Infants and Toddlers: Young Scientists Exploring the World Around Them: An Annotated Bibliography for Course Developers

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Early Educator Central

Pathways to Credentials and Degrees for Infant-Toddler Educators

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Introduction

Science teaching and learning in the U.S. K-12 education system is shifting from covering a large number of topics in a fragmented, disconnected and shallow way (often characterized as a mile wide and an inch deep) to a focus on a small number of core or big ideas in four content areas (NRC, 2012; see annotated review in Defining Science Education section of this paper.) This new approach also emphasizes the critical needs for students to "practice" science and attend to "cross-cutting" concepts. The framework emphasizes the integration of three dimensions: 1) eight science practices; 2) seven cross-cutting concepts; and, 3) the core ideas in four content domains, into the teaching and learning of science (e.g., learning science by doing science).

Although this new framework begins at kindergarten (K), there is also much interest in science education for younger children. A major national report that was a precursor to the new K-12 framework has an entire chapter devoted to the advantages of beginning science education earlier than K (Chapter 3: Foundations for science learning in young children, National Research Council, 2007; see annotated review in Understanding Infant-Toddler Development section of this paper.) Also, in just a few years, states have transitioned their early learning standards from including only a few science indicators embedded in a general "cognition and knowledge" domain to including science as a free standing elaborated readiness domain[1]. In addition, the Head Start Early Learning Outcomes Framework: Ages Birth to Five[2], designed as a continuum of learning from infancy through preschool, designates "scientific reasoning" as one of its central domains. Also this year, an entire edited volume was published on research in early childhood science education.[3]

This emerging literature on science education in early childhood has largely been focused on the preschool years (ages 3 to 5 year olds). However, three years of age is not a "magical" time to begin science education. Indeed, infants have been characterized as "scientists in the crib"[4]. Just as preschool serves as the foundation for science education in elementary school, attention to the developmentally appropriate aspects of science learning in infancy and toddlerhood will aid the three year old on her journey as a young scientist.

Because of the lack of knowledge on evidence based practices in science for infants and toddlers, this review draws upon more basic theory and research on infant and toddler development, highlighting its relevance to science education for these age groups. This is a more useful and necessary approach given the lack of a literature supporting evidence-based practices for

[1] Barnett, W.S., Carolan, M.E., Squires, J.H., Clarke Brown, K., & Horowitz, M. (2015). *The state of preschool 2014: State preschool yearbook*. New Brunswick, NJ: National Institute for Early Education Research.
[2] Department of Health and Human Services, Administration for Children and Families, Office of Head Start (2015). Head Start early learning outcomes framework: Ages birth to five. Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/hs/sr/approach/cdelf/index.html
[3] Trundle, C. & Saçkes, K. (2015). Research in early childhood science education. New York: Springer Publishing.
[4] Gopnick, A., Meltzoff, A. & Kuhl, P. (1999) The Scientist in the Crib: Minds, brains and how children learn. New York, NY: HarperCollins Publishing Co.

introducing infants and toddlers to science. Such evidence will hopefully accumulate over time, as has been the case with the emergence of evidence based practices for science for preschoolers[5].

This review supports the goal of creating greater continuity in young children's development across all of early childhood (typically defined as birth through 8 years of age). To this end, the new K-12 conceptual framework for science is reviewed. The framework has relevance for children prior to kindergarten and states have already begun to create preschool early learning standards that are modeled after the framework[6]. The framework also has relevance for development during infancy and toddlerhood.

[5] Trundle, C. & Saçkes, K. (2015). Research in early childhood science education. New York: Springer Publishing.
[6] Worth, K. & Winoker, J. (2013, January, February). The development of pre-k science, technology, and engineering standards. Presentation at a series of community forums for proposed preschool science, technology, and engineering (STE) standards sponsored by the Massachusetts State Government Office of Education. MA: various locations.

Quick Reference Table

Topic Area	Age Group	Document Type	Full Citation
Defining Science Education	K-12	Book	National Research Council (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.
Why Science in Early Childhood	Early Childhood	Empirical Research	Greenfield, D.B., Jirout, J., Domínguez, X., Greenberg, A., Maier, M.F., & Fuccillo, J.M. (2009). Science in the preschool classroom: A programmatic research agenda to improve science readiness. Early Education and Development, 20, 238-264.
Why Science in Early Childhood	Early Childhood	Webinar/ Empirical Research	Greenfield, D.B. (2013, January). Science in the preschool classroom: Why and how this can be a teacher's best friend. Front Porch Series, National Center for Quality Teaching and Learning, University of Washington, Seattle, WA. Available from http://eclkc.ohs.acf.hhs.gov/hslc/tta-system/teaching/practice/fp/fpArchive2013.html
Why Science in Early Childhood	Early Childhood	Book Chapter	Greenfield, D.B. (in press). The power of inquiry: Why science belongs in early childhood classrooms. In E. Näslund-Hadley and R Bando (Eds.), The death of rote memorization: Early grade math and science learning in Latin America and the Caribbean. Washington, DC: Inter-American Development Bank.
Early Science, Executive Functioning and Approaches to Learning	Early Childhood	Empirical Research	Bustamante, A.S., White, L.J. & Greenfield, D.B. (2015). Approaches to learning and school readiness in Head Start: Applications to preschool science. Manuscript submitted for publication.
Early Science, Executive Functioning and Approaches to Learning	Early Childhood	Empirical Research	Nayfeld, I., Fuccillo, J.M. & Greenfield, D.B. (2013). Executive functions in early learning: Extending the relationship between executive functions and school readiness to science. Learning & Individual Differences, 26, 81 – 88.
Assessment	Early Childhood	Book Chapter	Greenfield, D.B. (2015). Assessment in early childhood science education. In K. Trundle, & M. Saçkes (Eds.), Research in early

Topic Area	Age Group	Document Type	Full Citation
			childhood science education (pp. 353 – 380). N.Y.: Springer Publishing Co.
Understanding Infant-Toddler Development	Early Childhood	Monograph	Chouinard, M. M. (2007). Children's questions: A mechanism for cognitive development [Monograph]. Society for Research in Child Development, 27(1), vii–ix, 1–126.
Understanding Infant-Toddler Development	Early Childhood	Book	Committee on the Science of Children Birth to Age 8. (2015). Transforming the workforce for children birth through age 8: A unifying foundation. L. Allen, & B. Kelly (Eds.). Washington, D.C.: The National Academies Press.
Understanding Infant-Toddler Development	Early Childhood	Book	National Research Council (2007). Taking science to school: Learning and teaching science in grades K-8. Committee on science learning: Kindergarten through eighth grade. R. A. Duschl, H.A. Schweingruber & A.W. Shouse (Eds.). Washington, DC: The National Academic Press.
Understanding Infant-Toddler Development	Early Childhood	Book	Piaget, J. (1969). The psychology of intelligence. N Y: Littlefield, Adams.
Understanding Infant-Toddler Development	Early Childhood	Book	Piaget, J., & Inhelder, B. (1969). The psychology of the child. NY: Basic Book, Inc.
Understanding Infant-Toddler Development	Early Childhood	Book	Vygotsky, L. S. (1978). Mind in society: The development of higher mental processes (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Trans.). Cambridge, MA: Harvard University Press.
Guided Learning	Early Childhood	Empirical Research	Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2010). Does discovery-based instruction enhance learning? Journal of Educational Psychology, 103, 1–18.
Guided Learning	Early Childhood	Empirical Research	Weisberg, D.S., Hirsh-Pasek, K., & Golinkoff, R.M. (2013). Guided play: Where curricular goals meet a playful pedagogy. Mind, Brain & Education. 7 (2), 104 – 112.
Guided Learning	Early Childhood	Empirical Research	Ferrara, K., Hirsch-Pasek, K., Newcome, N.S., Golinkoff, R.M., & Lam, W.S. (2011). Block talk: spatial language during block play. Mind, Brain & Education, 5 (3), 143- 151.

Topic Area	Age Group	Document Type	Full Citation
Supporting Early Science Learning	Infants & Toddlers	Practical Tips/ Research	Early Head Start National Resource Center. (2013). Supporting outdoor play & exploration for infants & toddlers (Technical Assistance Paper #14). Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/tta-system/ehsnrc/docs/ehs-ta-paper-14-outdoor-play.pdf
Supporting Early Science Learning	Infants & Toddlers	Practical Tips	U.S. Department of Health and Human Services, Administration for Children and Families, Office of Head Start. (2008, July). Infant/Toddler math & science development: Does Early Head Start support math and science development with infants and toddlers? (Tip Sheet # 29). Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/tta-system/ehsnrc/cde/curriculum/DoesEarlyHeadS.htm
Supporting Early Science Learning	Infants & Toddlers	Practical Tips	U.S. Department of Health and Human Services, Administration for Children and Families, Office of Head Start (2014, May). News you can use: Early science learning for infants & toddlers, News for Head Start, Early Head Start & Migrant/Seasonal Programs Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/tta-system/ehsnrc/cde/curriculum/early-science.html
Supporting Early Science Learning	Early Childhood	Book	Shillady, A. (Ed.). (2013). Spotlight on young children: Exploring science, Washington, D.C.: National Association for the Education of Young Children.

Defining Science Education

National Research Council (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.

This volume resulted from the work of a National Research Council taskforce that reviewed the current approach to K-12 science education in the context of concerns about the need for the training of science and engineering professionals for the U.S. to stay competitive in the international arena with an eye towards increasing the number of women and members of minority groups in these fields. Although not all K-12 students would be expected to choose such career paths, an additional concern was that the education system needs to create scientifically literate citizens who can make informed public and personal decisions, as science, engineering and technology play ever increasing roles in all phases of American life.

The report documents the prior approach to science education in the U.S. and why this fragmented, "mile wide, inch deep" approach, disconnected from students' everyday lives has led to largely science illiterate citizens who do not view science and engineering as interesting or important career paths.

The new framework consists of three dimensions that are to be integrated for teaching and learning science. The new framework focuses on students learning a small set of core "big" ideas in depth across the entire K-12 system in the context of doing science. Eight science practices (e.g., asking questions, planning and carrying out investigations) comprise the first dimension of the framework. The second dimension consists of seven cross-cutting concepts that are relevant in all areas of science (e.g., patterns, cause and effect). The third dimension is a small set (2 to 4) of core or big ideas, in each of four disciplinary areas (life science, physical science, earth and space science, and engineering).

The science practices, cross-cutting concepts and core ideas in the K-12 framework all have high relevance for infant and toddler development. The general theories of development briefly reviewed are highly consistent with the framework and understanding the framework will aid in making these theories come alive when they are applied to practice.

Applying the K-12 framework to infants and toddlers, however, is challenging as the framework is not written in "early childhood friendly" language. The author of this paper and his team are working on a document that provides a more "early childhood friendly" version of the framework as part of an Early Science Initiative (ESI) grant funded by the Buffet Early Childhood Fund. The "early childhood friendly" version of the framework should be available in early 2016 on a website developed for the ESI project. Some preliminary work on this document is highlighted below:

Dimension 1- Science practices/developing and using models:

- In K-12 framework – "construction and use of a wide variety of models and simulations to help develop explanations about natural phenomena"
- Preschool friendly example – drawing a house and building it in the block center.
- Infant-Toddler friendly example – stacking blocks to make a simple structure

Dimension 2-Cross-cutting concepts/systems and system models:

- In K-12 framework – "defining the system under study – specifying its boundaries and making explicit a model of that system"
- Preschool friendly example – the gears and parts of a wind-up toy exist within a system and interact to make it function.
- Infant-Toddler friendly example – the parts of my body and how I can use them to interact with the world in specific ways (i.e. I use my hands to pick things up)

Dimension 3- Disciplinary core ideas/motion and stability and forces and interactions:

- In K-12 framework – "how one can explain and predict interactions between objects and within systems of objects"
- Preschool friendly example - kicking a ball makes it roll.
- Infant-Toddler friendly example – shaking a rattle makes a sound

Why Science Education Belongs in Early Childhood Classrooms

Despite many states now including science as a separate and free-standing school readiness area and the Office of Head Start designating "scientific reasoning" as one of its central domains, science remains largely absent from early childhood classrooms. This is unfortunate, as science provides many advantages for high quality teaching and learning. The references cited in this section are briefly reviewed to provide insight into this issue. Much of the discussion is focused on the importance of increasing science education during the preschool years; however, these issues and concerns are just as relevant for the birth to three age range, as educators of young children should not wait until children turn three years of age to take advantage of infants' and toddlers' strong interest in exploration and inquiry about the world in which they live.

Greenfield, D.B., Jirout, J., Domínguez, X., Greenberg, A., Maier, M.F., & Fuccillo, J.M. (2009). Science in the preschool classroom: A programmatic research agenda to improve science readiness. Early Education and Development, 20, 238-264.

This journal article contains 3 empirical studies.

The first study analyzed data on eight school readiness domains in a large cohort of four year olds attending Head Start programs across the state of Florida, using a formative assessment system (Galileo, http://www.ati-online.com/galileoPreschool/indexPreschool.html) implemented by teachers. IRT provides interval level of measurement so that these eight domains can be compared directly in terms of initial ability level at the beginning of the school year and the amount of gain across the school year (height and weight are other examples of interval level of measurement systems; a key property of interval level of measurement is that the unit of change is identical across the entire range of values, e.g., an increase of five pounds is an identical gain in weight, regardless if the person weighs 100 pounds or 180 pounds). Science had the lowest fall scores and the least amount of gain across the school year. These results, anticipated to be similar in other states, indicate that on average, children attending Head Start programs are least prepared for science when entering kindergarten compared to their readiness in seven other domains.

The second study addresses the issue of why science is largely absent from early childhood classrooms. Based on qualitative analysis of focus groups with Head Start teachers these key factors emerged: 1) teachers feel poorly prepared to teach science and have misconceptions about how to teach science that reinforce these concerns and fears; 2) there are many readiness areas to cover; 3) given young children's short attention spans, fewer opportunities for instruction and the tendency to cover each readiness area one at a time in isolation, not all readiness areas can be adequately addressed. Since teachers are uncomfortable teaching science and view science as less importance because it is not typically assessed (see more about this below), it is the first readiness area to be left out of instruction, and as a consequence is largely absent from early childhood classrooms.

The third study uses a quasi-experimental design to test the impact of engaging a select group of Head Start teachers in a science unit that involved them in the hands-on learning that they then implemented in their classrooms over an extended period of time. Teachers met monthly as a professional learning community reflecting on their initial misconceptions, children's natural interest in the science learning and the ease of including other readiness areas in the science unit. Analysis of data from Galileo (see link to this system in Study 1) resulted in higher readiness scored for children in these teachers' classrooms in all readiness areas compared to a control group of teachers who were not part of this project.

In summary, this empirically based set of studies documents the reasons for a lack of focus on science education in early childhood classrooms that results in low science readiness at kindergarten entry. These studies also point to the potential benefits of engaging early childhood teaching staff in meaningful, goal-directed science inquiry with their young children to increases multiple areas of their school readiness including science.

Greenfield, D.B. (2013, January). Science in the preschool classroom: Why and how this can be a teacher's best friend. Front Porch Series, National Center for Quality Teaching and Learning, U of Washington, Seattle, WA. Available from http://eclkc.ohs.acf.hhs.gov/hslc/tta-system/teaching/practice/fp/fpArchive2013.html

This thirty minute webinar presentation is part of the Office of Head Start's National Center for Quality Teaching and Learning Front Porch Monthly series. The presentation is aimed at early childhood teaching staff. The website description for this webinar is: "Science is a Head Start mandated readiness domain. So why is science rarely present in Head Start classrooms? When surveyed, teachers report two key barriers: Feeling unprepared to teach science and a lack of time to devote to it, given all the readiness areas that need to be covered. Dr. Greenfield discussed why these barriers are false and how science can help teachers increase scores on the CLASS™ "instructional support" domain, and cover and improve multiple areas of school readiness for children." The link above provides access to this archived presentation from January, 2013 to 1) watch the webinar from the website; 2) download the webinar to watch later (mp4 file); 3) download the transcript of the webinar (pdf file); and 4) download the question and answer session following the live presentation (pdf file).

Greenfield, D.B. (in press). The power of inquiry: Why science belongs in early childhood classrooms. In E. Näslund-Hadley and R. Bando (Eds.), The death of rote memorization: Early grade math and science learning in Latin America and the Caribbean. Washington, DC: Inter-American Development Bank.

This chapter reviews theory, research and practice on early childhood science education. It is written for policy makers and early childhood educators in Latin America and the Caribbean, but is based on work conducted in the U.S., and has clear relevance for early childhood science education in the U.S. Chapter topics include why science is missing in early childhood classrooms, the benefits of fostering scientific learning in the early childhood classrooms, how children learn science, the benefits of science for high quality teaching, how science can support advances in other "readiness areas," early childhood teachers' misperceptions about teaching science, defining and assessing early science skills. The volume will be published in both English and Spanish, anticipated no later than early 2016. All chapters have undergone a rigorous review process and currently going through a final level of review prior to publication.

Early Science, Executive Functioning and Approaches to Learning

Teachable competencies that impact multiple domains of learning are beginning to receive increased attention in early childhood education. These include executive functioning with components such as flexibility, inhibition and working memory and approaches to learning with components such as curiosity, initiative, persistence, planning, and engagement in group learning. Being flexible and persistence, for example, aids a young child, regardless of what she is trying to learn.

The development of these competencies is well suited for goal directed learning. This can occur in any readiness area (e.g., learning to crawl or walk, learning the letters and sounds of the alphabet, learning to count). The references reviewed below extend the relationship of these competencies to early science and suggest that scientific inquiry and learning provide optimal experiences in which competencies such as persistence and planning may be practiced and refined because they take advantage of children's natural interest in the world around them and how it works.

Bustamante, A.S., White, L.J. & Greenfield, D.B. (2015). Approaches to learning and school readiness in Head Start: Applications to preschool science. Manuscript submitted for publication.

The purpose of this empirical study was to determine if the relationship between executive function (EF) and science found in the Nayfeld, Fuccillo and Greenfield study (2013) was present in another key early childhood competencies that affect multiple areas of school readiness area, approaches to learning (ATL). A large sample (N = 397) of children attending Head Start were directly assessed on their vocabulary, listening comprehension, mathematics, and science ability at the beginning and end of the school year. Teachers completed an ATL rating scale during the winter. End of year achievement scores, controlling for beginning of year achievement scores were analyzed in a structural equation modeling framework to assess the role of ATL in predicting increases in language, listening comprehension, mathematics and science. Only gains in science were significantly related to ATL.

In summary these two studies suggest that EF and ATL competencies, critical to early learning, may best be developed and utilized in the context of early science learning. EF and ATL competencies such as planning, group learning, initiative and flexibility are more likely to be utilized and developed when children are engaged in learning that require brainstorming, reasoning, and higher level thinking than when the learning is rote. Science learning in young children that involves exploration and inquiry not only has all these features, it is also generated by children’s motivated, goal directed curiosity to understand their world. This motivated, goal directed curiosity is present in young infants and toddlers making early science education an important opportunity to begin developing these important competencies.

Nayfeld, I., Fuccillo, J.M. & Greenfield, D.B. (2013). Executive functions in early learning: Extending the relationship between executive functions and school readiness to science. Learning & Individual Differences, 26, 81 – 88.

Prior research has shown that executive functions predict achievement in both language and mathematics during early childhood. The present empirical study replicates these findings and extends them to science. A large sample (N = 278) of children attending Head Start were directly assessed on their vocabulary, listening comprehension, mathematics, science and executive function ability at the beginning of the school year. Vocabulary, listening comprehension mathematics and science ability was assessed again at the end of the school year. End of year achievement scores, controlling for beginning of year achievement scores were analyzed in a structural equation modeling framework to assess the role of executive function (EF) in predicting increases in language, listening comprehension, mathematics and science. EF significantly predicted the gains in all four areas. However, the relationship between EF and science was stronger than the relationship between EF and vocabulary, listening comprehension and mathematics. In other words, higher EF was related to greater gains in science than gains in the other three areas that were assessed.

Assessment in Early Childhood Science

Greenfield, D.B. Assessment in Early Childhood Science Education. (2015). In K. Trundle, & M. Saçkes (Eds.), Research in early childhood science education (pp.353 – 380).N.Y.: Springer Publishing Co.

Empirical research that validates the effectiveness of early childhood programs and practices is an essential component of establishing a strong evidence base for what constitutes best practices. Practices and programs in early science are not exceptions. To conduct such research, assessments that are reliable and valid are needed to answer the questions being addressed for the specific population that is being assessed.

This chapter reviews the current state of assessment in early science education. There is unfortunately, little of this assessment work that has been completed or published, but promising work is underway and also reviewed. In addition, the chapter provides a comprehensive approach to assessment that is consistent with the new K-12 framework for science education in the hope of providing consistency in the assessment work that lies ahead. In addition to a section on this framework there are sections on: 1) summative assessments of young children's science competence; 2) screening and formative assessment of young children's science competence; 3) assessing teachers; and 4) assessing classrooms. Each section provides a review of the purpose of each type of assessment, a review of existing and promising instruments and a summary of the section.

Included in this chapter are descriptions of assessments developed by Dr. Greenfield and his University of Miami research team to assess young children's emerging science competence in English and Spanish, using touch-screen computer adaptive technology and a teacher survey assessing their attitudes and beliefs about science teaching in early childhood.

Understanding Infant-Toddler Development

Chouinard, M. M. (2007). Children's questions: A mechanism for cognitive development [Monograph]. Society for Research in Child Development, 27(1), vii–ix, 1–126.

A recent theory that has high relevance for infant and toddler classrooms, but is largely absent in the organization and work in early childhood classrooms themselves, is the work of Michelle Chouinard. In a series of studies that include detailed analysis of infant and toddler talk, she shows that from the time infants are able to speak they are question-asking machines. In one study where she analyzed transcripts of young children's spontaneous questions with their parent, they asked an average of 108 questions per hour. The majority of these questions were information seeking questions to fill gaps and inconsistencies in their knowledge base. Analysis of these tapes also indicates that for the most part, parents answer these questions, but when they do not, the children persist. Most interesting is that if the adult provides a direct answer to the child's question, the child typically obtains a factual piece of information. However, if the adult engages in a back and forth feedback loop with the child, making the child's own thinking process visible, the child acquires a deeper, richer understanding of the concept underlying the initial question. A second study shows that preverbal infants use vocalizations and gestures to recruit information from adults. Chouinard concluded that children's questions are powerful tools for advancing their cognitive development.

Committee on the Science of Children Birth to Age 8. (2015). Transforming the workforce for children birth through age 8: A unifying foundation. L. Allen, & B. Kelly (Eds.). Washington, D.C. The National Academies Press.

This comprehensive volume focuses on the competencies needed to support greater consistency among professionals who are responsible for the daily care and education of young children. The volume consists of five major sections and appendices that include: a) introduction and context (Chapters 1 and 2); b) the science of child development and early learning (Chapters 3 and 4); c) implications of the science for early care and education (Chapters 5 - 7); d) developing the care and education workforce for children birth through age 8 (Chapters 8 - 11); and e) blueprint for action (Chapter 12). Information relevant to early science for infants and toddlers appear in a number of chapters. These include Chapter 4 (Child Development and Early Learning) in the sections on cognitive development, learning specific subjects and general learning competencies; Chapter 6 (Educational Practices) in the section on cross-cutting principles for instructional practices and the section on science; and Chapter 7 (Knowledge and Competencies) in the section on foundational knowledge and competencies.

National Research Council (2007). Taking science to school: Learning and teaching science in grades K-8. Committee on science learning: Kindergarten through eighth grade. R. A. Duschl, H.A. Schweingruber & A.W. Shouse (Eds.). Washington, DC: The National Academic Press.

This volume served as a foundation to the NRC, 2012 K-12 conceptual framework, setting the stage for the three dimensional, integrated approach to science education. The volume resulted from a series of meeting of a taskforce, informed by presentations from experts in cognitive, development, developmental psychology and science education. The work contains a review of research literature from multiple disciplines on how children learn the ideas and practices of science. Chapter 3, "Foundations for science learning in young children," describes the knowledge and skills young children bring to school, beginning with the earliest understanding of infants and is highlighted below.

The authors include a summary of three major themes that run through the research (see p. 54): 1) the central role of exploration and investigation in children's thinking and learning including even the youngest children's sensitivity to abstract patterns and causal relations; 2) the privileged status of the "science related" domains of knowledge in young children including physics, biology and chemistry (as well as psychology); 3) the interplay of domain specific (e.g., physics) and domain general (e.g., cross-cutting concepts) in the development of scientific thinking.

Chapter 3 provides an excellent review of development in infant and toddlers linked to science domains of knowledge. Theories referenced in this annotated bibliography (e.g., Piaget) along with original research articles are reviewed. A complete reference list is provided at the end of the chapter. Subheadings include Naïve Physics; Naïve Psychology; Naïve Biology; Substances and their Transformations (Chemistry); Earth Systems; Scientific Reasoning; and concludes with a section on Young Children's Understanding of Knowledge and of Science. For example, beginning on page 56, is a review of infants' and then toddlers' understanding of the properties of objects and the physical world. Under the topic of "Naïve Psychology" (beginning on page 63) research on young children's (beginning with infants and toddlers) understanding of intentional agents is reviewed with relevance for children's understanding of big ideas in life science. Knowledge about biology (beginning on page 66) is reviewed next, with relevance for the big ideas around living versus non-living.

Chapter 3 in this volume is an excellent review source for both infant and toddler development with relevance for how this development relates to young children as emerging young scientists

Piaget, J. (1969). The psychology of intelligence. NY: Littlefield, Adams.

Piaget, J., & Inhelder, B. (1969). The psychology of the child. NY: Basic Book, Inc.

The theory of how young children learn and develop that has dominated early childhood classrooms depicts the young child as an active explorer of his/her environment. For Piaget, learning is child-directed and organized within cognitive structures he calls "schema." Schema, in the form of reflexes such as grasping and sucking, are present in the newborn and provide the initial interactions with the child's immediate world. The newborn soon gains control over these reflexes as he/she begins to interact with the environment. These interactions are initially random, but during Piaget's birth-to-age-two sensory motor period these interactions become more intentional and goal directed as the infant discovers important domain general concepts (e.g., cross-cutting concepts; dimension 2 in the new K-12 framework). These concepts include cause and effect relationships (e.g., shaking the rattle makes a noise), structure function relationships (e.g., objects with handles can be used to get objects that are beyond arm's reach) and patterns (e.g., wake up, cry, mommy comes and picks me and give me a hug).

For Piaget, active exploration is driven by an innate need to seek novelty. New information can only be added to an existing schema (Piaget terms this "assimilation") and then a complementary innate need to make sense of the new information in the context of what is already known leads to changes in the schema (Piaget terms this "accommodation"). Moderate degrees of novelty are most "attractive" to the young learner, versus something that is already mostly well known (not enough novelty) or too different to make sense of, given existing knowledge (too much novelty). Piaget posits a third process termed, "equilibration" which requires the "assimilation" and “accommodation” process to stay in balance with each other. These processes in the active young explorer build more sophisticated knowledge structures that aid young children in making sense of their world.

Observing infant and toddler classrooms through the lens of Piaget, one can clearly see his influence. Early childhood classrooms are organized into interesting areas with interesting objects to explore. The child is given ample opportunities to activity explore. Piaget’s theory also provided insight into what makes for an interesting area with interesting objects for young infants (birth to about 9 months), versus mobile infants (about 9 to 18 months) versus toddlers (about 18 to 36 months). In keeping with Piaget’s theory, where children learn by building on concepts (schema) they already understand, infant toddler educators set up classroom environments and provide experiences to expand young children’s understanding. To extend upon a young children’s existing knowledge, infant toddler educators can offer new information, introduce a slightly more challenging play prop or toy, or encourage the use of toys in a novel way. Taking advantage of the natural curiosity of infancy and toddlerhood, early educators observe children’s current level of understanding of a concept and take into account children’s experience with particular objects to identify the kinds of concepts, objects, and environments that provide the best opportunities for learning and development. For example, understanding the development of infants’ and toddlers’ ability to grasp objects provides insight into what types of objects to introduce for the young child to explore.

Vygotsky, L. S. (1978). Mind in society: The development of higher mental processes (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Trans.). Cambridge, MA: Harvard University Press.

Piaget views child development as child-directed where creating an engaging environment that maintains the right amount of novelty is the main ingredient. Vygotsky views development from a more socially driven, expert-novice perspective. Vygotsky focuses on adults helping children acquire the abilities that are just beyond their reach in what he refers to as the “zone of proximal development.” This perspective on learning and development requires both knowledge and action on the part of the adult. Adults need to know the child’s current capabilities, what capabilities come next and then be able to guide the child into this proximal zone of development.

Guided Learning

Piaget and Vygotsky suggest very different roles for the adult in young children’s learning. For Piaget, the role of the adult is to create an environment at the right level of novelty and then allow the child to actively explore. Vygotsky, on the other hand, expects the adult to be involved in guiding the child’s learning. There is now considerable research to support Vygotsky in the important role that adults play in guiding the learning of young children. A meta-analysis is reviewed along with one review of research in early childhood classrooms and one study focused on the role of parents in young children’s learning.

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2010). Does discovery-based instruction enhance learning? Journal of Educational Psychology, 103, 1–18.

This review paper presents two meta-analyses that included 164 studies to address whether allowing children to actively explore on their own (referred to as “discovery learning’) benefited learners compared to other more directed forms of learning. Meta-analysis is a method of comparing a large number of studies that do not necessarily follow the same procedures or research design. Each study, however, typically involves children who are exposed to different learning approaches. Average difference between the learning approaches are calculated and converted to a common metric referred to as the “effect size” which is measured in standard deviation units. (For example if the two approaches produce a mean difference of 10 units and the standard deviation is 30 units, then the effect size is .33 or 10 divided by 33). The effects size from these studies are combined to give an overall picture of the effectiveness of the approaches that are being compared. Effect size of .30 and above are considerate moderate. Effect sizes of this order were reported in this review paper based on 360 comparisons. Groups of children participating in explicit instruction and other forms of more directed learning approaches showed greater learning when compared to groups of children participating in discovery learning approaches.

Weisberg, D.S., Hirsh-Pasek, K., & Golinkoff, R.M. (2013). Guided play: Where curricular goals meet a playful pedagogy. Mind, Brain & Education. 7 (2), 104 – 112.

One might conclude from evidence provided in such meta-analyses as reviewed above that the preschool day should be filled with direct instruction. The authors of this article, however, who are strong believers in the importance of learning though play in early childhood classrooms, advocate for a “middle ground” between free play and teacher directed instruction. They provide a strong argument, supported by empirical evidence, that this middle ground approach, referred to as directed play, often produces better academic outcomes that direct instruction. The article defines guided play, provides evidence for its effectiveness and then concludes with a discussion of why guided play is not only effective, but needs to be prominent in early childhood classrooms. Guided play provides a learning goal and scaffolding while still allowing children the critical and important role of being active and engaged partners in their learning.

Ferrara, K., Hirsch-Pasek, K., Newcome, N.S., Golinkoff, R.M., & Lam, W.S. (2011). Block talk: spatial language during block play. Mind, Brain & Education, 5 (3), 143- 151.

Parents also play an important role in young children’s learning as demonstrated in this empirical study on block building. From a very early age, young children engage in block play. These activities should be encouraged in both boys and girls, as they aid in the development of spatial skills, and are important not only for science learning, but are also a part of intelligence and play a role in one’s everyday life. This empirical study compared block play in a sample of 72 young children (half were between 3 and 4.5 years of age; half between 4.5 and 5 years of age; half were female) and their parent or guardian (two fathers and the rest mothers). Each pair (child and parent) were randomly assigned to one of three block building conditions – free play, guided play and preassembled play. Each condition used the same materials. Results of this study showed that parents who engage in a guided play intervention with their children while constructing with blocks use significantly more spatial language (e.g., words like ‘‘over” and ‘‘between’’) than parents who play with preassembled block structures with their children or who play freely with their children.

Supporting Early Science Learning

Although the scientific evidence base for best practices in science education for infants and toddlers is not well developed, there are practitioner oriented publications that provide helpful tips and descriptions of supporting early science learning. These publications focus on ways to engage young children in activities that involve the scientific practices, cross-cutting concepts and core ideas. The two main sources for this information are Early Head Start/Head Start and the National Association for the Education of Young Children. The National Association for the Education of Young Children publishes a practitioner oriented journal, Young Children that includes many articles with relevance to science for infants and toddlers. Past articles in Young Children are archived (www.jstor.org) and can be searched with keywords. For example, a search using the keywords “toddlers scientific exploration” produced a number of articles from Young Children, including “Toddlers scientific explorations: encounters with insects,” (2009; Vol 64 (6), 18 – 23); “Dancing with trees: infants and toddlers in the garden,” (2005; Vol 60 (3) 40 – 46; “Exploring the natural world with infants and toddlers in an urban setting (2008; Vol 63 (1) 22-25); and “Science in the Air,” (2009; Vol 64 (6) 10 -14).

Early Head Start National Resource Center. (2013). Supporting outdoor play & exploration for infants & toddlers (Technical Assistance Paper #14). Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/tta-system/ehsnrc/docs/ehs-ta-paper-14-outdoor-play.pdf

This report begins with a summary of the current state of outdoor play and the advantages of outdoor play for infants and toddlers. Considerations for creating safe outdoor play spaces are then provided followed by strategies for maximizing outdoor play learning opportunities for infants and toddlers. In this section examples are provided that support the K-12 science framework and the role of adult in creating an interesting space (Piaget), and scaffolding learning (Vygotsky) and supporting children’s inquiry (Chouinard) as well as maintaining a positive attitude. Relevant standards are provided along with references, resources and an appendix that again supports science learning (e.g., creating surfaces for rolling toys, and places for water and sand play).

U.S. Department of Health and Human Services, Administration for Children and Families, Office of Head Start. (2008, July). Infant/Toddler math & science development: Does Early Head Start support math and science development with infants and toddlers?

(Tip Sheet # 29). Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/tta-system/ehsnrc/cde/curriculum/DoesEarlyHeadS.htm

This tip sheet begins with a discussion of the importance of creating trusting relationships with infants and toddlers that allow them the security to explore. The text then provides examples of how to support math and science. The examples, although not labeled in this way, are highly consistent with the K-12 conceptual framework discussed in this review. Examples include exploring what is under a rock (science practice – exploration and observation), dropping a spoon from a high chair (cross-cutting concept – cause and effect) and trying multiple ways to fit a toy inside a container (big idea in physical science – properties of objects).

The role of the adult is discussed including providing appropriate materials for exploration (Piaget), joining in activities to both scaffold (Vygotsky) and answer children's questions (Chouinard), and showing positive attitudes in these interactions. Relevant performance standards are listed along with resources. Also included is an addendum that lists 3 broad science categories and three broad math categories, each with examples. The three science categories are K-12 science practices or cross-cutting concepts (patterning, classifying and measuring).

U.S. Department of Health and Human Services, Administration for Children and Families, Office of Head Start. (2014, May). News you can use: Early science learning for infants & toddlers, News for Head Start, Early Head Start & Migrant/Seasonal Programs. Retrieved from http://eclkc.ohs.acf.hhs.gov/hslc/tta-system/ehsnrc/cde/curriculum/early-science.html

This publication defines science for infants and toddlers, focusing on science practices ("science is not just a body of knowledge – it's a way of thinking and acting …a way to discover the nature of things. Science learning at any age involves curiosity, exploration and discovery."). Five science practices (observing; developing one or more hypotheses/predicting; investigating/experimenting; analyzing results/drawing conclusions; communicating) are outlined in a table with definitions and examples.

Acquiring science knowledge is also discussed with a focus on science is everywhere ("Where can science learning happen? Everywhere and anywhere."). Core ideas (physical science, natural science – both life science and earth and space science) are also defined and discussed. Sections on how staff and families can support early science learning for infants and toddlers; and science and school readiness for infants and toddlers are also provided along with additional resources and a study guide.

Shillady, A. (Ed). (2013). Spotlight on young children: Exploring science, Washington, D.C.: National Association for the Education of Young Children.

This book is a collection of 12 articles (and an article introducing the volume, a resource section and a concluding chapter reflecting, discussing and exploring questions and follow-up activities) published in Young Children from 2009 through 2012. The articles cover a variety of ages from infancy through kindergarten, with a number of articles focusing on infants and toddlers.

Summary: Why Science for Infants and Toddlers

As outlined in the introduction, the past few years have seen a major focus on early science in preschool classrooms. A new conceptual framework for K-12 science education focuses on learning a small set of core ideas in four disciplinary areas in the context of children doing science and attending to cross-cutting concepts that are essentially truth about the world. This framework is gaining considerable momentum in the preschool world along with an emerging body of evidence to support best practices.

As I have also pointed out in the introduction, three years of age is not a "magic number" for early science and much of the K-12 conceptual framework has relevance for infants and toddlers. The Office of Head Start/Early Head Start has made it clear that early science is for infants and toddlers. Very early on, infants are observing and exploring their immediate world and making use of cross-cutting concepts. Even before they become verbal, young infants' more advanced receptive language ability and use of adults as resources lead them to use gestures and vocalization as tools for gathering information. Once they can talk, they ask explanatory questions, and persist when adults do not provide answers.

Adults play a critical role in young children's development, providing a safe, interesting environment to explore, scaffolding children into zones of proximal development, and answering children's questions with sustained feedback loops to move from factual information to deeper levels of understanding and concept development. Early childhood educators' understanding of the K-12 conceptual framework, relevant theories of development (e.g., Piaget, Vygotsky and Chouinard) and children's curiosity and natural, goal-directed exploration to make sense of their world, will not only prepare young children for preschool and K-12 science education, but will also serve as best practices for setting them on a pathway for life-longing learning and development.

About the Author

Daryl Greenfield, Ph.D., Professor of Psychology & Pediatrics, University of Miami, Coral Gables, Florida has over 35 years of experience conducting partnership-based research with young children, serving as the Principal Investigator (PI) on over 20 multiyear projects. He is currently the PI on two Institute of Education Science (IES) measurement grants to create linked, computer-adaptive touch-screen assessments of young children's science competence (English; Spanish); an Administration for Children and Families grant to assess motivation orientation in young children; a multi-site early science inquiry based coaching grant for infants, toddlers and preschoolers, funded by the Buffet Early Childhood Fund; and serves as the research partner for the Miami site of the National Educare Implementation Study. He is also Co-PI on a National Science Foundation funded development project integrating science, engineering and technology with young children co-constructed with teachers and families involving two immigrant populations; and an IES funded partnership planning grant to create an integrated database system linking data from programs serving birth to age five children in Miami-Dade County with the data on these children from the Miami-Dade County Public School System. He is also involved at the interface of research, policy and practice at the National, State and Local Level. These include (National) serving as the technical adviser for early science for each of the three funded statewide Consortia (one led by Maryland; one let by North Carolina; one led by Texas) to create greater continuity between early childhood and the early elementary grades); a member of the Program Committee for the 13th Annual Head Start Research Conference to be held in 2016; an adviser to the Office of Head Start for early science for the new Head Start Early Learning Outcomes Framework (Birth to Five); a member of the Chicago Community Trust taskforce on early childhood STEM; (State) co-chairing the Florida Head Start Research Committee, an official arm of the Florida Head Start Association; chairing committees for the Office of Early Learning to create Florida's Early Learning Standards; serving for 3 years as one of three technical advisers for the Florida Office of Early Learning; (Local) co-chairing the Miami-Dade County Head Start/Early Head Start Citywide School Readiness Council. He is widely published and a sought-after speaker with recent talks on his work in early science to researchers at Northwestern University, the University of Nebraska, the University of Washington, Tufts University, Rice University, the University of Texas, the University of Illinois at Chicago and Cambridge University in England. In addition he has presented his work on science to early childhood policy makers, practitioners and teaching staff including the keynote address at the 25th anniversary of the Florida Early Childhood One Goal conference, and presentations to key early childhood staff in 12 state departments of education, the Chicago Public School System's Office of Early Learning and the Illinois Governor's Office of Early Childhood Development.