Martinez-Alvarez et al. (2012) examined the effects of a science curriculum (InSciRead) on reading comprehension outcomes, and found only moderate effects of the intervention.

Greenfield et al. (2009) and Gonzalez et al. (2011) examined science outcomes for preschoolers. Greenfield et al. used an inquiry based science curriculum (ECHOS), but the outcome measures were scores on developmental readiness domains. Gain scores across the eight domains ranged between 12.2 and 88.5. Significant treatment effects were found for four the domains (*Approaches to Learning, Early Math, Language & Literacy, Creative Arts*), marginally significant effects were found for two domains (*Science, Social & Emotional*), and no significant treatment effects were found for two domains (*Motor Development & Physical Health*). The more recent study conducted with preschoolers examined the effects of a shared reading intervention on receptive and expressive vocabulary measures (Gonzalez et al.). There were no significant differences on pre-posttest scores on the standardized receptive measures, but there were significant differences on expressive vocabulary measures for the children in the shared reading condition ($ES = 0.30$).

## Discussion

The purpose of this literature review was to examine the research on the types and effects of science instruction for young children with special needs in order to identify evidence based teaching practices for this population. The 12 studies reviewed represented a wide range of diverse learners across age, ethnicity and ability. Most of the participants were at risk preschoolers, but most of the school age participants were fourth graders identified with learning disabilities. The literature also included participants with mild to severe intellectual disabilities, autism, behavior disorders, multiple disabilities, and other health impairments. Diverse cultures were also represented in this literature. The majority of participants were African American (49 %) and Latino (21 %).

According to special education law, preschoolers do not have to be diagnosed with a disability to receive services, they only need to show a developmental delay or have a documented risk. Many of the preschoolers who participated in this research may have had disabilities, but were not formally diagnosed. It was not possible to distinguish which children had disabilities in these studies, and there were no research studies for preschoolers identified with disabilities. We decided to include these studies because this chapter focuses on early childhood science education, and the information derived from these studies provides developmentally appropriate ways for teachers of young children to introduce science concepts to their students of all ability levels.

In the 12 studies, science instruction consisted of intervention packages that included a combination of at least some of following critical components: hands on inquiry learning opportunities (e.g., observation, prediction, experimentation), application of science concepts, explicit instruction of concepts or skills, teacher guided instruction and questioning, students working in pairs or in small groups, and frequent opportunities for active student responding (using a variety of response modes). The interventions targeting vocabulary development and reading comprehension also included explicit instruction of concepts, strategy instruction, and frequent opportunities for active student responding.

A common approach of many of the intervention packages for students with special needs was combining explicit instruction of science concepts with inquiry based learning and application of concepts (e.g., Bay et al., 1992; Knight et al., 2011; Smith et al., 2013). Programs designed for the students with more intensive learning needs incorporated more explicit systematic instruction and teacher guidance than interventions for students needing less intensive support. For example, the *Early Science Curriculum* examined by Smith et al. used scripted lessons that incorporated frequent active responding with immediate corrective feedback. Task analyses were developed and used to introduce vocabulary, provide explicit instruction of concepts, and provide opportunities for students to engage in inquiry skills (e.g., experimentation).

All five of the single subject research experiments demonstrated a functional relation of the independent variable on the dependent variable. Aydeniz et al. (2012; Electric Circuit Kit Book), Nelson et al. (1992; summary writing strategy), and Utley et al. (2001; classwide peer tutoring) demonstrated the most robust findings with 100% of non-overlapping data points across students and dependent variables. Smith et al. (2013) and Knight et al. (2011) also demonstrated a clear functional effect of the independent variable (as indicated by an immediate upward trend of responding each time the intervention was introduced). The intervention packages of Smith et al. and Knight et al. were used for participants with severe intellectual disabilities and placed heavy emphasis on explicit instruction procedures combined with inquiry activities as well as alternate response modes (e.g., touching pictures or manipulating objects instead of speaking or writing).

Two control group design experiments comparing two different science curricula, Bay et al. (1992) and Dalton et al. (1997), demonstrated interesting results for their participants with learning disabilities. The results of Bay et al. demonstrated that a discovery teaching condition was no more effective than a direct instruction condition for acquisition of science content. However, the students with learning disabilities in the discovery teaching condition outperformed the students with learning disabilities in the direct instruction condition on generalization outcomes. The generalization measure in this study consisted of a performance based assessment in which the participants were expected to apply the scientific process they learned in a previous lesson about flotation to a new lesson about pendulums. Dalton et al. also found interesting results for students with learning disabilities on assessment measures. Although all of the participants in the Supported Inquiry Science (SIS) condition achieved better outcomes compared to the participants in the Activities Based Science (ABS) condition, the students with learning disabilities achieved less growth than the low and average achievers on the questionnaire test. However, the students with learning disabilities in the SIS condition achieved as much growth as the low and average achievers on the diagram test (i.e., answering questions based on a visual diagram).

Three of the control group experimental design studies did not measure science content as a dependent variable. Martinez-Alvarez et al. (2012) used a reading comprehension measure (i.e., detecting incongruities) and found moderate effects. Greenfield et al. (2009) assessed developmental domains and found significant treatment effects for four of the eight domains, but only marginally significant effects for the science domain. Gonzalez et al. (2011) measured expressive and receptive vocabulary and found significant differences on expressive measures, but not receptive. In general, the studies that directly measured science content produced better effects than the studies that measured another outcome or skill.

## *Implications for Practice*

Although the research on teaching science to young children with special needs is relatively sparse, this literature review identifies several promising implications for how teachers can plan and deliver effective instruction. Considering that the majority of students with special needs receive science instruction in inclusive general education classrooms, teachers are presented with the challenge of designing effective instruction for a wide range of diverse learning needs. When planning instruction in inclusive classrooms, teachers must build in varying levels of support as needed by individual students so that all students can be successful. The Response to Intervention (RTI) model is an evidence-based practice for achieving this goal. RTI enables practitioners to address the needs of children of all ages along a continuum of increasingly intensive levels of instruction, or Multi-Tier Systems of Support (MTSS), according to individual students' responsiveness to intervention (Greenwood et al., 2011).

There are three tiers of support in an RTI model. Tier 1 is commonly known as the universal level of supports, and it is comprised of the general classroom environment, curriculum, and instructional strategies (i.e., whole class instruction). When children are identified as needing additional assistance, more targeted supports are provided at Tier 2, along with more frequent progress monitoring and more intensive small group instruction. Students who continue to struggle receive Tier 3 instruction, where more intensive and individualized services are implemented (i.e., one on one instruction). An RTI model offers science educators a systematic process for identifying and addressing the needs of diverse learners, and guiding the attainment of optimal outcomes for all young scientists.

The results of this literature review provide science teachers with a variety of effective instructional activities that vary in intensity of support and can be used for each tier of instruction. Depending on the needs of students in each unique inclusive classroom, we provide the following recommendations for using the instructional approaches identified in this literature review: inquiry based science instruction, explicit instruction, peer-mediated instruction, shared reading, graphic organizers, and technology.

## Inquiry Based Science Instruction

**Science Kits** Science kits offer schools a way to provide teachers with straightforward instructions and premade materials that can be used in their classrooms with ease. Six studies used kits, including Electric Circuits Kitbook (Aydeniz et al., 2012), Science Activities for the Visually Impaired/Science Enrichment for Learners with Physical Handicaps (SAVI/SELPH; Bay et al., 1992), Delta Science Modules (Dalton et al., 1997), Early Childhood Hands-On Science (ECHOS; Greenfield et al., 2009), InSciRead (Martinez-Alvarez, Bannan, & Peters-Burton, 2012), and Science and Technology for Children (STC; Mastropieri et al., 1998). Teachers can implement kit-based curricula during whole class instruction (i.e., Tier 1). Students with special needs can work with peer buddies or in cooperative learning groups. Students needing more intensive intervention and closer monitoring can participate in small group (Tier 2) or one-on-one (i.e., Tier 3) instruction using science kits. Manufacturers of kit-based curricula offer professional development opportunities for science teachers including teacher guides, online or in-person workshops, and training conferences. Several companies also recommend teachers form onsite groups to support one another in kit implementation. In addition, some science kits offer supports for teachers of students with special needs, such as adaptive equipment for students with visual or physical impairments.

Although some in the science education community disagree with the use of science kits due to the risk of being implemented incorrectly and perpetuating misinformation, Dickerson, Clark, Dawkins, and Horne (2006) found that implementation of a kit-based science curricula can be effective for elementary students. Other researchers have noted such positive outcomes as an increase in student participation and teacher content knowledge, which leads to greater confidence in teaching science and teacher job satisfaction (Gennaro & Lawrenz, 1992; National Research Council [NRC] 2000). While the use of kits may not be appropriate for every teacher in every classroom, they can assist teachers in becoming more comfortable with teaching science and allow students to become familiar with investigations and evidence.

**Hands-on Inquiry Activities** Scientific inquiry with hands-on exploration helps students gain a better understanding of science concepts. Inquiry, according to the National Research Council, is direct experience coupled with understanding (NRC, 2000) In addition, there is an emphasis on using evidence to support claims (i.e., "I think that…because of this piece of evidence…"). For example, students in Bay et al. (1992) experimented with rafts and weights of various dimensions to examine the rafts' weight-bearing capacities. Following experimentation and data recording, students made predictions about other rafts and tested their hypotheses. This process, identified as discovery teaching, lead to increased retention of material and facilitated the generalization of acquired skills for the participants with learning disabilities (Bay et al., 1992). Analysis of discovery teaching audiotapes demonstrated that students verbalize more during hands-on activities, providing more opportunities to develop higher-order thinking skills and extended responses. Inquiry learning engages students in a child-centered curriculum, increases exposure to authentic experiences across content areas, develops problem-solving skills, and stimulates learning. Hands on activities can and should be used at every tier of instruction in an inclusive classroom.

**Questioning** Dalton et al. (1997) and Scruggs et al. (1994) both integrated questioning strategies into their science instruction. Dalton et al. used productive questioning to lead students to understanding a scientific model of electrical circuits, and Scruggs et al. used structured interrogation to teach facts about animals to fourth graders with mild learning disabilities (e.g., Why does this fact make sense?). Elstgeest (2001) defines a productive question as one a child can answer him or herself using data gathered through sensory information, such as via observations and experiments. Productive question types recommended by Elstgeest are attention-focusing (e.g., "What did you notice about your shadow during recess today?"), comparison (e.g., "Is your shadow longer when you come to school in the morning?"), action (e.g., "What would happen if…?"), measuring and counting (e.g., "Which is more?"), and problem-posing (e.g., "Can you find a way to…?"). Once students have mastered some of the necessary inquiry skills, they are ready to solve more sophisticated problems through self-generated question asking.

Relating new information to background knowledge and experiences of students with mild learning disabilities can them help remember novel concepts. Characteristically, students with learning disabilities struggle to make relational inferences with new information, and explicitly facilitating inference-making can help these students overcome such challenges (Scruggs et al., 1994). Making explicit connections between new and prior knowledge is appropriate for all students receiving Tier 1 supports, and the strategy can be modified in level of intensity according to student need. Scruggs et al. (1994) further suggested that structured teacher questioning may be more useful than simply stating the information. Students in need of more explicit support in making inferences and relating new information to prior knowledge would benefit greatly from Tier 2 (small-group) and Tier 3 (one-on-one) instructional arrangements that incorporate structured questioning with explicit instruction. Small group and individual instructional arrangements will increase struggling learners' opportunities to actively respond to instruction and receive immediate feedback and close monitoring.

## Explicit Instruction

Using the Model-Lead-Test strategy, Knight et al. (2011) explicitly provided background knowledge to students with autism before engaging them in inquiry science activities, which increased students' ability to participate successfully in the class activity. The following is an example of Model-Lead-Test procedure for a student with more intensive educational needs. The teacher shows an object and models the name of the object (*Model*: Teacher says, "My turn. This is a shell."), then prompts the student to say the name of the object with her (*Lead*: Teacher and student say together "Our turn. This is a shell."), and finally prompts the student to respond independently (*Test*: Teacher says, "Your turn." Student says, "This is a shell."). Frequent active student responding with immediate feedback for each response will help students become more proficient with basic terms and enable them to benefit more from hands on application activities. Explicitly teaching background knowledge and vocabulary in a one-on-one setting can help students gain the prerequisite skills needed to begin engaging in higher level thinking or application activities. This intensive, one-on-one teaching arrangement (i.e., Tier 3 instruction) may be challenging to implement in many inclusive general education classrooms unless a co-teaching arrangement is in place. The movement toward increased inclusion and collaboration with special education has made these kinds of teaching arrangements more feasible. If a co-teaching arrangement is not possible, teaching assistants, peer tutors, and parent volunteers can also assist with one-on-one instruction.

**Time Delay** Smith et al. (2013) demonstrated that teachers can successfully implement time delay procedures with students with severe intellectual disabilities. Employing a hierarchy of prompting strategies ranging from gestural prompts and modeling to physical guidance via time delay can facilitate accurate student responding and acquisition of new science vocabulary. During the first learning trials, Smith et al. used a zero time delay by stating the questions, immediately pointing to the correct response, and praising the child for imitating the response (or using physical guidance to help the child point to the correct response). On subsequent trials, there was a 5 s time delay for the child's response which was immediately followed by praise or corrective feedback. Using a time delay procedure is a good way for teachers to implement errorless learning and reduce student frustration as they learn new skills. Providing such support through small-group (i.e., Tier 2) or one-on-one (i.e., Tier 3) science instruction helps students with more intensive learning needs acquire and apply new skills.

## *Peer-Mediated Instruction*

**Cooperative Learning Groups** The National Research Council (NRC) standards emphasize that students should work in cooperative learning groups completing hands on, performance based projects to gain skills in collaboration and teamwork (NRC, 1996). Three studies involved students working in dyads or triads; two with fixed grouping (Bay et al., 1992; Dalton et al., 1997), and one with flexible groups (Aydeniz et al., 2012). Dalton et al., who used fixed grouping, encouraged students to share predictions and outcomes with each other and engage in explanative discourse. Aydeniz et al. (2012) utilized flexible grouping so that students who were attaining proficient progress on the unit could act as peer tutors for their group mates. Either type of grouping can be implemented in the inclusive classroom for a wide variety of activities such as conducting experiments, engaging in collaborative problem solving activities, creating a presentation, and helping each other study concepts. Teachers can increase the effectiveness of cooperative learning groups by allowing team members to take turns serving in different roles (e.g., leader, note taker, time keeper, spokesperson, etc.). Additionally, teachers should provide rules for interacting in groups (e.g., be good listeners, be polite, don't interrupt) and explicit directions for the task (e.g., categorize these objects by function). In addition to providing opportunities for active student responding, cooperative learning groups also provide students with much needed opportunities to practice social skills.

**Classwide Peer Tutoring** The effectiveness of classwide peer tutoring (CWPT) is supported by at least three decades of experimental research. CWPT has demonstrated positive effects for a wide range of diverse learners with and without special needs in elementary, middle, and high school (see Morgan, 2006). In this review, Utley et al. (2001) used CWPT to teach health science and safety concepts to second graders with developmental disabilities. CWPT can be used to help students practice science content across wide range of topics as part of Tier 1 instruction in inclusive classrooms. Each child is provided with a folder containing pockets of flashcards (which can be individualized by student). The flashcards can have a vocabulary word (picture, diagram, etc.) on one side of the card and the definition on the other side. Students can work in reciprocal dyads in which they reverse roles as tutor and tutee. CWPT is highly structured whole class activity that includes procedures for prompting and providing corrective feedback. Additionally, CWPT is a socially valid approach with high levels of teacher satisfaction concerning procedures, ease of implementation, cost effectiveness, improved student performance, and continued usage and generalization to other content areas (Utley et al., 2001).

## *Shared Reading*

Gonzalez et al. (2011) utilized a shared reading intervention to effectively increase the expressive science vocabulary of low-income, at-risk preschoolers. The researchers demonstrated that brief (i.e., 20-min) content-focused shared reading and explicit vocabulary instruction lead to improvements in expressive language and science vocabulary. Gonzalez et al. addressed nature and living things as the primary themes, but their procedures could easily be modified to address different age groups, school district curricula, state content standards, national recommendations (e.g., NAEYC standards). Shared reading and explicit vocabulary instruction are appropriate strategies for all grade-levels (pre-K to high school), for students with and without special needs, and for use in whole class, small groups, and one-on-one formats. Once the teacher selects the science curricula topics, she can select relevant and age appropriate literature on for that topic, and identify key vocabulary for explicit instruction.

## *Graphic Organizers*

**KWHL Charts** Smith et al. (2013) used a KWHL chart to help students to activate their background knowledge and connect new knowledge to prior experiences. KWHL is an acronym for what you *Know*, what you *Want* to know, *How* you are going to find out, and what you *Learned*. Teachers can create a KWHL chart by drawing four columns with one letter at the top of each column (K, W, H, and L). The teacher can begin the activity by asking students what they already know about a topic and write their responses under the K column. Then the students generate responses for what they want to know and how they are going to find out. After the students complete the experiment or learning activities related to the science topic, they generate statements about what they learned. Teachers can use KWHL charts for instruction at all tiers using a chalkboard, dry erase board, SMART™ board, or chart paper. Students can also complete their own personal charts individually, in pairs or in small groups.

**Drawing Diagrams** Dalton et al. (1997) demonstrated that drawing diagrams of electricity moving through circuits was beneficial for students with learning disabilities. Visual representations are a powerful tool for learning and understanding scientific concepts, and the ability to record observations through drawing is a skill that scientists in many (if not all) disciplines use frequently. A geologist may draw a field sketch of rock layering, or a biologist could record the shape and location of a unique plant. This low-tech intervention can benefit students who learn best through visual representations. Additionally, sketching may help students better remember their experiences, and assist with generalizing to novel situations (Eshach, 2006). Teachers can easily adapt the strategy of diagram drawing for use with various ability levels and a wide range of science topics. For instance, students learning about space science can look at pictures of the school and talk about where the sun is positioned in the sky when they arrive as compared to when they leave school. Using a sketch of the building, students can track the sun's movement from east to west over the course of a school day and make connections concerning the movement of the moon and stars as well.

## Technology

**Smart Board™** Smith et al. (2013) used SMART™ boards to teach science to young children with severe intellectual disabilities. These popular, interactive whiteboards display computer monitor images on a giant touch screen that is mounted on a wall or mobile (Preston & Mowbray, 2008). Students can take turns touching response options for structured questioning or presenting science reports to their peers on the SMART™ board, and teachers can employ time delay and prompting procedures to enhance student participation (Smith et al.). Ideas, information, animations, images, audio, and video can be shared and manipulated for everyone to see. Appropriate for activities such as completing KWHL charts and drawing diagrams of concepts and processes, SMART™ boards make lessons come alive and promote active student responding (Dalton et al., 1997; Preston & Mowbray; Smith et al.). SMART™ boards can foster learning through physical interaction and enhance young children's confidence with science and technology (Preston & Mowbray). Science lessons featuring SMART™ board technology are particularly useful for whole class instruction.

**Web Based Instruction** Martinez-Alvarez et al. (2012) designed a web-based virtual environment that employed a cooperative science inquiry approach to help fourth grade students with and without disabilities comprehend geomorphologic processes. The program included pictures from the students' school that had been uploaded along with computer-generated metacognitive prompts, and students worked with partners and as a class to answer and generate questions collaboratively. The computer program included a "Super Question Bank" which allowed students to enter and answer questions on a forum visible to other pairs, and there was also a "Super Dictionary," used to identify and clarify terminology. Following a series of classroom lessons using the web-based system, students gained hands-on experience in the "field," exploring their school grounds, gathering additional information, and taking more pictures to upload to their computer program.

There are several ways in which teachers and practitioners can adapt the procedures used by Martinez-Alvarez et al. (2012) to address the needs of learners of various ages and at each tier of the RTI model. Computer technology can be used to create open forums where students post and respond to an assortment of peer- and teacher-generated questions. Classwide, students can be paired to work together, and the forums can facilitate sharing and question answering. Students can also collaborate to create class dictionaries for various science units. Computer- and web-based technology can also be very useful for enabling students with special needs to work independently. Computer programs can provide students with individualized practice and feedback on science content so they may be less reliant on the teacher.

## Limitations and Future Research

This body of research provides several promising strategies and tactics for effectively teaching science to young children with special needs, however, the small number of experimental studies published in the past two decades limits the extent to which we can draw definitive conclusions about their effectiveness in general and across populations. Additionally, several limitations common to many of the studies can provide direction for refining this body research in future studies. Regarding population, there were no experimental research studies examining student outcomes at the kindergarten or third grade level, and only a couple studies with first and second graders. With regard to preschoolers, the inclusion of those deemed "at risk" was utilized in order to identify children younger than kindergarten aged who might have a yet-to-be-diagnosed disability. Future research should examine the effects of various science interventions for children at different grade levels (especially kindergarten and early elementary), children with a range of mild to severe learning needs including sensory disabilities (i.e., visual or hearing impairments) and physical disabilities. It would also be useful for future research to examine different ways to make modifications so that children ranging in age and ability level could benefit from science interventions. Future research could incorporate different types of technology to accommodate struggling learners. For example, computer programs and devices (e.g., Ipads) can be used to prompt students through the steps of a conducting an experiment.

In general, this body of research included a wide variety of ways to accurately assess science knowledge and skills (e.g., multiple choice questions, open ended questions, skill performance, object manipulation, verbal reasoning). One limitation, however, is that some studies did not use a direct measure of science knowledge or application to assess the outcomes of an intervention. For example, Greenfield et al. (2009) used the ECHOS curriculum and measured the effects on developmental domains. Martinez-Alvarez et al. (2012) used the detecting incongruities test, and Nelson et al. (1992) assessed reading comprehension. Future research for each of the above studies should also include a direct measure of science content to supplement the other kinds of measures. Including science outcome measures would provide additional support about the extent to which a practice is evidence-based for teaching science.

An important limitation of some of these studies, particularly the science inquiry studies, is that the authors did not adequately describe the intervention well enough to replicate it in future studies (e.g., Bay et al., 1992; Greenfield et al., 2009). For example, Bay et al. (1992) described the assumptions upon which the discovery teaching condition was based (e.g., children construct knowledge through interaction with the environment) and provided only brief statements of procedures (e.g., "In Session 1, students explored the notion of displacement and why objects float or sink" p. 560). Future research would benefit from more specific descriptions of the science intervention including step by step procedures, a task analysis, and specific information about the type and nature of support provided by teachers during science inquiry instruction. For example, how much teacher guidance, prompting, and feedback are needed for the intervention to be effective? What types of independent exploration activities are appropriate for struggling students? Many of the research studies on science curricula found positive effects for students with special needs when hands on inquiry based learning was accompanied by explicit instruction and guidance. Future research could benefit from an examination of different degrees of teacher support needed for successful inquiry based science instruction to optimize learning at different age and ability levels.

Another limitation related to the specifics of the intervention procedures, is that there was no treatment fidelity reported in some of the studies (e.g., Bay et al., 1992;

Dalton et al., 1997; Greenfield et al., 2009). For example, in Greenfield et al., teachers were trained in groups to use the curricula, they were trusted to deliver instruction in the way they were trained, and they self-reported their own experiences when they met back with their training group for follow up. An experimenter was never present in the classroom to observe the extent to which the intervention was implemented as intended. This is a critical limitation. Future research should always assess treatment fidelity of the intervention in order to determine if the effects are really the result of the intervention (and not the result of confounding variables).

Another limitation to this body of research is that many studies did not include maintenance or generalization measures. Only six studies assessed maintenance and only three studies assessed generalization. Unless an intervention can produce maintenance and generalization outcomes, the usefulness of that intervention is severely limited. Future research would be enhanced by an examination of interventions that deliberately program for generalization. Cooper, Heron, and Heward (2007) identify several generalization programming tactics that can be examined within science instruction research. Some of those tactics include teaching enough examples (representative examples), programming common stimuli (i.e., making the training setting similar to generalization setting), programming unpredictable reinforcement, setting behavior traps (i.e., designing instruction based on student interests), teaching self-management, reinforcing creative responses, and asking significant others (e.g., parents) in the generalization settings to reinforce newly learned target skills.

## Conclusion

An important finding in this body of research is that young children with special needs benefit the most from hands-on, activity based inquiry instruction that is supplemented with appropriate levels of guidance and explicit instruction (depending on the needs of the student). This body of research has also identified several important instructional strategies that can be used to enhance instruction for all children learning science in inclusive classrooms. Within the RTI model, whole class instruction such as cooperative learning groups and classwide peer tutoring can provide frequent opportunities for active responding to science problems or content. Because whole class instruction is usually more feasible in general education settings, teachers in inclusive classrooms will value whole class interventions that are effective for as many students as possible. Students needing additional support can receive more intensive small group or one-one instruction using a variety of instructional procedures such as creating graphic organizers, drawing diagrams, or engaging in technology mediated instruction. The key to providing effective science instruction to young children with special needs is to select and implement empirically validated interventions based on the individual strengths and needs of the child.

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# Chapter 15
# Science Education for Young Emergent Bilinguals

Leslie C. Moore and Mandy McCormick Smith

## Introduction

This chapter presents an overview of the research on science education for young emergent bilinguals. This small body of work provides important insights into science teaching and learning, but much remains to be researched in linguistically diverse early childhood educational contexts. For many years, research on the education of emergent bilinguals has focused on the development of oral proficiency and literacy in English as a second language, while little research was conducted "on how to make instruction more accessible and meaningful to [emergent bilinguals] in areas considered challenging by native English speakers (i.e., science, math)" (Genesee, Lindholm-Leary, Saunders, & Christian, 2005). Research on science education for learners of English as a second or additional language has increased in recent years. However, most of this work has been done in the upper elementary grades, middle school, and high school. The bulk of the early childhood research has been conducted with third grade teachers and students, while few empirical studies have been conducted with emergent bilinguals in the Kindergarten through second grade bands and none have been conducted in pre-Kindergarten settings.

In this chapter we examine the published empirical research on science education for children from birth to age eight who are identified as learners of the primary language of the school as a second or additional language and are receiving language support services. We begin the chapter with a brief discussion of terminology and context in which (research on) science education for young emergent bilingual takes place. Next we provide an overview of the empirical research,

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discussing four different foci: curriculum development, teacher professional development, student outcomes, and classroom interaction. We conclude with a discussion of the implications of the research for educational practice and directions for future research.

## Terminology

In this chapter we use the term emergent bilingual to emphasize that "through school and through acquiring English, these children become *bilingual*, able to continue to function in their home language as well as in English – their new language and that of the school" (García & Kleifgen, 2010, p. 2). Several other terms are also used in research, practice, and policy discussions of students who are in the process of learning English and who have a first language other than English. The federal government and many state governments use the term Limited English Proficient (LEP) to refer to students who have been identified as eligible for English as a second language or bilingual education services according to state criteria. This term is widely rejected as one that labels children as having a deficiency. English language learner (ELL) is the term most commonly used by researchers and educators, along with the alternate form English learner (EL). Dual language learner is used to refer to young children who are acquiring two languages simultaneously or are learning a second language while continuing to develop their first language.

The phrase culturally and linguistically diverse (CLD) is often used to refer to students from homes and communities where English is not the primary language of communication, as are the terms language minority and linguistic minority. However, these terms do not specify whether or not the student is learning English as a second or additional language. A language minority or CLD student may be highly proficient in English and another language or languages, having exited or having never participated in English as a second language (ESL) or bilingual education. The terms are also sometimes used to refer to students who are native speakers of a variety of English that is different from the variety that is privileged in school. In this chapter we focus specifically on research in science education for young children who are participating in English as a second language or bilingual education programs.

## Theoretical Frameworks and Methodologies

A range of disciplinary perspectives, theoretical frameworks, and methodological approaches have been brought to bear in researchers' efforts to understand and improve science educational processes and outcomes for emergent bilinguals in early childhood educational contexts. Concepts and research methods from anthropology, cognitive science, education, and linguistics have been applied, sometimes within a single project. Constructivist theories of learning inform the invention-based studies, and the curricula and professional development under study emphasize hands-on, inquiry-based science education.

These studies also reflect the understanding that the communication and development of science concepts and practices are to a great extent organized by and accomplished through language. Thus, researchers attend to not only to the cognitive demands of science education activities, but also to the linguistic knowledge and language practices the activities entail. The theory of language that has been most influential in this body of research is systemic functional linguistics (Halliday, 1994; Halliday & Martin, 2003), an approach that views language as a set resources for meaning-making, with particular emphasis on texts (Fang, Schleppegrell, Lukin, Huang, & Normandia, 2008). Interactional discourse analysis is used in a few studies to illuminate the social and cultural organization of talk in the science classroom, often taking a more critical perspective on current science education practices and efforts to reform them.

Issues of equity are central to all the research discussed in this chapter. For years, children who were learning English as a second or additional language have been likely to have limited access to science education for several reasons: English proficiency was widely regarded as a prerequisite for science learning (Collier, 1989), basic literacy and mathematics were emphasized for emergent bilinguals (Lee, 1999), and science instruction rarely took into account the language needs and resources of these students (Lee, 2005). Researchers have sought to rectify these persistent inequities by identifying, developing, and/or illuminating ways of providing emergent bilinguals with equitable science learning opportunities. The complexity of this endeavor is evident across the studies. Researchers and the educators with whom they collaborate navigate a landscape of increasing linguistic and cultural diversity, continuing emphasis on high-stakes testing, and widespread wariness of languages other than English (Solórzano, 2008; Understanding Language, 2012).

## Contexts of Science Education for Young Emergent Bilinguals

Before reviewing the research, it helpful to consider the context in which the research is conducted. By context, we mean several things: demographics, educational (language) policy, and early childhood classroom settings and participants. Consideration of these aspects of context helps us understand the current research and consider the complexity faced by researchers and those with whom they conduct their research.

While the term emergent bilingual emphasizes the child's developing abilities in two (or more) languages, the term culturally and linguistically diverse highlights the fact that language diversity and cultural diversity go together. When discussing young emergent bilinguals, is it important to keep in mind that these children are not only using and learning (in) more than one language, but also participating in more than one cultural community. A child brings to school not only the language(s) learned at home, but also knowledge and strategies for learning that are valued and practiced in his/her family and home community. Many scholars have argued that, to provide equitable learning opportunities, teachers and teacher educators must recognize, appreciate, and incorporate into classroom practice these linguistic and cultural resources (Barton & Osborne, 2001; Buxton & Lee, 2010; Darling-Hammond, 2001; Dyson, 2005; Lee & Luykx, 2006; Moll, Amanti, Neff, & Gonzalez, 1992; Nieto, 2002; Rosebery & Warren, 2008).

The emergent bilingual population in the U.S. is highly heterogeneous, bringing to classrooms a great variety of prior experiences and knowledge. These children and their families vary on many dimensions, including language background and language proficiency, ethnicity and race, cultural values and beliefs, economic resources, experiences with literacy and schooling, and (im)migration history. The majority of emergent bilinguals were born in the U.S. (Batalova & McHugh, 2010). Spanish is by far the most common home language, but over 150 languages are spoken by emergent bilinguals, and in seven states a Spanish is not the most common language: Ojibwa is the most common in North Dakota, Dakota in South Dakota, Yupik in Alaska, Ilocano in Hawaii, Somali in Maine, Bosnian in Vermont, and American Indian languages in Montana (Hanson, 2010). There is considerable socioeconomic diversity within this population, but emergent bilinguals are more likely than native-English speaking students to come from low-income families and to have parents with limited formal schooling (Garcia & Cuellar, 2006; Hernandez, Macartney, & Denton, 2010).

Linguistic diversity among school-aged children in the United States has grown rapidly over the last 30 years, and this trend is expected to continue in the coming years (Garcia, 2002; NCELA, 2007). In the 1980 Census, 10 % of children aged five to seventeen were reported by a member of their household to speak a language other than English at home, but by 2009 that number had more than doubled (NCES, 2012a). In the 2009 American Community Survey, 75 % of those children who were reported to speak a language other than English at home were reported to speak English "well" or "very well" (NCES, 2012a). In that same year, more than ten percent of school-aged children were identified by their school districts as English language learners (NCES, 2012b), and this percentage is projected to grow to about 40 % over the coming two to three decades (Thomas & Collier, 2002). Since 1974 federal law requires states and schools to provide these students with equal educational opportunities by addressing their needs as learners of English as a second or additional language. How the term English language learner (or, in some states, LEP) is defined and how students come to be designated as such varies by state and even by school district, as do the support services provided (Linquanti & Cook, 2013).

There is a range of approaches states and school districts may take to supporting emergent bilinguals. Content-based ESL or English for speakers of other language (ESOL) programs provide instruction in English language and academic content by incorporating strategies that increase emergent bilinguals' access to content. In ESL pull-out models, students spend part of the school day in a mainstream classroom and are regularly taken out to receive ESL instruction in another classroom. In ESL push-in or co-teaching models, ESL teachers work alongside their grade-level counterparts in the mainstream classroom. In bilingual education programs (of which there are several models), instruction is conducted in English and the students' home language. Despite strong evidence that bilingual instruction strengthens the academic skills and content knowledge of emergent bilingual students, there has been a steady decline in public support for and provision of bilingual education over the past two decades (Crawford, 2007; García & Kleifgen, 2010). Most science educators working with emergent bilinguals do so in all-English educational contexts, and most emergent bilingual students who are learning science do so in a language they are still developing as a second or additional language (Garcia & Frede, 2010; Rosebery, Warren, & Conant, 1992).

Standardized measures of academic achievement in science and other subjects indicate that many schools struggle to provide sufficient support for emergent bilinguals (Fry, 2008). The No Child Left Behind Act (NCLB, 2001) included specific mandates concerning these students, referred to in NCLB as Limited English Proficient (LEP). NCLB requires they be placed in "high quality language instruction educational programs that are based on scientifically based research demonstrating the effectiveness of the programs in increasing (a) English proficiency; and (b) student academic achievement in the core academic subjects" (Title III, Sec. 3115(c)(1)). The law also requires the inclusion of LEP students in the state mandated standards based testing and that schools be held accountable for these students' academic progress as measured by these tests. States must test students annually in math and English language arts beginning in third grade, while science testing is required (at least) once in each of the following grade periods: 3 through 5, 6 through 9, and 10 through 12.

Research suggests that NCLB's emphasis on math and reading in the early elementary years has led to a decrease in instructional time being dedicated to science, particularly in the K-2 grade band (National Research Council, 2012; Griffith & Scharmann, 2008; Plummer & Kuhlman, 2008). Federal testing mandates may have an unintended consequence for the science education of young emergent bilinguals in particular. Because math and reading are tested in the early grades but science is not, young children in ESL pull-out programs are more likely to be pulled out during science class than during math or reading (Luykx, Lee, & Edwards, 2008). NCLB assessment mandates have been interpreted in many districts to mean that all testing must be done in English. This has led schools to spend more of young emergent bilinguals' instructional time on English language development – and less on science – in the hope that this will raise reading and mathematics test scores (Zwiep, Straits, Stone, Beltran, & Furtado, 2011).

In addition, research indicates that most elementary teachers feel unprepared for teaching science and that their (perceived) lack of science content knowledge and familiarity and facility with science pedagogy leads to less instructional time being devoted to science learning (Appleton, 2007; Schwartz & Gess-Newsome, 2008). The science education of emergent bilinguals in the early elementary grades is affected not only by teachers' attitudes toward teaching science, but also by teachers' attitudes toward teaching students who are learning (in) English as a second language. Research indicates that the majority of mainstream classroom teachers feel unprepared to work with emergent bilinguals, and researchers found that feeling unprepared for and unsupported in their work with emergent bilinguals were major factors in teachers' negative attitudes about having these students in mainstream classrooms (Lucas, Villegas, & Freedson-Gonzalez, 2008; Nieto, 2002; Walker, Shafer, & Iiams, 2004). Walker et al. (2004) suggest that such attitudes are likely to worsen in the coming years as teachers are increasingly held accountable for the academic achievement of emergent bilinguals. As Lee (2005) observes, "educational policies, especially accountability measures, influence educational practices with [emergent bilinguals] more strongly than mainstream students" (p 493).

## Review of the Research

To date, the body of empirical research on science education for young emergent bilinguals is relatively small, and most of the research that falls within the birth to age eight range has been conducted with third grade teachers and students. While there is not extensive research on science education for young emergent bilinguals, this research is informed by other, larger bodies of research: research on first-language science education; research on science education for diverse student groups; research on English as a second language and English language and literacy development; and research on science education for emergent bilinguals in the upper elementary grades, middle school, and high school. In the research on science education for young emergent bilinguals, hands-on, inquiry-based science education figures prominently, as does the integration of science education and English language development.

Nearly all of the publications reviewed in this chapter report on research conducted in the context of some form of science education intervention. Most of the intervention-based studies included (1) professional development in which teachers receive training on how to teach science content and support English language development and (2) the development and implementation of curriculum in which science content instruction and English language development are integrated. Across and within projects and publications, researchers emphasize different participants in and aspects of science education for emergent bilinguals. Teachers' professional development has received the most attention in published reports of research. Curriculum development is another focus, as are student outcomes in formal assessments of academic achievement. A few researchers have focused on classroom interaction, examining language and social processes in science education settings that include young emergent bilinguals.

We organize our overview of the research along four dimensions that emerged as the main analytic foci across studies: (1) curriculum development, (2) teacher perceptions and professional development, (3) outcomes of interventions for students, and (4) interaction in the linguistically diverse science classroom. All of the studies seek to improve science education for young emergent bilinguals, in most cases by developing, implementing, and studying the effects of interventions. While sharing a common goal, the research ranges both across and within projects in terms of focus, theoretical orientation, and methodological approach.

## Curriculum Development

We begin our overview of the research with curriculum development because changing the science curriculum is a potentially high-impact "starting place" for efforts to provide young emergent bilinguals with more equitable science education opportunities (National Research Council, 2000). In the under-resourced schools where linguistic and cultural minority students are concentrated, curricula that meet current science education standards are often not available (National Research Council, 1996). Many scholars call not only for rigorous and complete science curricula for *all* students, but also for curricula that has been designed and/or adapted for student populations that have been traditionally underserved by school science, including emergent bilinguals (Buxton & Lee, 2010; Lee, 2005).

Despite the centrality of high quality and appropriate instructional goals, methods, and materials to the interventions that have been studied, curriculum development and adaptation have received limited attention in publications of research on early childhood science education for emergent bilinguals. For example, Amaral, Garrison, and Klentschy (2002), report on the Valle Imperial Project in Science (VIPS), an intervention conducted in grades K-6 in a school district in rural southern California that served a predominantly Mexican-origin students. They describe the intervention as "a mosaic of second generation, high quality, research-based instructional units in the form of kits or modules" drawn from multiple sources, including Science and Technology for Children and Full Option Science System (p. 220). However, they do not discuss the processes through which this mosaic was pieced together, adapted for emergent bilinguals, or modified over time.[1]

Most of research reviewed in this chapter examines efforts to integrate rigorous science content instruction *and* opportunities and support to develop academic language, the specialized language functions and forms used in talk and texts about topics in academic subjects. In nearly all of the studies, academic language means academic *English*. Efforts to integrate science and English language development (ELD) build on evidence that inquiry-based science instruction is beneficial for emergent bilinguals (Amaral et al., 2002; Cuevas, Lee, Hart, & Deaktor, 2005; Fradd, Lee, Sutman, & Saxton, 2002). These efforts are also grounded in research that indicates that second language learners benefit from content area curriculum that is academically challenging and thematically organized and that incorporates language development components (e.g., language objectives for each lesson in

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[1] Klentschy and Thompson (2008) draw upon the VIPS experience in their book on science inquiry lesson design.

addition to content objectives) and sheltering techniques (e.g., building background and modifying linguistic input to maximize student comprehension) (Berman, Minicucci, McLaughlin, Nelson, & Woodworth, 1995; Cummins, 1981; Echevarria, Short, & Powers, 2006; Genesee et al., 2005; Swain & Lapkin, 1985).

The goal of science/ELD integration is to provide emergent bilinguals with rigorous and accessible science instruction that will improve their facility in the academic language that is central to science achievement and academic achievement more broadly. One example of integrated science/ELD curriculum development comes from the Promoting Science among English Language Learners (P-SELL) project (http://www.education.miami.edu/psell/index.html). Participants in this 5-year project were third through fifth grade students and teachers at twelve urban elementary schools in Miami-Dade County public schools that enrolled large numbers of emergent bilinguals (Spanish-speaking students in six of the schools, Haitian Creole-speaking students in the other six).[2]

A team of scientists, science educators, bilingual/ESOL educators, and district administrators worked collaboratively to develop curriculum in which science education and English language development were integrated, as well as mathematics. Aligned with state mandates and national standards in science, the curriculum focused on science inquiry, with a gradual progression from teacher-directed in third grade to more student-initiated inquiry by fifth grade. The curriculum units took 8–10 weeks and focused on key topics in physical and earth/space sciences. For grade 3, the topics were measurement, changes of states of matter, and the water cycle and weather. Schools were provided with student books, teacher guides, and science materials (Lee & Maerten-Rivera, 2012). Units incorporated activities and strategies to promote literacy, with particular attention to the English language development needs of emergent bilinguals. For example, in the student books, each lesson included (1) a list of science vocabulary in English, Spanish and Haitian Creole, (2) comprehension questions designed to call students' attention to language used for inquiry activities, and (3) texts that activated students' prior knowledge (Lewis, Maerten-Rivera, Adamson, & Lee, 2011). Teacher guides provided explanations of how to promote science inquiry and how to incorporate English language development into each lesson. Teacher and student materials encouraged the use of multiple modes of communication, including speech, gesture, text, and graphics. (Adamson, Secada, Maerten-Rivera, & Lee, 2011; Lee et al., 2008; Lewis et al., 2011).

While publications from the P-SELL project do not discuss the curriculum development process in much detail, Lee, Adamson et al. (2008) report on how results from a study of third-grade teachers' perceptions of the intervention was used to revise the curriculum materials. Teachers provided their feedback during workshops over the course of the first year of the intervention and in a questionnaire at the end of that year (n = 38). In order to identify strengths and areas for potential

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[2] The P-SELL project built on prior work by Lee and colleagues on elementary science education for culturally and linguistically diverse student groups (Fradd and Lee, 1999, Lee and Fradd 1996, 1998, Hart & Lee, 2003; Lee Hart Cuevas Enders 2004; Luykx, Cuevas, Lambert, & Lee, 2004).

improvement in the intervention, one set of questions elicited teachers' rankings of the three most effective components in the intervention and three components needing improvement. The teacher guides were the second most commonly reported strength of the intervention, after the provision of supplies. Student booklets were the third most commonly reported strength and the most commonly reported as needing improvement.

Lee et al. describe the revisions of the curriculum that the project team made and did not make on the basis of teachers' feedback. To the teacher guides they added more teaching suggestions and visual materials, a glossary of science terms, and suggestions for assessment. To the student booklets they added questions to activate students' prior knowledge, more visual materials, and more varied types of assessment. Some of the teachers' suggestions were not followed, and the authors explain why. For example, several teachers requested that the language demands of student booklets be reduced for students with lower levels of English proficiency. Rather than lower the reading level, the researchers added more non-linguistic supports such as supplies and visual materials because they wanted to maintain the same expectations for all students. Other curricular revisions were made on the basis of the researchers' observations in classrooms and professional development workshops during the first year of the intervention, including increased emphasis in the teacher guides on the importance in science inquiry of accuracy in measurement, control of variables, and multiple trials.

Another example of curriculum development in which science and English language development are integrated is Zweip et al.'s (2011) study of the development, initial implementation, revision and refinement of a blended program in three K-4 elementary schools in large urban school district in California. The district had been identified as needing improvement, particularly with respect to the education of emergent bilinguals, so it assembled a team of district personnel, faculty from local universities, ELD and science educators, and professional development experts to develop and deliver a professional development program. The goal was to merge ELD and science instruction so that emergent bilinguals could have more ELD instructional time without losing science instructional time. Thus the professional development team sought to place equal emphasis on the improvement of English skills and the development of high-level thinking and content area knowledge through participation in inquiry-based science.

Zwiep et al. examine the challenges of integrating science and ELD in a single program, which, the authors note, "requires reconciling two very different perspectives about teaching and learning" (p. 770). During the initial development of a blended lesson design template, differences within the professional development team quickly became evident. The science educators used Bybee (1997) 5E lesson design, and lessons were structured to activate students' prior knowledge of a concept and then provide a series of experiences through which students could build on their prior understanding. ELD educators focused on making the language of the lesson accessible to the students, often through explicit instruction on specific vocabulary and grammatical structures and their expressive functions prior to their use in a science content-focused task. For example, ELD lesson plans typically provided sentence frames such as ‘I think ______ because ______’ to help children produce sentences that would be relevant in an upcoming activity. Zwiep et al. observe that these different lesson plan structures reflected different philosophies: “the science education philosophy was grounded in inquiry instruction where concepts and language unfold out of student-centered learning experiences, while the ELD philosophy relied more on highly-facilitated instruction where the teacher frames, directs, and monitors student language use, accommodating for varied English language proficiency levels” (p. 774).

The professional development team developed a science/ELD lesson design template, but new challenges arose when it was field tested by teachers. Zwiep et al. found that the lesson design template was overwhelming and impracticable for the teachers. The authors explain this as a consequence of the template not being a blend of ELD and science instruction, but rather a compilation of all the elements found in science and ELD lessons, a compilation in which “the science did not truly support language development and the focused ELD instruction impeded the development of scientific understanding” (p. 774).

On the basis of extensive feedback from teachers, ELD coaches, district personnel, and the professional development team, the lesson design template was revised in several ways. In the new format, the science was planned first so that the ELD focus on language forms and functions could emerge from teachers’ collaborative lesson planning of accurate and level-appropriate science content instruction, rather than the language being artificially imposed. A language function column was added to the template to help teachers plan opportunities and specific language supports for students to practice different language functions and forms central to the activity at each stage in the lesson. The template was also modified to help teachers plan accommodation for students’ varied English proficiency levels. In their subsequent study of participating teachers’ practices and perceptions (discussed in the next section), Zwiep et al. found that the lesson design template (and the program as a whole) helped teachers support students’ science learning, develop students’ language, and accommodate different levels of English proficiency.

The work by Lee, Adamson et al. (2008) and Zwiep et al. (2011) illustrates the complexity inherent in the development of high quality and appropriate science curriculum for young emergent bilinguals. In all-English educational contexts (increasingly the norm in the U.S.), children are learning science in a language that they are still developing as a second or additional language (Rosebery et al., 1992). Thus, program goals, methods, and materials must address science learning goals *and* the language demands entailed therein. Because there is variation among emergent bilinguals with respect to their English language resources and needs, curriculum must include multiple options and supports – including non-linguistic options – for taking in, working with, and expressing understanding of science content. Integration of science instruction and English language development is a promising trend, but one that requires collaboration between two groups of educators who often subscribe to very different philosophies and who have different pedagogical foci.

## Teacher Professional Development

Teacher professional development has received the most attention from researchers studying science education for young emergent bilinguals. The question driving this work is how can we prepare and support teachers to provide effective science education for young emergent bilinguals? The studies discussed in this section provide insights into teachers' perceptions, knowledge, and practices before, during, and after interventions. Nearly all the studies were conducted in all-English educational contexts, and the training of teachers to integrate science education and English language development figures prominently in the published reports. Research indicates that science/ELD integration is effective for students but that teachers are often resistant (Luykx et al., 2004). The studies discussed here show that professional development can have a positive impact on teachers' perceptions, knowledge, and practices with regard to science/ELD integration and science education for emergent bilinguals more generally.

Stoddart, Pinal, Latzke, and Canaday (2002) examine change over time in teachers' understanding of science/ELD integration. This study was conducted in the context of a project in rural central California that trained experienced teachers to provide inquiry science instruction to emergent bilinguals, Language Acquisition through Science Education in Rural Schools (LASERS). The authors developed a science-language integration rubric to provide a conceptual framework to guide professional development activities and assess changes in teachers' beliefs and practices. Stoddart et al. used interviews with 24 first- through sixth-grade teachers to develop the rubric, which includes five levels of understanding of the connections between science and language, from a view that they are unrelated domains to "the recognition of the superordinate processes that create a synergistic relationship between inquiry science and language development" (p. 664). The authors found that novice and experienced teachers who participated in LASERS developed more elaborated understandings of how and why to integrate inquiry science and language development, as well as motivation to do so. Stoddard et al. propose that their rubric may be used by educators to examine, reflect on, and improve the integration of science and ELD in curriculum and instruction.

In their study of the development and implementation of a blended science/ELD program, Zwiep et al. (2011) examined the impact of the program on teachers' practices and perceptions. The program included intensive 2-week summer institutes that provided three school principals, six ELD coaches, and 60 teachers with training in science content, science pedagogy based on the 5E instructional model (Bybee, 1997) and a functional linguistic approach to ELD pedagogy. In addition, the program included site-based lesson study teams throughout the school year. During the first 2 years of the program, the researchers collected teacher-generated lesson plans and conducted classroom observations, semi-structured interviews with three principals, and informal and semi-structured interviews with 29 teachers. With respect to practice, Zwiep et al. found that teachers used the lesson design template to provide more effective support for students' science learning and English language development. However, there emerged a pattern of over-reliance on sentence frames to accommodate students with limited English skills, which limited students' displays of understanding of science concepts. The authors report that the teachers came to recognize this and to explore other, non-linguistic means to support students in the early stages of English language learning to express their thinking, such as realia, graphics, and manipulation of materials.

In terms of teachers' perceptions, Zwiep et al.'s focused coding of the interviews revealed three "key insights" into the impact of the program on participating teachers and schools. First, teachers reported that, in connecting science to ELD, the program had enhanced the status and appeal of science in their eyes of teachers and the students. This shift was connected to the second insight, which was that students were talking about science much more than previously and that they were using more English overall. The third insight was that teachers' expectations for their emergent bilingual students had risen and that this change had made the teachers more critically reflective about their own teaching practice and how it supported (or not) the science and language learning of all their students.

Shanahan and Shea (2012) examine the impact on teachers of a professional development program in which strategies to promote student talk were explicitly embedded into science inquiry lessons. The program involved 68 K-2 mainstream classroom teachers from a low performing school district in southern California. In monthly workshops during the second year of the program, teacher-leaders demonstrated science lessons in which multiple opportunities for students to talk in groups or pair had been built into each stage of the 5E lesson planning model. Immediately before using a specific student-talk strategy, the teacher-leader explained how it promoted students' development of linguistic, cognitive, and interactional skills. The teachers participated in these lessons as if they were students, after which they discussed the strategy, how they could incorporate it in their own teaching, and what kinds of challenges might arise. Back at their schools, teachers shared these experiences with colleagues and then taught the lesson to their own students.

To examine the impact of this program on teachers' practices and on their perceptions of their learning and their students' learning, Shanahan and Shea conducted interviews and classroom observations with participating teachers. In fall and late spring they observed 21 teachers who had been randomly selected. Six of these teachers were selected for semi-structured interviews at the end of the program on the basis of their grade level, rate of participation in the workshops, and shifts in their implementation of student-talk strategies over the course of the year. The researchers found that, among the observed teachers, those who attended 75 % or more of the workshops grew significantly more in the use of student-talk strategies than did teachers who attended less frequently. Data from the interviewed teachers indicated that they had improved their understanding and appreciation of science/ELD integration and felt more efficacious with regard to it and to science teaching more generally. In addition to the findings from their study, Shanahan and Shea discuss the tool they developed and used to record teachers' use of strategies to promote content-based language learning, the Peer Classroom Observation Protocol

(PCOP), proposing that it may be used by other researchers and practitioners to study professional development programs and their outcomes.

Multiple publications on teacher professional development come from the P-SELL project. In addition to the development and implementation of a series of curriculum units in which science and ELD were integrated, the project provided throughout the school year teacher workshops that focused on implementation of the curriculum. Workshops addressed science content, hands-on activities, and potential student learning difficulties for each lesson, all with reference to state standards and assessments. Workshops also focused on the incorporation of English language and literacy development into science lessons, including strategies to promote reading and writing skills, adjust to various levels of language proficiency, and use multiple modes of communication to support student comprehension. In order to develop, improve, and assess the impact of the P-SELL project, Lee and her colleagues used questionnaires, classroom observations, and interviews to study teacher perceptions, knowledge, and/or practices before, during, and after the professional development intervention.

Teachers' initial perceptions, knowledge, and practices were investigated by means of a questionnaire administered to 221 third through fifth grade teachers (Lee, Maerten-Rivera, Buxton, Penfield, & Secada, 2009). Teachers reported that they felt generally knowledgeable about science content for their grade level and that they often used pedagogical practices that promoted scientific understanding and inquiry. In contrast, the teachers reported infrequent use of strategies to support the learning of science or English by emergent bilinguals, despite the fact that most had ESOL endorsement. Collaboration with colleagues in science teaching was reported to be frequent, but discussions of diversity (linguistic or otherwise) were reported to be rare. Lee et al. found that, consistent with prior research, teachers felt that their science teaching was hindered by school-level constraints (large classes, lack of time, and shortage of science supplies); the state-level emphasis on high-stakes assessments of literacy and math; and the students' academic skills, parents, family, and community.

Third grade teachers are the focus of three of the P-SELL publications on professional development, all based on data collected during the first year of the intervention. Lee, Adamson et al. (2008) examined third-grade teachers' perceptions, elicited through workshop discussions and an end-of-year questionnaire. Teachers ($n=38$) rated on a 4-point Likert-type scale the effectiveness of different components of the intervention, gave written responses about their perceptions of the impact of the project on students' learning and on their own professional knowledge, and identified strengths of the intervention and areas for improvement. The study found that participating teachers perceived the intervention as being effective in promoting students' science learning as well as their English language development and mathematics learning. Lee, Adamson et al. (2008) used classroom observations and post-observation interviews conducted to study the knowledge and practices of the same group of teachers before and after their first year of participation in the intervention (in addition to the questionnaire data discussed in Lee et al. (2009). They found that the teachers' science content knowledge and practices for promoting scientific understanding, scientific inquiry, and English language development fell short of project goals. Using the questionnaire and classroom observation data, Lewis et al. (2011) examined relationships among domains of science instruction with emergent bilinguals, among domains of teachers' practices, and between teachers' perceptions and their practices. Teachers' self-reports indicated that teaching practices to support scientific understanding were related to practices to support scientific inquiry and practices to support English language development. Classroom observations indicated that practices for understanding were related to practices for inquiry, practices for English language development, and teacher knowledge of science content. The researchers found a weak to non-existent relationship between teachers' self-reports and their observed practices.

In their analyses data from third, fourth, and fifth grade teachers over the 5-year duration of the project, the P-SELL team found similarities and differences across grade levels. Focusing on change in teachers' knowledge and practices over the course of their participation in the project, Lee and Maerten-Rivera (2012) used questionnaires and classroom observations to measure teachers' reported and observed use of practices promoted by the intervention. Before beginning the intervention and at the end of each school year, 191 teachers completed the questionnaire (used in Lee et al. (2009), and 156 teachers were observed in the fall and spring of each year. The researchers found growth in teachers' knowledge and practices in teaching science to emergent bilinguals, but many teachers fell short of reform-oriented practices, particularly with respect to scientific inquiry practices. For example, third grade teachers often taught the hands-on activities in the unit on measurement as routine procedures rather than as inquiry-based approaches to estimation and problem solving.

Adamson, Santau, and Lee (2013) investigated participating teachers' reported implementation of instructional strategies promoted by the intervention, using interviews conducted over the 5 years of the intervention. Their statistical analysis of 213 post-observation interviews collected from 104 third grade, 72 fourth grade, and 37 fifth grade teachers revealed similarities across and significant differences between grade levels and by years of teacher participation in the intervention. Teachers consistently reported using similar strategies to promote science learning (e.g. making connections to prior knowledge, engaging in hands-on activities) and English language development (e.g., developing science vocabulary, using multiple modes of representation). They did not report the use of more advanced inquiry-based strategies, such as asking questions that could be answered using scientific inquiry, and using simulations or models to construct explanations. The researchers found that teachers in their third year of participation were more likely to report that they made connections between science and prior experience and knowledge and allowed emergent bilinguals to use their home language. Third grade teachers more frequently reported using home language, allowing students to plan and design their own original scientific investigations, engaging students in hands-on activities, and relating science to other subject areas.

De la Colina and Cuellar (2011) is the only published report on a professional development intervention conducted in a bilingual educational context. The researchers used *Know, Want to know and Learned* (KWL) charts to conduct an initial needs assessment with 19 bilingual/ESL education teachers in grades K-4 in a central Texas school district that followed a late-exit bilingual education model. They found that many teachers had limited theoretical knowledge of bilingual education or second language acquisition, and several teachers were not familiar with academic Spanish and Spanish science vocabulary. A 1-year, 100-h professional development program was designed to address these topics, as well as core science concepts and inquiry-based pedagogy, teaching and assessment strategies for academic language development in Spanish and English, and specific guidelines for how to configure delivery of English and Spanish language instruction. At the end of the program, the teachers completed evaluation questionnaires in which they were asked what they had learned. Researchers report that participants felt the intervention had helped them become more informed and more effective bilingual/ESL science educators.

These studies of professional development for science teachers who work with young emergent bilinguals show positive outcomes during and after participation in interventions. Teacher reported generally positive perceptions of the interventions, and interviews, surveys, and classroom observations showed increases in reported and observed use of teaching practices promoted by the interventions. Interventions in which science and English language development have been studied by several researchers and with multiple methods, but much more work remains to be done on professional development for teachers working in bilingual education programs.

## Student Outcomes

Student outcomes of science education include more than achievement scores on standardized tests. They also include "meaningful learning of classroom tasks, and affect (attitudes, interest, motivation) in science" (Lee, 2005, p. 493). In this section we review studies that examine a variety of student outcomes and take different approaches to doing so. All of the studies discussed in this section were concerned with the promotion of science learning for students who were learning English as a second or additional language. However, many of the participating students were not receiving ESL or bilingual education services. We focus here on findings related to young learners who were receiving language support services, but it is important to point out that an important overarching finding from this work is that science education curriculum and instruction that is effective for emergent bilinguals is also effective for students who are proficient in English (August, Artzi, & Mazrum, 2010).

Shanahan, Pedretti, DeCoito, and Baker (2011) examine the impact of Scientists in Schools (SiS), an elementary science outreach program in Ontario, Canada that provided hands-on, inquiry-based workshops in schools with the goal of fostering awareness of and positive attitudes toward science. To gain insight into the responses of three groups traditionally underrepresented in science – emergent bilinguals, girls, and students at low achieving schools – the researchers surveyed 403 students from 152 first through fourth grade classrooms.[3] The questionnaires consisted of five questions with a three-point Likert-type response format and were designed to gauge students' responses to the SiS program with respect to the program's ability to engage students and inspire interest in science. Prevented by school policy from collecting language data for individual students, the researchers used a group variable for the emergent bilingual grouping, assigning students to the high ELL group (those attending schools with an ELL population percentage above the group mean of 20 %) or the low ELL group (those attending schools with an ELL population percentage at or below the group mean). Compared to students at low ELL schools, students at high ELL schools reported significantly higher levels of enjoyment of SiS workshops and reported that the program helped get them excited about science. Shanahan et al. link this finding to arguments made by Lee and colleagues that hands-on science learning experiences are particularly valuable for emergent bilinguals because they reduce the linguistic burden and provide opportunities for contextualized language use in small-group collaboration (Hart & Lee, 2003; Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008).

Lee and her colleagues have used standardized achievement tests and project-developed science tests to measure the impact on students of the P-SELL intervention and their prior work on which P-SELL built. We focus here on outcomes for third grade students. To measure the impact of the first year of P-SELL on outcomes in science and mathematics, Lee, Adamson et al. (2008) analyzed data from roughly 1,000 third grade students at schools where the intervention was implemented and another thousand at eight comparison schools. On a statewide mathematics test, the treatment students received higher scores than the comparison students. At the beginning and end of the first year of the intervention, the researchers administered to the treatment students a project-developed science test and selected items from the National Assessment of Educational Progress (2000) and the Third International Mathematics and Science Study, *TIMSS* (1995). They found that the treatment students' science achievement scores increase significantly over the course of the school year. Moreover, students who were receiving ESOL services showed gains that were comparable to those of students who had exited or had never been identified as eligible for ESOL services. Adamson et al. (2011) investigated the impact of the intervention on the mathematics achievement of third grade students in schools that had participated in all 3 years of the third-grade intervention. The authors used a hierarchical linear modeling (HLM) approach to compare students' measurement achievement scores on the statewide mathematics assessment at six treatment schools (n = 844, 16 % of whom were receiving ESOL services and 50 % had exited within the last 2 years) and six comparison schools. They found that students at the treatment schools scored significantly higher than students at the comparison schools.

To explore the intersection of science learning and English language development, Lee, Penfield, and Buxton (2011) examined the relationship between the

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[3] The larger study included students in grades 5–8, and data were analyzed separately.

content and form of science writing among third grade students for whom English is a second or additional language who participated in the P-SELL intervention. They also investigated whether the relationship differed across students at varying levels of English proficiency, comparing writing test scores from students who were receiving ESOL services with scores of students who had never received services or had exited within the last 2 years. At the beginning and end of each school year, teachers administered to students a writing test designed by the researchers, in which students were prompted to explain the water cycle. Project personnel scored the tests using two rubrics, one to assess language form (conventions, organization, style), one to assess science content knowledge. Taking an HLM approach, the researchers analyzed the scores of the 2,020 students for whom they had scores for the fall test (used as pretest scores) and the spring test (used as posttest scores). They round significant relationships between writing form and content at both pretest and posttest, with a stronger relationship at posttest. This suggests that students with better science knowledge also had better English writing skills and that the P-SELL intervention strengthened that association. Level of English proficiency had significant and negative effect on the magnitude of the relationship only at posttest, indicating that students with lower English proficiency benefitted less from the intervention in terms of simultaneous development in science knowledge and English writing skills. Lee and her colleagues conclude that interventions like P-SELL, "which primarily present science curriculum and instruction in English, might be expected to have limited positive effects" for students at the beginning and intermediate levels of English proficiency (Lee et al., 2011, p. 1425).

For young emergent bilinguals, the complexity of English-language texts can hinder their science learning. Arya, Hiebert, and Pearson (2011) address the issue of text accessibility, investigating the effects of syntactic and lexical complexity on third grade students' comprehension of science texts. They give specific attention to the question of whether these two forms of complexity have any additional effects for what the authors referred to as English language learners. Conducted in northern California, the study included 142 third graders from four schools. The researchers classified as ELL those students who spoke a language other than English at home (n = 49), and students who spoke only English at home were classified as non-ELL (n = 93). Data collection was done in three sessions over a 3-week period, with assessments of students' oral reading and prior vocabulary knowledge completed in the first session, the passage reading/comprehension tasks conducted over the second and third. The 16 experimental texts on four science topics were about 200 words, the middle 100 words of which were rewritten to create for each topic one text that was syntactically simple with everyday vocabulary, one that was syntactically complex with everyday vocabulary, one that was syntactically simple with academic vocabulary, and one that was syntactically complex with academic vocabulary. Each student read four passages, all on different topics. After reading a passage, students were given as much time as they needed to answer 10 questions about it without the use of the text. Using HLM to analyze the data, Arya et al. found that lexical complexity had a significant impact on students' comprehension on two of the four topics while syntactic complexity had no impact, and no additional effects were found for the students classified as ELL. The authors acknowledge that their dichotomous classification of students as ELL or non-ELL may have limited their ability to explore additional effects for students who are reading in a second or additional language.

When discussing outcomes for young emergent bilinguals, it is important to keep in mind that their responses to academic assessments are affected by linguistic and cultural influences. This is illustrated in a study by Luykx and colleagues of third and fourth grade students' open-ended responses to science tests developed for an elementary science education intervention for culturally and linguistically diverse students (Luykx et al., 2007).[4] After scoring revealed that students misinterpreted some test questions and that scorers had difficulty interpreting some students' responses, the researchers took a qualitative approach to analyzing the approximately 6,000 tests, with the system of codes and categories emerging over time. Luykx et al. identified and analyzed instances when linguistic, cultural, or languacultural influences led to misinterpretations by child or scorer. Linguistic influences were cases when the phonological, orthographic or semantic features of a child's home language led to confusion. Cultural influences fell into two types: when a child referred to beliefs or experiences from home when they did not have the science knowledge, and when a child's response indicated they did not understand the practices, norms, and/or beliefs implicit in the test question. The third category, languacultural, refers to instances when language form is intertwined with cultural ways of being and knowing.[5] In the students' test responses, the authors found many instances of confusion around how to interpret and produce the academic writing genres, textual conventions, and discourse conventions that are common in science texts and tests. Observing that cultural and linguistic influences are part of every aspect of instructional and assessment practices, Luykx et al. suggest that "the goal of designing culturally neutral assessments is unrealistic [because] test developers are faced with a multitude of decisions concerning formatting, wording, visual cues, and textual organization", all involving culturally specific knowledge that is largely unconscious (p. 917).

The research discussed in the chapter seeks to understand how we can provide equitable science learning opportunities for young emergent bilinguals that will support desired science outcomes. In the next section we review studies that explore classroom interaction as the site where equitable science learning opportunities are talked into being – or not.

## Classroom Interaction

Classroom observations were an important part of several of the studies reviewed in this chapter, but none of the articles discussed thus far paid close analytic attention to classroom interaction. In this section we discuss discourse analytic studies of

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[4] The project, which ran 2001–2004, was similar to and built upon by the P-SELL project.

[5] For a discussion of the concept of languaculture, see Agar (1994).

interaction in science classrooms that include emergent bilinguals. In this work, researchers examine the linguistic and social processes through which science education is enacted by teachers and students. These studies take a cultural-historical perspective on learning and are grounded in the premise that language is the primary means through which shared meanings are constructed, mediated, reproduced, and transformed. The focus on face-to-face interaction serves to illuminate the central role of language in the production of science curriculum, science learners, and scientific knowledge. Researchers analyze classroom talk, identify patterns in language use, and examine the ways in which these patterns support or hinder students in building upon their current language abilities and scientific understandings.

Taking a critical discourse perspective, Luykx et al. (2008) examine the organization of talk in two languages during science lessons in a combined third and fourth grade ESOL class. Part of the same larger intervention project, Luykx et al. (2007) studied 23 students at the beginning stages of learning English as a second language, their English monolingual teacher, and their Spanish-English bilingual co-teacher. Transcripts of classroom discourse were based on field notes made by the first author during classroom observations, which were not video or audio recorded. In analyzing the discourse, Luykx et al. looked for “rich points”, instances when differences in language and/or culture interfered with communication.[6] They also compared two different communicative situations: typical lessons, in which the co-teacher assisted the teacher, and an atypical lesson, in which the co-teacher was not present. In the typical lessons, the teacher taught in English while the bilingual co-teacher provided impromptu Spanish translation for the students, and negotiation of meaning was infrequent, even when rich points arose. In this situation, the co-teacher’s role was limited to that of interpreter, while students were positioned as passive recipients of science content. In contrast, during the atypical lesson the teacher relied on a few students to interpret for classmates who were less proficient in English, and students were much more active in negotiating meaning both with her and with each other, using English and Spanish.

Luykx et al. discuss how language ideologies shaped the organization of interaction in the classroom in ways that limited opportunities for participants to engage with the science content and each other. The school practice of providing emergent bilinguals with instruction delivered in English and spontaneously translated to Spanish framed the translation of science content from one language to another as a mechanical process of encoding and decoding. The practice also steered teachers and students into communicative roles that inhibited their negotiation of meaning of science content and the language forms used to communicate it. Consequently, rich points that arose during science instruction went unexplored during typical lessons, as did emergent bilinguals’ linguistic and cultural resources for constructing scientific understandings. Underlying these interactional patterns, Luykx et al. identify an ideology that languages are “neutral media for the transmission of science content and that science content is therefore independent of the language in which it is delivered” (p 664). The authors argue that critical examination of this ideology is

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[6] For a discussion of the concept of rich points, see Agar (1994).

essential to the development and actualization of effective science education policy and practice for young emergent bilinguals.

Whereas Luykx et al. describe a classroom in which different ways of speaking and knowing go unexamined by the teachers, Gutierrez, Baquedano-López, and Tejeda (1999) analyze a teacher's purposeful use of diversity to promote science learning. Drawing on cultural-historical theories of learning and using ethnographic and discourse analytic methods, they studied the social practices of a combined second and third grade classroom in a dual immersion elementary school in Southern California. They focus on the hybrid culture of the classroom, in which teacher and students create activities and language practices that are "neither part of the normative practice of the school nor of the home" (p 292), a social space for development that the authors call the Third Space. Gutierrez et al. illustrate this construct through their analysis of classroom talk recorded during a 6-week unit on human reproduction designed by the teacher and the students with parental and district participation. They found that participants used and accepted diverse forms of discourse and knowledge in strategic ways to bridge home and school. For example, when eliciting answers from students to the question "Why do women have breasts and men don't?", the teacher the used three different words for breast(s), including a colloquial Spanish term. The teacher thereby diffused tensions between local knowledge and school curriculum, as well as demonstrating that a range of registers can be used to make meaning in science lessons. The authors propose that a focus on hybridity is useful not only for understanding learning in linguistically diverse classrooms, but also for organizing it.

Gutierrez et al. emphasize that tensions are intrinsic to learning contexts and have the potential to promote learning and development. Baquedano-Lopez, Solis, and Kattan (2005) elaborate on this idea in their conceptualization of adaptation within classroom learning, which they describe as "a set of improvisational and strategic processes carried out by teachers and students as they negotiate tensions arising from ongoing learning activity" (p 2). The authors illustrate these processes in their analysis of interaction in a third grade Spanish Bilingual classroom where a scripted science curriculum was being implemented. The study is part of the Science Instruction for Grade Schools (SIGS) project, a 3-year longitudinal study of the implementation in three states of a science curriculum developed for culturally and linguistically diverse students. Project data included student test scores, ethnographic field notes from weekly classroom observations, pre- and post-interviews with teachers, and video recordings of 52 lessons (50 h) across 10 classrooms.

Taking a conversation analytic approach to the video data, the researchers examined how teachers and students negotiated the implementation of the SIGS curriculum. The authors focus on breaches – disruptions or discontinuities to agreed-upon routines and activities that make visible the expected forms of participation – and participants' responses to them. Through close analysis of a representative sequence, in which a lesson on the three states of matter is implemented, the authors show how teacher and students respond to breaches of classroom norms and expectations in ways that lead to adaptations of routine classroom science activities. Adaptations include shifts in which knowledge is made salient, who is positioned as expert, and how and which connections are made to prior experiences. The authors argue that a focus on adaptions help us understand how curricula are actualized in classrooms and "how learning takes place both within and without the scripted curriculum" (p 21).

Solís, Kattan, and Baquedano-López (2009) explore notions of time in science instruction, examining how these notions are encoded in and constructed through classroom discourse. Working with the same data set as Baquedano-Lopez et al. (2005), the authors focus on adaptations during science lessons in two bilingual third grade classrooms and one fourth grade classroom. They explain and illustrate how time is socially constructed through classroom talk in ways that shape the construction of knowledge and participation in science classrooms. In their analysis of a lesson on the states of matter, they show how shifts in temporality are made through discursive strategies used by teachers and students as they recover and make connections to past history, memory, and experience of individuals or groups. In a lesson on weather patterns, the teacher's use of a hypothetical scenario, which entails the construction of an alternative temporal frame, is shown to position the teacher as the sole authority. The authors examine talk during an inquiry activity about evaporation to show how time-coded language (in English and Spanish) used by teacher and student reflect an orientation to strict adherence to an official task timeline, an orientation that interfered with the learning of science. Solís et al. (2009) point out that taken-for-granted notions of time are embedded in teaching practices, curricula, schools, educational standards, and theories of learning and that this has implications for any effort to implement culturally and linguistically responsive science curricula.

These studies of classroom interaction provide insights into science educational processes and the centrality of language to these processes. The identification and examination of patterns in the use of language(s) raises our awareness of ideologies of language, learning, and science that underlie these patterns and may undermine effective science instruction. Close attention to language use in science lessons makes visible the social and cultural organization of science education, as participants' talk displays their expectations for and (mis)understanding of the on-going learning activity. And finally, this work calls our attention to the fact that science curriculum is actualized, not merely enacted, by teachers and students in fluid, face-to-face exchanges to which they bring prior experience and knowledge.

## Implications and Future Directions

Although the body of research on science education for young emergent bilinguals is relatively small, it has yielded findings that have important implications for educational practice, as well as questions to be answered by future research. First, we reiterate that most of the research discussed in this chapter was conducted with third grade teachers and students. Moreover, many of the studies involved participants from fourth and fifth grades, and published reports did not always distinguish among participants from different grade levels. Caution is needed when applying to younger children lessons learned from research with emergent bilinguals who are on the cusp of middle childhood. There is a need for more research in Kindergarten through second grade, as well as in preschool, which has been overlooked thus far. Empirical attention to the science education in these contexts, which tend to be more interdisciplinary, may increase our understanding of how integrated and thematically organized curricula support the science and language learning of young emergent bilinguals, providing multiple and diverse opportunities to engage with science concepts and language.

Several studies reviewed in this chapter found that inquiry-based science instruction can be effective for young emergent bilinguals. The process of inquiry provides opportunities for observation and hands-on engagement with tools and materials, which allows students to participate while still developing proficiency in the language of instruction. Collaboration with peers and the availability of linguistic and non-linguistic resources to communicate (speech, writing, gesture, tools and materials, pictures, graphic devices) creates a meaningful and multimodal context for developing science skills and knowledge and academic language. However, the inquiry-based learning processes of young emergent bilinguals have not been studied closely. Longitudinal case studies may illuminate how these learners move from directed inquiry to guided inquiry to full inquiry, as well as how their language use changes over time and across types of inquiry-based instructional activities. Research that makes multimodality a focus will provide useful insights into how emergent bilinguals develop inquiry skills, scientific understandings, and academic vocabulary and language skills.

The bulk of research discussed in this chapter was on interventions in which English language development and science instruction were integrated, and these interventions were found to have positive outcomes for teachers and students. Traditionally, science instruction and English as a second language instruction were conducted separately, but in recent years integration of the two has become central to science reform efforts focused on emergent bilinguals. Science education is potentially a rich context for language development, but this potential is difficult to realize without instructional strategies that simultaneously promote science learning and English language and literacy development. Working within an increasingly all-English educational context, researchers and educators have sought effective ways to provide emergent bilinguals with both rigorous science content instruction and opportunities and support to develop the academic language the students need to engage in and understand science topics. With the advent of the Common Core standards and the Next Generation Science Standards, these efforts have expanded, led by the Understanding Language Project. The project seeks to understand the language demands of the new standards, identify points of convergence across content area standards, create a clearinghouse of research, and develop a collection of exemplars of that show how CCSS- and NGSS-aligned instruction can be adapted for emergent bilinguals (Understanding Language, 2013).

The research shows that the integration of science instruction and English language development is challenging for program developers and teachers. Zwiep et al. (2011) describe a long process of integrated curriculum development that made clear that "teaching ELD with science needed to be conceptualized differently than simply teaching ELD and science" (p 775). They also found that teachers needed time and collaborative reflection on their teaching to learn how to use the new tools and strategies effectively. While teachers participating in the P-SELL intervention showed positive changes in their reported and observed practices, Lee and her colleagues found that many teachers fell short of reform-oriented practices, particularly with respect to scientific inquiry practices. Our understanding of teacher professional development would be enriched by qualitative studies of teachers' evolving perspectives and practices over the course of such interventions and in their collaborative work with colleagues.

The studies taking a discourse analytic approach to spoken or written discourse demonstrate that science education needs to take into account young emergent bilinguals' home languages and cultures. Instruction and assessment may be hindered when students' home and community ways of speaking and knowing are not recognized, whereas strategic use of these resources by teachers and students can create opportunities for learning. Where instruction in the home language is not an option, use of the students' home language as an instructional support for science learning is recommended (Buxton & Lee, 2010; Lee, 2008). This aspect of practice has not been examined empirically in early childhood science education settings, and such work is needed if we are to understand what constitutes effective home language support under different instructional circumstances. Because language and culture are deeply intertwined, the use of students' home language as a support may sometimes require a fairly high degree of bilingual and bicultural competence. The classroom interaction studies show that the adaptation of science instruction for emergent bilinguals involves more than translation of terms or turns at talk. As Luykx et al. (2008) note, "simply knowing their students' language is not enough; rather, teachers need to establish spaces in which different discourses and bodies of knowledge – from science disciplines, the science classroom, and students' lives – are brought together" (p 646).

As the field continues to expand, we look forward to more research in which different discourses and bodies of knowledge are brought together to explore and improve science education for emergent bilinguals. In this chapter we have discussed projects in which researchers with different expertise and disciplinary perspectives worked together – science educators, applied linguists, linguistic anthropologists and educational psychologists. We hope to see more such collaborations, which have brought together diverse theoretical perspectives and methodological approaches in fruitful efforts to understand and improve science educational processes and outcomes for emergent bilinguals in early childhood educational contexts. Deeper and on-going integration of these perspectives and approaches will advance our understanding of how language, culture, and other forms of diversity shape the content, organization, and outcomes of science education.

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# Chapter 16
# Assessment in Early Childhood Science Education

**Daryl B. Greenfield**

## Assessment in Early Childhood Science Education

The state of research and practice in early childhood science education is at a critical tipping point. The encouraging news is that there is considerable activity around early childhood science education including national task force reports, a focus on science in state's early learning standards, greater attention to science in curricula and an emerging literature on potential best practices for teaching science in early childhood classrooms. At the national level, a National Research Council (NRC) task force report on science teaching identified the critical need to begin science teaching and learning in early childhood. In this comprehensive NRC report, charged to focus on science in K – 8th grade, the authors spent considerable time discussing science in early childhood (National Research Council [NRC] 2007). A major section of this report documented the importance of the preschool period for introducing science and the need to capitalize on cognitive research on how young children learn. The NRC's focus on science in early childhood continues to garner national support (e.g., National Association for the Education of Young Children (NAEYC), 2009; National Science Board, 2009). Similarly, the new Head Start early learning standards emphasize Science Knowledge and Skills as a key school readiness domain – an "area of child development and early learning that is essential for children's future school success" (Head Start Child Development and Early Learning Framework; Head Start Bureau, 2011, p. 1). Only a few years ago, a very limited amount of science (e.g., knows some basic characteristics of living things; classifies objects based on physical properties) was included in state's early learning standards, embedded in the "Cognition and General Knowledge" readiness domain (Greenfield, Jirout, Dominguez, Maier, & Fuccillo, 2009). More recently, however,

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states have placed a greater emphasis on science by designating science as its own school readiness domain (Greenfield, 2011b; Sackes, Trundle, & Flevares, 2009; also see, Barnett et al., 2010, p. 187 for links to each state's early learning standards document).

With respect to curricular efforts, traditional early childhood curricula that only gave science a cursory nod are being infused with science activities (e.g., Epstein, 2010; Heroman, Trister Dodge, Kai-lee Berke, & Bickart, 2010). Companion books filled with science activities for preschoolers to supplement existing curricula are being published (e.g., Ashbrook, 2003; Neill, 2008; Ritz, 2007; Shillady, 2013). A handful of developers are creating early childhood curricula that use science as the foundational focus (e.g., Brown & Greenfield, 2006; French, 2004; Gelman, Brenneman, MacDonald, & Roman, 2010; McWayne, Brenneman, Greenfield, Mistry, & Zan, 2012; Quinn, Taylor, & Taylor, 2004). Finally, a body of literature is emerging that describes potential best practices for providing quality science in early childhood classrooms (e.g., Barnett, VanDerHeyden, & Witt, 2007; Chen & McNamee, 2007; Lehr, 2005; Witt & Kimple, 2006; Yoon & Onchwari, 2006).

The flip side, however, is that there is a dearth of empirical research validating the effectiveness of these preschool science activities and early childhood curricula that use science as the foundational focus. A major barrier to conducting such research is the lack of reliable and valid assessments to provide a strong evidence base on what constitutes best practices in science education, key factors that support these practices and how these practices affect the development of young children's competence in science. The National Research Council recently conducted a review of early childhood assessments, and recognized and endorsed the need and importance of science teaching and learning early in childhood (Snow & Van Hemel, 2008). The NRC report also acknowledged, however, that it was not possible to include sections exclusively on science in its report, as it had for the social/emotional, language/literacy, and mathematics domains, *"because of the paucity of research-based information" about science assessments in early childhood* (Snow & Van Hemel, 2008, p. 107). The report reviewed both validated instruments to assess children's learning and validated instruments to evaluate the quality of early childhood settings, and a clear need emerged for instruments focused on science in both of these arenas.

Science education is not the first early childhood readiness domain in which quality assessment has lagged behind effective practice. Similar situations occurred when language and emergent literacy, and subsequently early mathematics took center stage in early childhood. The current situation of the state of assessment in early childhood science is, therefore, not unexpected. A science assessment, for example, shown to be a valid measure when used with older students, might not be valid when used with younger students. As early childhood science programs are developed and implemented, procedures need to be put in place to collect and analyze data to ensure that the scores being generated by early childhood science assessments are valid for the purposes for which they are being used (e.g., evaluating whether or not a particular science program was effective in improving young children's competence in the area of physical science). Guidelines for developing quality assessments are available that need to be followed AERA/APA/NCME, 1999; Snow & Van Hemel, 2008).

Given the current state of assessment in early childhood science education, and the urgent need for the development of high quality assessments, the focus of the present chapter is twofold: (1) to describe a framework that would help guide development of a comprehensive assessment system for programs seeking solid evidence to understand what constitutes best practices in early childhood science; and (2) to provide a progress report on where we are to date. Although very little of this critically needed assessment work has been published there is promising work underway.

## A Framework to Guide Assessment in Early Childhood Science

Until recently, a conceptual framework for guiding early childhood science has been non-existent. This historical lack of science in the early years resulted from beliefs that preschool children could not engage in science learning, resulting in the unfortunate neglect of focus on this domain of learning (e.g., Piaget & Inhelder, 1969). Cognitive research over the past decades, however, has shown that preschool children can indeed engage in scientific ways of thinking (Carey, 2009; Carver, 2001; French, 2004; Gelman & Brenneman, 2004; Gopnick & Schulz, 2007). Learning science and engaging in inquiry are also natural for young children with their strong interest in exploring the world around them (Shonkoff & Phillips, 2000).

### *State Early Learning Standards and Early Childhood Curricula*

In arguing for a greater focus on early childhood science, Greenfield and colleagues (Greenfield et al., 2009) reviewed 29 national and state pre-kindergarten/kindergarten science standards (e.g., Massachusetts Department of Education, 2001; National Committee on Science Education Standards and Assessment, National Research Council, & National Academy of Sciences, 1996) and ten early childhood curricula, including the small subset of curricula focused on science (e.g., French, 2004; Gelman & Brenneman, 2004; Quinn et al., 2004). The result of this review was a framework for defining early childhood science that included three broad content domains: *Life Sciences*, *Earth/Space Sciences*, and *Physical/Energy Sciences* and eight science practice skills: *observing, describing*, *comparing*, *questioning*, *predicting*, *experimenting, reflecting*, and *cooperating*. Within the context of an Institute of Education Sciences (IES) funded development grant (Brown & Greenfield, 2006), Greenfield and colleagues used this framework as the blueprint for creating an IRT based direct assessment of preschool children's science knowledge and science practice skills (Greenfield et al., 2015; see later section for more detail on the *Preschool Science Assessment*).

## *The K-12 Conceptual Framework and Next Generation Science Standards*

More recently, in response to the landmark call for a radically new approach to the teaching of science in the K -12 education system (NRC, 2007), a new conceptual framework for science education (NRC, 2012) and a companion set of common core Next Generation Science Standards (Achieve, 2013) have been created and are being adopted by states. The framework and standards do not include preschool, covering only K – 12 science education. However, states are beginning to think strategically about what this framework would look like for preschool. For example, preschool standards for science are currently being developed for use in Massachusetts. A draft of these standards was released in December, 2012, followed by a period of public review (January through March, 2013) with a final version released later in the year (Worth & Winoker, 2013).

The K-12 science framework (NRC, 2012) closely follows the recommendations from the earlier NRC report (NRC, 2007). Science competence is defined in the context of three interrelated dimensions: (1) science and engineering practices *(asking questions--for science and defining problems – for engineering; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations – for science and designing solutions--for engineering; engaging in argument from evidence; obtaining, evaluating, and communicating information); (*2) crosscutting concepts that have common application across fields (*patterns; cause and effect: mechanism and explanation; scale, proportion, and quantity; systems and system models; energy and matter: flows, cycles, and conservation; structure and function; stability and change*); and (3) core ideas in four disciplinary areas (Physical Sciences – *matter and its interactions; motion and stability: forces and interactions; energy; waves and their applications in technologies for information transfer*; Life Sciences – *from molecules to organisms: structures and processes; ecosystems: interactions, energy, and dynamics; heredity: inheritance and variation of traits; biological evolution: unity and diversity*; Earth and Space Sciences – *earth's place in the universe; earth's systems; earth and human activity*; and Engineering, Technology, and the Applications of Science – *engineering design; links among engineering, technology, science, and society*).

Although this comprehensive approach covering all of K-12 science education may seem daunting for application in early childhood, the companion Next Generation Science Standards (Achieve, 2013) provide guidelines for what these integrated activities look like in each grade (beginning with kindergarten). State extensions of this framework to early learning standards for science provide guidelines and examples of what these integrated activities look like in young children (e.g., Worth & Winoker, 2013). This framework focuses science education on a small set of core ideas in four disciplinary areas where science competence is acquired by actively engaging in science practices and attending to cross-cutting concepts. The goal of this new framework for science education is to create deeper levels of understanding of a small set of broadly relevant core ideas through direct and active science exploration. The anticipated results are science literate adults with experience and competence in four interrelated science strands that involve: "know, use and interpret scientific explanations of the natural world; generate and evaluate scientific evidence and explanations; understand the nature and development of scientific knowledge; and participate productively in scientific practices and discourse." (NRC, 2007, p. 2). Young children's strong interest in exploring the world around them makes them ripe for enthusiastic participation in appropriate scientific practices and experiences so that they can begin to develop a strong foundation for subsequent science literacy.

States are adopting the K-12 conceptual framework for science education (NRC, 2012). That there is a strong correspondence between the Massachusetts preschool draft science standards and the K-12 science framework is not coincidental. States have already begun to update their early learning standards with an eye to creating links and continuity with K-12 common core standards in language arts and mathematics. States will create similar updates to their science early learning standards. Thus, despite minor variations, early learning standards for science across states will look very similar as states create the link and continuity with the K-12 science framework.

## *Summary*

The new science conceptual framework (NRC, 2012) and accompanying Next Generation Science Standards (Achieve, 2013) provide a compelling blueprint for the development of science assessments for early childhood. As a result of implementing this new framework, assessments for K – 12 science education will need to be developed that conform to the NRC framework. Given that assessments in early childhood science education are mostly lacking, there are major advantages to also using the new conceptual framework for science education (NRC, 2012) as the guiding blueprint for assessment development for early childhood science education. Unlike other established areas where well entrenched pedagogical practices have predated the creation of common core standards (i.e., language arts and mathematics), evidence based pedagogical practices for science in early childhood and the primary grades are virtually non-existent (e.g., National Institute of Child Health and Human Development-Early Child Care Research Network, 2005; Nayfeld, Brenneman, & Gelman, 2011; Saçkes, Trundle, Bell, & O'Connell, 2011). In a real sense, the very recent focus on creating a strong evidence base for science in early childhood and the concomitant call for reliable and valid measures to assess these practice places early childhood science in a unique position to address the call for greater continuity in education and assessment from early childhood through the primary grades (e.g., Reynolds, Magnuson, & Ou, 2006; Takanishi, 2010). Linking early childhood assessment in science to the new conceptual framework for science education (NRC, 2012) provides the opportunity to create this continuity.

## Assessing Young Children's Science Competence

Before reviewing the current state of assessing young children's science competence, a brief discussion of how to define science competence is warranted. In order to assess any hypothetical construct, a test developer must decide on an operational definition for how the hypothetical construct will be measured. This is not a simple decision as there are multiple appropriate ways to measure a construct. Theory should play a role in guiding this decision as well as consideration of the purpose of the test. A young child's science competence, for example, based on Piaget (e.g., Piaget & Inhelder, 1969) would focus on the preoperational child's active exploration of the environment, This would look very different than competence based on Vygotsky (1978) where competence is acquired through expert-novice social interactions. In adopting the K-12 conceptual framework (NRC, 2012), assessing a young child's science competence would require assessing knowledge of core ideas, science practices and cross-cutting concepts. Although the term "science competence" is used throughout the next sections, readers should attend to how science competence is operationalized by different research teams and test developers.

One additional issue that is especially relevant for assessing young children's science competence is the basic principle that a comprehensive assessment system must be a multi-informant, multi-method approach. Ideally, such an approach would include data from teachers, observation, and direct assessment of children using multiple methods. Including multiple measures using different formats can take advantage of structural equation modeling data analytic approaches to create measurement models that remove the error inherent in each data source (Bollen, 1989). However, special attention needs to be paid not only to the particular biases inherent from each informant and each method, but also to the biases associated with the limited abilities of young children. For example, has each assessment approach been designed to take into account young children's limited attention span? Have approaches that require verbal responses (e.g., interviews) provided appropriate supports to engage children and address young children's limited verbal and memory ability? Such issues are important in insuring that a multi-informant, multi-method approach provides strong validity evidence for assessing young children's science competence.

## *Summative Assessment*

### Assessing Related Constructs

One approach to evaluating the effectiveness of early childhood science programs has been to assess constructs that fall outside of the realm of science competence. Using quasi-experimental data collected on cross-sectional cohorts attending ScienceStart!© classes in different years, French (2004) reported on the more distal effects of ScienceStart!© on general vocabulary skills, rather than on the more proximal effects on science competence. Children participating in ScienceStart!© classrooms had greater improvement on their general receptive vocabulary skills, as assessed by the Peabody Picture Vocabulary Test-III (Dunn & Dunn, 1997), when compared to a control groups of children. Van Egeren and colleagues also reported at a national Head Start research conference (Van Egeren, Watson, & Morris, 2008) on an assessment battery they developed to evaluate the *Head Start on Science* program. Tasks (e.g., theory of mind) were based on research from the developmental psychology literature, and not from a test blueprint or table of specifications defining science competence.

### Curriculum Specific Assessments

Other research teams have developed curriculum-based assessment tools to assess the impact of what was specifically taught in a particular early science curriculum (e.g., French, 2004; Gropen, Clark-Chiarelli, Hoisington, & Ehrlich, 2011; Klein, Hammrich, Bloom, & Ragins, 2000; Witt & Kimple, 2006). In each of these programs, science competence is defined only in terms of what was specifically covered in the program. Although such an approach addresses how well children learned what was presented to them, such assessments have limited use in that they each are only applicable when using a particular curriculum.

### Achievement Tests

One might be tempted to assess science competence with validated achievement tests that include items or subsections on science. Existing achievement measures, however, are inadequate for assessing young children's science competence. Achievement tests such as the Woodcock Johnson III (Woodcock, McGrew, & Mather, 2001) and the Peabody Individual Achievement Test (Markwardt, 1997) do include items that assess science competence. These achievement tests, however, were designed as broad achievement measures and do not have an adequate number of science items appropriate for young children. Normative data are provided only for the broad measure and not for the science component and, thus, lack validity evidence supporting their use as direct assessments of science competence.

## Broad Based Adaptive Assessments of Science Competence

One approach where the focus has been on developing adaptive instruments to directly assess young children's science competence more broadly, and not linked to a particular curriculum has been the work of Greenfield and his colleagues. With funding from the Institute of Education Sciences (IES) in the context of one development grant (Brown & Greenfield, 2006; Greenfield, 2011a) and two measurement grants (Greenfield, 2009, 2013) this research team has developed broad based assessments of young children's science competence following strict measurement development guidelines with a series of steps (e.g., Crocker & Algina, 1986; Osterlind, 2006) that: (1) establish the test's purpose, (2) create a table of specifications, (3) create items, (4) submit items to an expert panel for review, (5) collect data on item characteristics with a large sample from the target population of young children, (6) conduct preliminary item analyses, (7) revise items as necessary, (8) collect additional data with the sample population on item characteristics of revised items, (9) conduct follow-up item analyses, and (10) collect validity data on a large sample from the target population. A brief review of this work follows.

**Preschool Science Assessment** The *Preschool Science Assessment* (PSA) (Greenfield et al., 2015) is an 80 item IRT based direct assessment of young children's (ages 3–5) science competence. Items cover three broad content areas: *Life Science* (e.g., "point to the one that is alive" – item shows rabbit, piece of cut wood, ice cream, chocolate)*, Earth and Space Sciences* (e.g., "point to nighttime" – item shows three different pictures in daylight and one picture of nighttime with the moon and stars) and *Physical and Energy Sciences* (e.g., "point to the picture of something that is hard" – item shows teddy bear, paper towel roll and part of a brick wall), as well as eight science practices: *Observing*, *Describing*, *Comparing*, *Questioning*, *Predicting*, *Experimenting*, *Reflecting*, and *Cooperating* (e.g., "This car won't work. Why do you think it won't work?" – item shows car sitting on blocks with no wheels; "Sandra got an ice cream cone but she left it outside in the sun. What do you think will happen to the ice cream?" – premise picture shows Sandra with cone standing in sun; choice pictures show ice cream unchanged, ice cream changes color/flavor, ice cream melting). Each item consisted of a set of pictures, (i.e., photos and/or graphics) or manipulatives (e.g., cards, measuring squares), or both. Items were assembled in a flip-book format where one side of the book contains the pictures for the child to see, and the other side of the book lists instructions and a verbal prompt for the examiner. Examinee's response formats included answering verbally, pointing, sorting, sequencing, and measuring. Raw scores are converted to interval level ability scores using the dichotomous Rasch model (Rasch, 1960). Although Rasch modeling differs from IRT conceptually, the dichotomous Rasch model is mathematically identical to a one-parameter IRT model where item difficulty level is the parameter estimated for each item.

Eighty items selected from the total pool of 236 items (initial pool of 160 items and 76 new or revised items resulting from steps 1 through 9 outlined above) were used in a validity study of 279 children attending the Miami Dade County Head

Start program (51.3 % girls; ages ranging 36–59 months with $M=48.29$ at the beginning of the school year; 63 % were Black or African American, 30 % Hispanic or Latino, and 7 % other ethnicities). Concurrent validity measures included a teacher rating scale of children's science achievement, two direct measures of children's academic skills in other domains, and two teacher rating scales of children's classroom behaviors. The data were collected within the context of a quasi-experimental study assessing the impact of the Early Childhood Hands-On Science (ECHOS) curriculum. All measures were collected both in the fall at the beginning of the school year and again in the spring near the end of the school year. Seventy-six of the items demonstrated adequate infit and outfit statistics (i.e., between the range of .7 and 1.3), covered a wide range of difficulty levels ($M\beta = .00$, $SD=1.31$, range$=-2.92$ to $+3.91$), and reached the recommended minimal .20 point-biserial value (two items had low point-biserial values −.10 and .14 and two items showed item bias). Overall, the data indicated high person reliability (.93) and item reliability (.98). PSA total scores, as expected, were moderately and positively correlated with vocabulary and mathematics scores as well as modestly and positively correlated with motivation and with attention/persistence. The strongest negative correlation was between PSA total score and social reticence/shyness. Finally, multilevel analysis of gains in PSA scores from fall to spring and controlling for all child-level predictors provided predictive validity, showing that children in classrooms where teachers implemented the science curriculum had significantly higher PSA gains compared to children in control classrooms (Greenfield et al., 2015).

Subsequent to this initial validation study, the PSA is currently being used as the key child outcome measure in an IES funded Goal 3 efficacy trial of the Early Childhood Hands-On Science curriculum (Brown & Greenfield, 2010). This study includes 90 classrooms (half randomly assigned to treatment and control) and two consecutive cohorts of 900 preschool children each, assessed three times per year (fall, winter and spring). The Greenfield research team has also trained three other research teams on administration of the PSA and verified the reliability of these teams' child assessors. These teams are currently using the PSA as a child science outcome measure in a study in Chicago, Houston and West Virginia, respectively.

**Lens on Science** *Lens on Science* (Greenfield, 2009; Greenfield et al., 2011) is an IES funded Goal 5 measurement grant to create a computer adaptive extension of the PSA for administration on a touch screen tablet. In recent years, the field of early child education has seen the widespread use of computers in the classroom as well as the home. Computers offer innovative ways to assess children; they have considerable benefits over traditional paper/pencil tests or one-on-one methods. Information gained about a child's pattern of correct and incorrect responses automatically guides item selection, which reduces the number of items necessary for obtaining a reliable score. Because an adaptive test selects items for each examinee that provide a maximal amount of information about the examinee's ability, a computer adaptive test (CAT) achieves a desired level of stability (or error) of the ability estimate using fewer items than fixed-format counterparts. Traditional methods of assessment and instruction do not allow for this quick and efficient response to answer patterns of each child. Expensive trainings for well-paid assessors to become reliable and to collect data are no longer necessary. Rich and comprehensive data that are difficult and expensive to capture with traditional formats are easily obtaining in a CAT environment. Expensive and error prone capturing of data at administration by hand and transferring of data from paper to electronic format are also no longer necessary, greatly reducing error and cost. Finally, because CAT selects items from an item bank such that each examinee receives a unique set of items tailored for that examinee, the item bank can be expanded with additional items over time. This property of CAT allows the proposed test the flexibility of augmenting the item bank over time to continuously improve the assessment process. These desirable properties of CAT compared to fixed test formats are well documented in the measurement literature (Wainer, 1990).

Following the same sequence of steps for measure development described above that was used to develop the *Preschool Science Assessment*, 498 items have been developed for the *Lens on Science* (*Lens*) assessment. The larger item pool is needed because each child receives a custom set of items based on her pattern of correct and incorrect responding. If a child begins the assessment answering a sequence of items correctly, her estimated ability level is moved quickly up the ability scale and she receives subsequently more difficult items. Similarly, a child who begins the assessment answering a sequence of items incorrectly is moved quickly down the ability scale and she receives subsequently much easier items. Once both a correct and incorrect answer occurs, the software on each subsequent trial then calculates the maximum likelihood ability estimator to estimate the child's current estimated score along with the standard error of that estimate. Items presented on each of the subsequent trials are selected based on this estimated score, resulting in each child receiving items with difficulty levels matching their current estimated score. This necessitates having a much larger item pool with many items at all difficulty levels. A major advantage of this approach is that it utilizes the child's response pattern on prior trials to maximize the accuracy of the estimate along with reducing the bias of the estimate (Baker, 1992). When the standard error of the ability estimate falls below a designated value (a configurable parameter in the system), the assessment ends.

The table of specifications for *Lens* is the new Conceptual Framework for K-12 science education (NRC, 2012). Each *Lens* item is coded by its disciplinary areas and core idea and whether or not the item includes a science/engineering practice and cross cutting concept as described in an early section of this chapter. If the item included a practice or cross-cutting concept, the specific practice and cross-cutting concept is also coded. The *Lens on Science* assessment system links to a Microsoft Excel spreadsheet generated from a project database that allows assessors to "look-up" identifying characteristics of a designated to-be-assessed child. Once the designated child is "verified" the system automatically creates a series of output files coded by the child's unique ID along with a time and day stamp. The fields included in the output files are flexibly controlled by a configuration file and typically include all relevant information on the child and items presented (each science item has a unique ID). Item difficulty, response time, expected response, actual response (for subsequent item bias analysis), total test time, expected versus actual response pattern (to identify patterns of random responding), ability estimate, standard error of the ability estimate, items where instructions required repeating are a sample of information that can be included in the output files.

Prior to administration of the *Lens* assessment, children must first pass a readiness screener that included embedded video demonstrating all required skills to use the system (e.g., "you can only touch a picture inside a black box") followed by guided practice on these skills assuring that children can follow the instructions in the *Lens* assessment. Modules are available to run the assessment in a sequential mode (items presented in a fixed order), random mode (a configurable number of random items are presented to each child to collect data to assess item characteristics) and adaptive mode.

The *Lens on Science* assessment currently contains an item bank of 498 items calibrated using the dichotomous Rasch model scaled to have a mean item difficulty of zero and unit-logit metric. Item difficulties (*b*-parameters) range from −2.7 to 4.4, with 80 % of items having difficulty values between −1.40 and 1.42. The item-measure correlation (correlation between the item and the ability estimate) exceeds .20 for 87 % of items, and exceeds .30 for 65 % of items, reflecting effective discrimination of the items in the bank and evidence of a common trait measured by the items of the assessment. For a sample of 1,753 students, the average standard error of the Rasch ability estimate was 0.31 (on the unit-logit metric), which corresponds to a reliability of .87. Additional items are being assesses for inclusion in the item bank. *Lens on Science* is also currently available for use by other research teams.

**Enfoque en Ciencia** Greenfield and colleagues have also begun an IES funded measurement project (Greenfield, 2013) to create a parallel, equated Spanish version of the *Lens on Science* assessment valid for use with Latino preschool children (*Enfoque en Ciencia*). The timeliness of the project reflects the dramatic increase in young Latino preschool children. The National Clearinghouse for English Language Acquisition (National Clearinghouse for English Language Acquisition [NCELA] 2006) reported that the population of English language learners increased at approximately seven times the rate of the overall school population. Estimates of the broader population of dual language learners are also high—approximately 20 % of school-aged children are believed to be dual language learners (Capps, Fix, Ost, Reardon-Anderson, & Passel, 2004). These estimates are even higher in public early childhood programs targeting low-income families—approximately 43 % of the children served in Head Start live in homes where a language other than English is spoken (Administration for Children and Families, 2006). Similarly, Latino or Hispanic children represent a large proportion and one of the fastest growing populations of children served in public early education programs (Barrueco, López, Ong, & Lozano, 2012; U.S. Census Bureau, 2011).

Very few early childhood assessments have been validated specifically for use with Latino or Hispanic children who are English Language Learners or Dual Language Learners (for a review, see Barrueco et al., 2012). High quality science assessments for use with low-income children from culturally and linguistically diverse backgrounds, who represent a large proportion of the population of children served in public education programs, are very much needed. *Enfoque en Ciencia* addresses this need.

When developing assessments for children from culturally and linguistically diverse backgrounds it is important to consider the heterogeneity in the population. Sixty-three percent of Latinos or Hispanics in the United States report being Mexican or of Mexican heritage, 16 % Caribbean (e.g., Cuban, Dominican, Puerto Rican), 8 % Central American (e.g., Salvadoran, Guatemalan), and 6 % South American (U.S. Census, 2010). Such heterogeneity has implications for the development of assessment items, both in terms of language and cultural load. For example, Spanish assessment measures must take into account discrepancies across the lexicon, prosody, pronunciation, and degree of anglicisms (e.g., Goldstein, 2007). Ignoring dialectical variations can curtail the validity and utility of the measure within specific Latino subgroups for both general and identification purposes (e.g., Gutiérrez-Clellen, Simon-Cereijido, & Wagner, 2008). The increasing variety of Latino subgroups is reflected in preschool classrooms, calling for the creation of Spanish-language measures that are linguistically, culturally, and psychometrically appropriate across dialects.

Another important issue to recognize when translating items into a different language is that the act of translating an item can alter the psychometric properties (e.g., difficulty and discrimination) of an item, which in turn impacts the interpretation of the scores generated by an assessment (Hambleton & Patsula, 1998). That is, common practices such as translation followed by back translation do not ensure measurement equivalence across language forms. In order to ensure that the scores of a translated assessment are equivalent to those of the original language form of the assessment, the translated assessment must undergo (a) a rigorous content review for linguistic and cultural equivalence of the items to those of the original language form (International Test Commission, 2010); (b) a complete examination of the measurement equivalence of translated items via the framework of differential item functioning (Penfield & Camilli, 2007); and (c) a formal equating process that places the scores of the translated assessment on the same scale as that of the original language form (Kolen & Brennan, 2004; Rapp & Allalouf, 2003; Sireci, 1997).

The *Enfoque en Ciencia* project will follow the same sequence of steps recommended for measure development described above that was used to develop the *Preschool Science Assessment* and the *Lens on Science* Assessment. In addition, the issues of dialect variation, measurement equivalence of translated items and formal equating discussed above have been addressed in the project design. The table of specifications for *Enfoque en Ciencia,* is the same one used for *Lens,* the new Conceptual Framework for K-12 science education (NRC, 2012). *Enfoque en Ciencia* will run on the same computer adaptive touch screen tablet platform that was developed for the *Lens* project.

## Performance Based Measures

An alternate method for assessing young children's science competence is using a performance based method. Data collection with this approach is more labor and time intensive than the computer adaptive approach described above, but has the potential to provide a deeper look into children's science competence as they problem solve in front of you. Gropen and colleagues (Gropen et al., 2011) have had success with such an approach in their development and efficacy work in the area of young children's physical science. The *Preschool Assessment of Science (PAS)* (Gropen, Clark-Chiarelli, & Hoisington, 2010) is a measure of preschoolers' concepts, facts, knowledge, and skills in physical science. The *PAS* includes two "types" of tasks: prediction tasks, and challenge tasks. Prediction tasks measure children's predictions of a scientific concept, their ability to test that prediction against an observed occurrence, and finally their ability to revise an incorrect prediction based on conflicting observational evidence. The second type of task corresponds to a challenge cycle, in which children are presented with a set of materials and a particular problem to solve within 2 min. The *PAS'* internal consistency using Cronbach's alpha (α) is 0.73.

## Summary

Summative assessments with strong validity evidence to evaluate the impact of early childhood science education on young children's developing science competence are not currently available. One study evaluated a science program (i.e., ScienceStart!© ) using a receptive vocabulary test. Another science program (*Head Start on Science*) was evaluated using tasks (e.g., theory of mind) derived from developmental psychology. That a more proximal measure of science competence was not included in these studies speaks to the dearth of direct assessments of young children's science competence. Some researchers have created assessment tools directly based on what was being taught in a particular curriculum. Such an approach is limited to assessing a particular curriculum and is often difficult to evaluate since these approaches have not followed the more time consuming guidelines for assessment development, and psychometric properties of these instruments are often not reported. Using existing achievement tests to assess science competence is also not a viable alternative. Although some achievement tests do include science items, these tests do not include a sufficient number of science items appropriate for young children. Since normative data are not provided for the science component, no validity evidence supporting their use as direct assessments of science competence is available.

The ongoing work of Greenfield and colleagues appears to hold much promise. This team is creating equated computer adaptive assessments of young children's science competence in both English and Spanish. The item specification table for these adaptive assessments is the new K-12 conceptual framework for science education. Early reports from states that are extending the K-12 framework to early childhood indicate strong concordance between what constitutes science competence in both early childhood and early elementary school. This bodes well for the continued relevance of these assessments. Although preliminary data from this team are very encouraging, it should be noted that this work is still in development. In addition, this approach relies on assessing science competence using multiple choice items. Whether or not such a method can adequately assess conceptual understanding is as yet an unanswered empirical question that could be informed by the availability of other methods for assessing competence (e.g., interviews, performance measures), further calling for the importance of a multi-informant, multi-method approach. Finally, as indicated above, special attention to issues around assessing young children is needed.

## *Screening and Formative Assessment*

In addition to summative assessment that evaluate the impact of a science curriculum or set of science activities on children' science learning, assessments are also needed to identify children with very low readiness abilities (screening) and an ongoing system for teachers to monitor children's progress across the school year to adjust and individualize instruction (formative assessment). Again, because of the lack of a science focus in early childhood science, there are no screening instruments for science readiness. Existing screening tools may include a few science items. For example, The State of Florida, as part of its statewide kindergarten screening system (Florida Office of Early Learning, 2010) includes the Early Childhood Observation System: ECHOS (Pearson Education , 2006). ECHOS contains 19 benchmarks covering seven readiness areas, only two of which focus on science (data analysis; scientific inquiry). Readiness is evaluated, however, only on the total score.

### Galileo System for the Electronic Management of Learning

At present, only one rating scale is available for teachers to track children's science readiness throughout early childhood, the Nature and Science scale of the Galileo System for the Electronic Management of Learning (Bergan et al., 2003). The scale includes 57 dichotomous items divided into ten subscales (e.g., using senses and scientific devices to learn, observing and describing the natural environment, classifying living things, predictions about living things, questioning and developing hypotheses). Items are ordered in increasing difficulty within each subscale. Each item is scored as either “learned” or ”not learned”; teachers mark each skill as “learned” if they observe the child demonstrate that skill at least three times. Galileo's developers report high internal consistency for the Nature and Science scale with a Cronbach's alpha of .97 (Bergan, Guerrera Burnham, Feld, & Bergan, 2009). Factor analytic studies support the validity of the structure of the Nature and

Science scale. All 57 items loaded significantly on their intended subscale; item loadings ranged from .39 to 1.00 (Bergan et al., 2009). Additionally, all ten subscales significantly loaded on a single underlying factor (Nature and Science); subscale loadings ranged from .80 to .93 (Bergan et al., 2009).

Teachers collected Galileo data for the Nature and Science scale as one of the concurrent validation measures for the development of the *Preschool Science Assessment* (Greenfield et al., 2015; see discussion of this instrument above). Scores on the PSA and Galileo Nature and Science scale were modestly and significantly correlated ($r = .37$; $p < .01$), but lower than PSA correlations with other similar formatted direct assessments of the related domains of language ($r = .71$ $p < .01$) and mathematics ($r = .65$, $p < .01$) of the *Learning Express* (McDermott et al., 2009).

## C-PALLS+

An encouraging research activity is the addition to and validation of science items to long-standing screening and progress monitoring systems that have previously focused on other school readiness domains. Zucker and colleagues (Zucker et al., 2013) have developed and are currently field testing a set of science and engineering items that will be included as part of a statewide professional development program that has used teacher-administered assessments to inform instruction for more than 10 years (Landry, Anthony, Swank, & Monseque-Bailey, 2009; Landry, Zucker, Solari, Crawford, & Williams, 2012). The newly developed science and engineering subtest will be part of this larger assessment system called CIRCLE Phonological Awareness, Language & Literacy + Math System (C-PALLS+; Landry, Assel, Gunnewig, & Swank, 2004) that directly evaluates vocabulary, letter recognition, phonological awareness and math skills and includes observational assessments of emergent writing, print and book knowledge, and social competence. C-PALLS+ is designed to provide teachers with a technology-based assessment (administered on computers or tablet devices) and data-summary reports that suggest ability-level groupings and appropriate classroom activities; the tool is primarily used as a universal (Tier 1) screening and progress monitoring tool with children ages 3.5–5 years, but some researchers have used it for Tier 2 progress monitoring purposes (Buysse, Peisner-Feinberg, & Burchinal, 2012).

The science and engineering subtest (Zucker et al., 2013) examines the four disciplinary areas in the National Research Council's (2012) framework for science education including: physical sciences, life sciences, earth and space sciences, and engineering and technology applications of science. An examination of pre-k curricula and state standards for several states guided the development of subtest items with content appropriate for preschool-age children to address these disciplinary areas. This subtest requires 10 min to administer. The measure was designed to provide an index of individual children's growth over time and to increase teachers' attention to science, given research showing that little effective instruction is devoted to science topics within typical early childhood classrooms (Greenfield et al., 2009; Nayfeld et al., 2011; Sackes, Trundle, & Bell, 2013; Tu, 2006).

Zucker and colleagues (T. Zucker, personal communication, August 16, 2013) are currently conducting a pilot study of potential items for the science and engineering subtest to examine English-speaking students' ($n = 327$) performance. From a pool of 43 initial items, and based on differential item functioning and factor analysis, the subtest was reduced to a set of 24 items with adequate score distributions to differentiate ability levels. Inter-scorer reliability was high ($M = 100$ %) and internal consistency was good (.80). Concurrent validity of the science and engineering subtest was assessed with the Preschool Science Assessment (PSA; Greenfield et al., 2015) and showed strong correlation ($r = .81$). A small sample of pre-k teachers ($n = 11$) utilized the test and gave detailed quantitative and qualitative feedback on content validity that indicating that most strongly agreed (using a 5-point Likert rating) that the concepts tested were important for preschool children ($M = 4.41$, $SD = .18$). These initial reliability and validity statistics suggest this is an appropriate tool for monitoring young children's science and engineering skills. A Spanish version of the subtest is currently being developed and tested with 150 primarily Spanish-speaking preschoolers so that future versions of the test can be administered in English or Spanish, depending on the child's language background and the instructional model. The researchers' goal in adding this science and engineering subtest to C-PALLS+ is to raise teachers' awareness and expectations for teaching pre-k students science and engineering within the core, Tier 1 curriculum in ways that support children's curiosity about how the world works and provide a foundation for later grades.

### Summary

As was the case with summative assessments of young children's science competence, there is also a critical need for screening tools and formative assessments to evaluate young children's science competence. Such assessments provide a critical complement to summative assessments by identifying children with very low science competence (screening) and providing teaching staff with ongoing assessment of science competence (formative assessment). Such ongoing assessment allows teaching staff to identify areas of science competence that may need greater class-wide attention as well as for individualizing science instruction for a specific child or subsets of children. The need for a comprehensive multi-informant, multi-method approach means that despite the encouraging work by Zucker and colleagues discussed above, more work in this area is sorely needed as well.

## Assessing Teachers

It would be difficult to find a theory of change model for improving young children's science ability that did propose a significant and critical role of the classroom teacher (e.g., Kennedy, 1998; Wayne, Yoon, Zhu, Cronen, & Garet, 2008). The theory of change model for the Early Childhood Hands-On Science efficacy trial (Brown & Greenfield, 2010), for example, proposes that the impacts on children's science learning are mediated through the classroom teacher and her changes in science knowledge, science teaching practices, beliefs and attitudes about science, and arrangement of the classroom to facilitate and encourage science. These key change components also require reliable and valid assessments if we are to understand causal links to improving young children's science competence.

## *Pedagogical Knowledge*

Research in other readiness areas, other than science, document the critical role that teacher knowledge of a subject area plays in effective teaching of that content area to young children (e.g., Clements, Sarama, & DiBiase, 2004). Science is unlikely to be an exception to this rule, and may in fact, be more sensitive to this relationship given the many misconceptions that adults have about basic science concepts (e.g., Treagust, 1998). Reviewed below is one existing measure of teacher pedagogical knowledge and a promising new approach that has recently been field tested and shown to have significant predictive effects on increases in young children's mathematics scores from fall to spring.

### Science Teacher Performance Tasks

The research team at Education Development Corporation (EDC) in Boston have developed *Science Teacher Performance Tasks (*STPTs*)* which are measures of science pedagogical content knowledge and include four 30-min performance tasks: (1) analyzing a video vignette of a science experience in the classroom, (2) interpreting a child's work sample, (3) analyzing misconceptions of water flow, and (4) planning a science experience (Clark-Chiarelli, Chalufour, & Hoisington, 2009). These tasks require teachers to analyze different aspects of science instruction and respond to a set of prompts that are designed to gauge teacher knowledge of science content and pedagogy. Based on each of the tasks, teachers construct written responses that are scored using a rubric with a 4-point scale. The scores for the four tasks may be averaged to create a composite score.

### Pedagogical Content Knowledge Interview

Researchers at the University of Miami are developing a pedagogical content knowledge (PCK) survey for early science. This PCK survey is based on a recently developed instrument to assess teacher pedagogical knowledge in early mathematics (McCray & Chen, 2012).

McCray and Chen (2012) provide a framework, format and supporting data for the validity of this new teacher interview for assessing PCK for preschool mathematics. The interview presents teachers with classroom-based scenarios that cover "a range of early mathematics concepts and skills through the mention of specific materials, the comments children make during the scenario, or the problems the children encounter and actions they take." (McCray & Chen, p. 293). The rationale for this approach is that the scoring of these scenarios assesses teachers' knowledge of mathematics content, teaching practices and preschool children's mathematical development, all of which are critical for effective early childhood mathematics instruction. Two scenarios, one describing children interacting in the dramatic play area and one describing children interacting in the block corner were read aloud to the teacher. Teachers were then asked a series of questions such as, "What kind of math do you see in this play?," "Where in the scenario do you see the math?", and "What might you say to help the children also see the math?" McCray and Chen (2012) report that teachers' Preschool Math PCK Interview (PM-PCK) scores positively relate to their frequency of teachers' math related language during the school day. In addition, the higher the teachers' PM-PCK scores the greater the gains of the children in their classrooms on fall to spring TEMA-3 (Ginsburg & Baroody, 2003) math scores.

### Summary

The EDC approach of directly assessing teachers in performance tasks in combination with a PCK science survey could provide the initial beginnings of a multimethod approach to assessing teacher pedagogical knowledge. Although promising, the EDC approach would benefit from broader availability through, for example, documentation in appropriate peer reviewed journals. Expansion of this approach to additional science disciplinary domains beyond physical science would also be useful. Creating scenarios and a corresponding scoring rubric for preschool science seems like a potentially viable and potentially useful approach as well. However, this work is still in the planning stages and challenges in creating a reliable rubric and valid measure should not be underestimated. In addition, since both of these tasks are labor intensive, a traditional multiple choice assessment of teachers' basic science content knowledge and knowledge about science practices and cross-cutting concepts would also be desirable. Some preliminary work by Dr. Greenfield and his colleagues at the University of Miami on creating such an assessment is underway.

## *Teaching Practices*

Another critical area where measures are lacking is the evaluation of quality science teaching practices in early childhood settings. With a greater emphasis on assessing fidelity, researchers are beginning to think more strategically about the critical change features of their program and are implementing procedures to determine whether or not these features are successfully transferred from theory to practice (e.g., Hulleman & Cordray, 2009; Hulleman & Cordray, 2010). Measures of fidelity, however, are not specifically designed to assess quality science teaching practices, but may do so indirectly in that aspects of quality teaching practices are likely to be critical change features of an early childhood science program. One such measure is reviewed below.

### Science Fidelity of Implementation Measure

To assess the degree to which teachers are incorporating the pedagogical principles and practices in the *Foundations of Science Literacy* program, Clark-Chiarelli and colleagues (Clark-Chiarelli, Chalufour, & Hoisington, 2009) developed the *Science Fidelity of Implementation Measure.* The conceptual framework of the fidelity measure focuses on the demonstrated ability of teachers to use effective plans, strategies, and materials to engage children in exploration, focus their exploration on relevant scientific concepts, use formative assessments to surface their naïve theories or misconceptions, and support their ability to discuss and reflect on those misconceptions.

Based on direct evidence obtained during a classroom observation, assessors use the *Science Fidelity of Implementation Measure* to rate 33 indicators of quality (e.g., teacher asks questions that encourage children to see relationships: "How did the long one move differently than the short one?"). Each indicator is scored on a four-point scale from Minimal/No Evidence to Limited Evidence, to Sufficient Evidence, to Compelling Evidence. The tool also provides opportunity for the observer to record specific examples of the indicator for qualitative analysis. For example, observers are prompted to record specific "what, when, where or how" questions a teacher uses to draw out individual children's contributions to a science conversation. When totaled, the indicators comprise an overall rating of fidelity and three scales*: (1) Conversation on Topic; (2) Direct Exploration of Science Phenomena; and (3) Environment.* In addition, through a brief pre-observation interview, information concerning dosage is collected from a teacher's report of the estimated amount of time children have the opportunity to engage in science. Classroom logs are used as a second source of dosage data. The logs also track individual children's level of participation.

### Summary

Considerably more research is needed in developing and validating assessments of the quality of science teaching in early childhood classrooms. One potential place to start are fidelity measures designed to assess critical features of a particular science program, since such measures often include aspects of quality science teaching practices. Such measures could be examined with an eye towards the fidelity components that assess generic high quality science teaching practices that are not unique to a particular program. In addition, similar to the area of pedagogical knowledge, research in this area needs to be subjected to the peer review process, documented in appropriate journals and made more broadly available.

## *Attitudes and Beliefs Towards Science Teaching*

Research has shown the importance of attitudes and beliefs on teaching in early childhood settings (e.g., Brown, 2005). There has been, however, little focus on the impact of attitudes and beliefs on teaching science in early childhood settings. This is likely due to the lack of measures that have been validated for assessing early childhood teachers' attitudes and beliefs towards teaching science. Such a measure is now available and is reviewed below.

### Preschool Teacher Attitudes and Beliefs Toward Science Teaching Questionnaire

Maier, Greenfield, and Bulotsky-Shearerer (2013) have recently developed the *Preschool Teacher Attitudes and Beliefs toward Science Teaching Questionnaire (P-TABS)*. Following recommended guidelines for measure development (Osterlind, 2006), the authors conducted an in-depth content review, created a potential pool of items using the content review as a guide and then had a panel of early childhood experts review all items. Data were collected on a large sample of over 500 preschool teachers across the state of Florida. The data analytic approach included exploratory and confirmatory factor analysis along with cross-validation of the factor structure to assess structural invariance and generalizability to important demographic subgroups. The 35 likert items produced three factors that were generalizable and invariant across subgroups: teacher comfort with teaching science, benefit of science for children, and challenges when teaching science. Teachers who reported participation in a science-related project during the past 3 years had significantly higher mean scores on both the teacher comfort factor and the child benefit factor than teachers who did not report participation in a science related project.

Additional data were collected on a smaller validity sample of 30 teachers participating in a quasi-experimental study involving the Early Childhood Hands-On Science (ECHOS) program (Brown & Greenfield, 2006). In comparison to their fall scores prior to ECHOS implementation, teachers who participation in the ECHOS program had significantly higher Teacher Comfort and Child Benefit scores at the end of the school year, whereas no fall to spring differences were found in any of the factors for comparison teachers who did not participant in the ECHOS program.

## Assessing Classrooms

Consistent with the Piagetian notion (Piaget & Inhelder, 1969) that learning and development require active exploration and engagement with an interesting and novel environment, the typical early childhood classroom is structured around a series of activity centers that often include an area to explore science. Time and opportunities are also provided for children to activity explore and engage with materials in these centers.

### *Availability of Science Materials and Time Spend in Science Activities*

Tu (2006) developed a set of instruments (Preschool Classroom Science Materials Checklist, Preschool Science Activities Checklist and the Preschool Teacher Classroom/Science Coding Form) to investigate the availability and use of science materials and the amount of time children were involved in science activities in 20 mid-western child care centers. With respect to materials: vinyl animals, plants, sensory tables, posters/charts and magnets were the most commonly available science materials. The most common natural science materials were plants, seashells, fossils and pine cones. During 2 days of videotaping children were not involved with any of the plants nor did the teacher talk with the children about the plants. With respect to time in science activities, only 4.5 % of the time did activities relate to formal science (making play dough). Informal science activities such as playing in the sandbox with shovels and buckets and at the water table occurred 8.8 % of the time. Most often, teachers interacted with children in the art area followed by sensory areas, and least often in the science area. Tu (2006) concluded that children were missing important opportunities to develop and enhance their scientific skills.

### *Science Observational Scales*

The recent focus on capturing quality classroom interactions (e.g., Classroom Assessment Scoring System; Pianta, La Paro, & Hamre, 2008) is seen in two science classroom observation scales. These are reviewed below.

#### Science Teaching and Environment Rating Scale

Chalufour, Worth, and Clark-Chiarellili (2009) developed the *Science Teaching and Environment Rating Scale (STERS)* to assess the quality of early childhood science teaching and learning environments. Using a 1–4 rating scale, the *STERS* measures the following aspects of science teaching in the preschool setting: (1) Physical Environment for Inquiry and Learning; (2) Direct Experiences to Promote Conceptual Learning; (3) Use of Scientific Inquiry; (4) Collaborative Climate that Promotes Exploration and Understanding; (5) Opportunities for Extended Conversations; (6) Children's Vocabulary; (7) In-depth Investigations; and (8) Assessment of Children's Learning. Internal consistency estimated to be at .94 (Cronbach's alpha). The ratings for the eight items are averaged to create a composite score.

### Preschool Rating Instrument for Science and Mathematics

The *Preschool Rating Instrument for Science and Mathematics (PRISM)* (Stevenson-Garcia, Brenneman, Frede, & Weber, 2010), still under development, is a 16-item structured observational tool that assesses the extent to which classroom materials and staff interactions foster a range of mathematical and scientific concepts and reasoning skills for young learners. The separation of the items into two broad areas (six items for materials and ten items for staff interaction) reflects the authors' desire to differentiate between classrooms with a lot of "stuff" but few supportive instructional interactions and vice versa. Of note, reported in a conference presentation (Brenneman, Jung, Stevenson-Garcia, & Frede, 2011) were the low median scores for interactions (three interactions had a score of 1; six interactions had a score of 2; scale ranges from 1– 7). For science, the authors found that in the majority of classrooms no interactions occurred to support young children's thinking and knowledge-building.

## Conclusions

This chapter began with a discussion of why the state of early childhood science education at a critical tipping point. On one side is national and state attention, and federal funding agencies, despite tight budgets, calling for more research in early science education. There is also a flurry of ideas for infusing more science into classrooms activities, and new curricula with science as the foundation. Recent research and theory on cognitive development has provided strong support for early childhood as an ideal age for science education, drawing on young children's natural curiosity and excitement in learning about the world they live in. States are adopting a new conceptual framework for integrating science education across the entire K-12 education spectrum. Early childhood science education is uniquely positioned with a window of opportunity to link to the new K-12 framework and answer the call for greater continuity in the education of children from early childhood through elementary school. On the other side is a teacher workforce ill prepared to address the call for more science in their classrooms, afraid to even stick their toe into the water. At present we do not have a research evidence base to provide information on which practices are effective let alone which practices are most effective. There is also a paucity of reliable and valid assessments to support research on identifying best practices. Much of the small corpus of existing assessment that do exist and could begin to create this evidence base are tucked away in internal reports and conference presentations that are not as available for broader exposure and greater credence associated with publications that involve a more rigorous peer review process.

A powerful illustration of this dichotomy is the work of Tu (2006) and Brenneman and colleagues (Brenneman et al., 2011) contrasted with the work of Nayfeld and colleagues (Nayfeld et al., 2011). Tu (2006) reports that the major science materials in the classrooms she observed were plastic animals and plants and that the plants were never discussed by teachers during the 2 days of observation. Brenneman, with data on 229 observations by highly trained observers lasting 3–4 h in early childhood programs in four states, reports minimal classroom interactions around science. In the majority of these classrooms no interactions occurred to support young children's thinking and knowledge-building. In contrast, Nayfeld showed that science areas with balance scales accumulating cobwebs could be transformed into an area of bustling activity, engaging social interactions and important science learning. All that was needed was a little help from an adult in the science area scaffolding young children in how the balance scale works and what fun it is making predictions about which object is heavier and then testing these predictions.

I have argued in this chapter that it is critical to have a major focus on creating a multi-informant multi-method, comprehensive, conceptually organized and psychometrically rigorous assessment system for early childhood science. Without such a focus we will tip over the cliff and not onto solid ground. What is my reason for this strong belief? Despite whether or not one agrees that assessment is the tail and should not be wagging the dog, what gets assessed has a strong influence on teacher behavior and practice. Before committing to learning new material, my undergraduate students continually ask, "will this be on the test?" Similarly, teachers will focus on what is on their "test." In this age of accountability, if how well you teach language is monitored and your students' language competence is assessed, but how well you teach science is not monitored and your students' science competence is not assessed, how much time and effort will teachers spend on science? The message to teachers is that if science is not being assessed that it must not be critical or important.

Why should we care now? Windows of opportunity only stay open so long before they close. Young children, especially those from diverse backgrounds, have missed important early learning opportunities in which their natural curiosity in science could serve as cognitive models for the challenging years of schools that lie ahead. The buzz and activity at the national, state, and local level focused on early childhood science education is providing a major opportunity to invigorate early childhood curricula with the excitement for learning and exploration that science provides. This movement must be driven by evidence-based research grounded in an organized, comprehensive and psychometrically sound assessment system that can affectively and accurately evaluate the full scope of the effectiveness of early childhood science practices.

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