We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Preschoolers Learning Science: Myth or Reality?

Heidi Kloos, Heather Baker, Eleanor Luken,
Rhonda Brown, David Pfeiffer and Victoria Carr

Additional information is available at the end of the chapter

1. Introduction

Teacher: "Now, kids, this is a book about dinosaurs. Are dinosaurs alive today?"

Preschooler 1: "Yeah, at the zoo."

Preschooler 2: "I saw one on TV."

Teacher: "The ones at the zoo are just pretend dinosaurs, aren't they? (Children nod). Does anyone know what the word 'extinct' means?"

Preschooler 3: "I farted ..."

Teacher: "Say 'Excuse me.'"

Preschooler 3 continues: "... in my house."

Teacher: "Let's keep thinking about dinosaurs...."

30 minutes later, Teacher: "Okay, listen up. I want you to think about what you've learned today. Can anyone tell me something they learned about dinosaurs?"

Several Preschoolers: "They're mean."

Teacher: "They're mean? Okay. Does anyone remember what the word 'extinct' means?"

Preschooler 4: "Farted."

(Pfeiffer, 2012)

After Piaget's seminal claims on children's slow emergence of adult-like thought, research in cognitive development has skyrocketed to reveal ever-so-amazing competencies in younger and younger children. These competencies pertain to understanding cause-effect relations, physical truisms, or mathematical operations, to name just a few (e.g., see Bremner & Fogel,

2004, for a summary). Many of these findings have had the effect of changing how children are taught, for example by pushing more complex curricula early on, building upon children's already existing understanding, and supporting children's abstract reasoning skills (e.g., Brenneman, Stevenson-Boyd & Frede, 2009; Eshach & Fried, 2005). In the current chapter we review the research findings of these efforts, focusing explicitly on early science learning.

The area of science learning, while only a small part within the field of children's learning, has several features that warrant interest for the cognitive-development community. First science concepts are abstract, transcending a concrete context that commonly embeds everyday concepts. As such, science learning relates to the emergence of abstract thought, knowledge transfer and symbol manipulation. Second, scientific concept formation is a specific case of everyday concept formation, thus shedding light on the dynamics of collapsing large amounts of information into systematic beliefs (cf., Havu-Nuutinen, 2005). Third, a focus on early learning is likely to uncover the spontaneous working of the mind, processes yet unaffected by formal instruction or by standardized assessment. An understanding of preschoolers' science learning therefore transcends the field of early childhood education and sheds light on the spontaneous development of abstract thought in young children.

Note first that early science learning is a rather unorganized terrain. Unlike the areas of reading or math, this area still grapples with questions of what constitutes success in science learning, how learning should progress, and how to assess its milestones. There are no generally agreed-upon 'letters' that form the alphabet of science, and there are no central 'operations' in science that constitute the base upon which to build. Indeed, research studies differ greatly in how 'science' is defined in the first place, for example whether science concepts need to be abstract, relevant to every-day experience, or interconnected with other concepts. Similarly, assessment tools differ greatly in whether they measure the presence of a particular concept, the way it is applied, or its semantic network. As a result, there are no generally accepted instructional tools (cf., Kirchner, Sweller & Clark, 2006), and there are no generally accepted assessments that could capture milestones of science learning across curricula (for reviews see Brenneman, 2011; Scott-Little, Lesko, Martella, & Milburn, 2007). The current chapter is a first step towards filling this gap.

For our purposes, science is defined to incorporate two aspects: scientific facts and concepts, and the processes by which science knowledge is generated. These two aspects – knowledge of science concepts and knowledge of how the science concepts were derived – are of course closely linked (cf. Schauble, 1990). We nevertheless treat them as separate for the purpose of organizing the research findings on early science learning. Note also that this review is by no means exhaustive. The literature on young children's science learning has exploded in the last decade, being published in numerous educational and cognitive-development journals, as well as in journals devoted to this topic entirely (e.g., *Science and Children; Research in Science Education*). Here we present a cross-section of pertinent research, as a means of finding a common thread and setting the stage for a more integrated discussion

about young children's learning. For example, we describe research on how to support young children's reasoning about abstract concepts, how to replace their mistaken beliefs with more appropriate ones, how to engage them in scientific discourse and explorations, and how to scaffold their attempt to organize isolated pieces of knowledge into coherent networks of interrelated facts.

2. Can preschoolers learn about scientific facts?

A central part of science is a shared understanding of concepts and facts, for example from the domain of physical sciences, life sciences, or earth and space sciences. Research in cognitive development has documented that even young children know something about these science domains. For example, young children know that the behavior of objects is affected by their physical properties (cf., Kotovsky & Baillargeon, 1998; Schilling & Clifton, 1998); they know that the identity of living things is determined internally (Simons & Keil, 1995; Springer, 1995); and they understand the effect of gravity (e.g., Vosniadou, 1994). Of course, sometimes their beliefs are mistaken; they hold misconceptions. For example, children believe that heavy stuff sinks fast (e.g., Kloos & Somerville, 2001; Penner & Klahr, 1996), that the sun is alive, but not plants (Venville, 2004), or that the earth is disc-shaped (e.g., Vosniadou & Brewer, 1992). To what extent can early science instruction build upon children's existing knowledge to convey new facts and change mistaken beliefs?

Conveying Something New. Science facts differ in the degree to which they rely on concrete versus abstract pieces of information. That is to say, science facts vary in whether relevant pieces of information are readily perceivable – or whether they need to be extracted from irrelevant information. That a spider has eight legs requires a relatively low level of abstraction, because the fact's relevant pieces of information are readily accessible in a single event. By contrast, the idea that caterpillars turn into butterflies is more abstract: caterpillars and butterflies need to be conceptually connected, while differences between the two need to be ignored (e.g., shape, behavior). Similarly, the idea that water can turn into ice is less abstract than the idea that materials consist of particles that are invisible to the naked eye. The latter requires the learner to ignore salient features of an object (e.g., the shape or size of a material), and instead note underlying patterns of how materials interact and change.

Can young children learn low-abstraction science facts? This question is relatively trivial, as one might guess from every-day experiences with children (e.g., Cumming, 2003). For example, preschoolers can learn with little effort the names of new species, the names of the planets, and even the terms associated with material properties and chemical change (e.g., Fleer & Hardy, 1993). However, educators sometimes worry that children's learning of facts is no more than passive rote memorization, far from reflecting 'truly understanding' the facts. At the crux of this concern is that young children might not be able to go beyond mere facts to interconnect them under a common concept. Even though there is evidence of spontaneous abstractions in young children (e.g., Hickling & Gelman 1995; Hickling &

Wellman, 2001), higher-order concepts pertinent to science knowledge might be too abstract for them. The more central question, therefore, is whether young children can learn abstract concepts.

There is an interesting drawback when it comes to learning abstract concepts. Unlike what one would expect, findings show that overly detailed and richly embedded learning materials have a *negative* impact on children's ability to abstract underlying concepts (e.g., Goldstone & Sakamoto, 2003; Goldstone, & Son; 2005; Kaminski, Sloutsky, & Heckler, 2008; Ratterman, Gentner, & DeLoache, 1990; Son, Smith, & Goldstone, 2008). For example, when the learning materials were colored shaped intricately, children had more difficulty discovering an abstract mathematical rule than when the materials were black-and-white simple shapes (Kaminski et al., 2008). When the shapes were such that they helped children intuit the rules, learning improved, but transfer to a new task nevertheless suffered, compared to using none-specific and generic shapes (see also DeLoache, 1995; Bassok & Holyoak, 1989; Mix, 1999; Ratterman & Gentner, 1998; Sloutsky, Kaminski, & Heckler, 2005; Uttal, Liu, & DeLoache, 1999; Uttal, Scudder, & DeLoache, 1997). Taken together, there seems to be a pronounced advantage of sparse contexts when learning abstract concepts. The advantage lies in minimizing distraction, undermining the possibility of forming mistaken ideas, and highlighting relevant pieces of information.

Of course, when it comes to young children, a motivational factor needs to be taken into account (cf., Mantzicopoulos, Patrick, & Samarapungavan 2008; Zembylas, 2008). A setting without rich details might fail to engage the child sufficiently to prompt learning. For example, a young child might not be inclined to explore objects unless they vary in color, shape, and texture in interesting ways. Therefore, to make abstract ideas accessible to young children, it might not be possible to strip the context of any unnecessary complexity. A different approach to instruction is needed, one that helps make abstract ideas visible to children, while, at the same time, retaining a richly detailed context. Such approach might require a pedagogy that bootstraps the understanding of abstract ideas, rather than waiting for young children to detect them by themselves. Findings show that such approach is indeed possible.

Take for example the abstract idea of object conservation, the idea that matter exists, even when it is not visible with the naked eye. To understand this concept, children have to ignore their phenomenological experience of an object's presence and therefore engage in abstract reasoning. Immersing children into a richly detailed environment might not make this abstract idea salient. On the other hand, providing children with the opportunity to reflect on guided explorations of material transformation improved their understanding of object conservation (Acher, Arca & Sanmarti, 2007). In particular, 7- to 8-year-olds were asked to observe possible changes in materials (e.g., stones, wood, water, metal) when they were trying to break them down, mix them in water, or burn them. After each manipulation, children were encouraged to draw the changes they observed in the materials. They also participated in group discussions designed to help them conceptualize their experiences. Findings show not only that children were able to express opinions and counter arguments,

but also that they could understand object conservation. Even 5-year-old preschoolers can appreciate the idea that water, when invisible to the naked eye, is nevertheless still present in some form (Tytler & Peterson, 2000).

Replacing Existing Beliefs. Learning about a new science concept can be problematic, beyond the required abstract-reasoning skills. This is because in some cases, children's naïve ideas about the domain conflict with the pertinent science concept. The detrimental power of mistaken ideas has been recognized for decades, leading to extensive research into understanding both the nature of the misconceptions across ages and how they can be changed (e.g., see Ohlsson, 2011; Vosniadou, 2008, for an extensive discussion). Indeed, existing misconceptions appear to be very difficult to change (e.g., Anderson & Smith, 1987; Gunstone, Champagne, & Klopfer, 1981; Hannust, & Kikas, 2007; Kloos & Somerville, 2001; Linn & Burbules, 1988; Schneps, 1987). In many instances, children prefer mistaken ideas over correct ideas, even after extensive training and even after shortcomings of mistaken ideas have been pointed out explicitly. Take for example findings with 5- to 7-year-olds who participated in an astronomy curriculum on the spherical properties of the earth (Hannust, & Kikas, 2007). The four-week curriculum involved hands-on mini-lessons designed to target several apparent contractions, for example why the earth is perceived to be flat, or why people living on the "down-side" of the earth do not fall off. Yet, despite this relatively extensive intervention, children's understanding did not change significantly over the course of the instruction. While their performance on a pretest was below chance (11% correct), it stayed low even after the lessons (15% correct). In fact, results show that children relied more heavily on their phenomenological experience after instruction than before (see also Kloos & Van Orden, 2005 for similar counter effects of teaching interventions).

Given such resistance to change, one might speculate that a child's mistaken ideas are innate. But upon closer look into the nature of beliefs, it turns out that misconceptions arise when misleading pieces of information are more salient than pieces of information that are relevant to the particular science concept (cf., Kloos, Fisher, & Van Orden, 2010). Therefore, to change a child's mistaken ideas in a science domain, a pedagogical approach is needed that can change the salience of relevant compared to irrelevant pieces of information (i.e., increase the salience of science-relevant pieces of information). With such change in making relevant information salient, misconceptions might be avoided altogether. Indeed, children who have benefitted from focused instruction seem to harbor fewer misconceptions in later years at school (cf., Novak & Gowin, 1984.)

A promising approach in this regard is the use of conceptual models, also known as conceptual schemas, mental models, or scientific models (e.g., Glynn & Duit, 1995; Kenyon, Schwarz, & Hug, 2008; Mayer, 1989, Penner, Giles, Lehrer, & Schauble, 1997; Smith, Snir, & Grosslight, 1992; Smith & Unger, 1997, for a review see Vosniadou, 2008). Conceptual models are abstract representations of a science phenomenon – external diagrams of some sort that children can internalize. Models do not represent the real world in its full degree of complexity. Instead, they are schematics of the real world, designed to highlight only a selected number of relations (the ones that are relevant to the science concept of interest),

while downplaying other relations (ones that are less relevant or misleading). Importantly, models represent predictive and explanatory rules, thus making visible the components of science phenomenon that are difficult to be perceived on the basis of phenomenological experience alone. As such, they make relevant science facts salient, in effect decreasing the salience of irrelevant pieces of information.

There are several studies that show the effectiveness of conceptual models in young children (e.g., Gobert & Buckley, 2000; Kenyon et al. 2008; Wiser & Smith, 2008; Baker, Haussmann, Kloos, & Fisher, 2011). An illustrative example uses the science domain of material density, a concept that is defined by the ratio of the two highly salient dimensions of mass and volume. Predictably, children often ignore density and use instead perceived heaviness of an object as the sole predictor of the object's buoyancy (e.g., Piaget & Inhelder, 1974; Kloos et al., 2010). To help children overcome this mistaken focus on an object's heaviness, a conceptual model of density was developed, also known as dot-per-box (e.g., Smith & Unger, 1997; Wiser & Smith, 2008). It involves a display in which the volume of an object is represented as a certain number of boxes, and mass is represented as number of dots inside the boxes. Thus, density is represented as the spacing between dots (the more crowded the dots, the more dense the material); and irrelevant variation of color, shape, and texture are omitted. Thus, density of the material is now similar in salience to that of mass or volume. Children indeed benefited from these abstract representations of density (for a discussion of these findings, see Wiser & Smith, 2008). Similar learning success was reported with 4- to 5-year-olds, whether children were recruited from Head Start preschools or from preschools serving upper middle class families (Baker et al., 2011).

Introducing conceptual models early on might have a positive effect on learning as children get older. Support for this claim comes from research in the domain of evaporation and condensation, another domain that is a notoriously difficult area of instruction in science (Kenyon et al., 2008). Children between 6 and 8 years of age underwent a multi-week training on evaporation and condensation, which included observing the evaporation and condensation in a soda bottle, drawing diagrams to capture the system through various moments in time, testing their models through experiments, using tools to measure the amount of water in the air, and revising their models as needed. Findings show that the instructed students significantly outperformed the uninstructed students in their understanding of relevant concepts. Importantly, when students began the formal study of science in Grade 7, instructed students improve in their understanding of concepts much faster than uninstructed students. Clearly, the students who were helped to form basic science concepts in early grades had developed an understanding of the domain that continued to facilitate their meaningful learning, further developing their understandings and reducing their misconceptions (for related discussions, see Muthukrishna, Carnine, Grossen, & Miller, 1993).

In sum, research-based evidence points in a clear direction when it comes to promoting an understanding of science concepts. Unlike what a Piagetian stage model of abstract reasoning might imply, young children are indeed able to learn abstract concepts early on, even when the concepts run counter to what children already believe. Their learning

strongly depends on an instructional environment that makes abstract relations salient, allowing them to visualize the relations without getting distracted by irrelevant information in the immediate context. To put it more pointedly, the limits on a child's ability to learn abstract science concepts might be the limits of the instruction that is provided. Open questions pertain to the exact interplay between decontextualized and carefully simplified environments to maximize children's learning about science concepts and events directly related to their lives (e.g., food, weather, seasons, animals, vehicles, light, magnets, etc.).

3. Can preschoolers learn to generate science knowledge?

The second aspect of science learning pertains to understanding the process by which science knowledge is generated. Rather than learning about established and accepted science facts and concepts, this aspect includes an understanding of how science facts are generated in the first place. This includes the ability to create settings that are sufficiently informative for science knowledge to be generated. And it includes the meta-cognitive understanding of how new information can change existing knowledge. It is important to note that the process of generating science concepts is in part affected by cultural norms. Norms pertain to constraints about what to count as an explanation of events (cf., Pearl, 2009), under what circumstances to abandon an existing theory (cf. Kuhn, 1996), or how to treat expected versus unexpected observations (cf., Popper, 1959). So far, these constraints have not been studied explicitly in the realm of early science learning. Instead, the emphasis is on understanding how children's everyday interactions with their environment can help children generate science knowledge (e.g., Zimmerman, 2000).

The question of children's ability to generate science knowledge through observations is debated heavily, both in cognitive development and in educational research. In cognitive development, the ongoing debate centers on the question of whether young children are at all capable of engaging in appropriate knowledge-generating activities. Such activities, referred to as *scientific reasoning*, require the child to detect gaps in their existing knowledge base, ask questions in response to the identified gaps, carry out the experiments that could lead to an answer, and critically evaluate the evidence (cf., Klahr, 2005). Each one of these steps can be difficult for children (and even for adults), for several reasons: First, the mind is biased towards perceiving order, making it difficult to perceive disorder, missing information, or gaps (cf., e.g., Quinn, Eimas, & Rosenkrantz, 1993). Second, the mind is biased towards confirming already existing beliefs, rather than questioning their shortcomings, making it difficult to spontaneously challenge existing beliefs (e.g., Schauble, 1990). Under this view, scientific reasoning has to be trained explicitly.

In contrast to the cognitive-development debate, educational research already presupposes the child's ability to generate science knowledge, following the theoretical bent of constructivism (cf., Olson, 1996). For example, it is generally accepted that children can engage in *inquiry*, the processes of wondering, questioning, exploring, investigating, discussing, reflecting, and formulating ideas and theories (e.g., Kuhn, 2010). Indeed,

preschool education places strong emphasis on exploration, the idea being that exploration is at the center of what allows children to generate knowledge about the world (e.g., Luken, Carr, & Brown, 2011). The debate then centers on the question of how children's spontaneous inquiry can be supported by teacher interventions, explicit instruction, and/or feedback. In what follows, we review findings that speak to this question. In particular, we focus on the efficacy of three strategies that help children generate science knowledge. They include (1) engaging children in scientific discourse, (2) teaching them to keep track of their observations, and (3) helping them organize their knowledge.

Can young children engage in scientific discourse? What is also referred to as 'science talk' (Lemke, 1990) or exploratory language (Peterson & French, 2008), scientific discourse differs from a standard question-answer format for which the person asking the question already knows, expects to hear, and rewards the right answer. Scientific discourse instead promotes sense-making of events: accepted science terms, concepts, and methods are transmitted in the context of children asking scientifically valid questions (cf., Crowder, 1996). It is therefore a large part of inquiry and scientific reasoning. While scientific discourse is heavily studied in school-aged children (e.g., Kafai & Carter Ching, 2001), preschool teachers and parents of young children are likely to engage in such discourse naturally, as they guide children's explorations of topics relevant to their everyday life. The ideal context is likely to require an active and knowledgeable listeners and a shared science vocabulary that children are sufficiently comfortable with (cf., Crowley, Callanan, Jipson, et al., 2001; Fleer, 1996; Pramling & Pramling-Samuelson, 2001).

The effectiveness of science talk with preschoolers was demonstrated empirically with the domains of metamorphosis and plant growth (e.g., Witt & Kimple, 2008). Children were first given a pretest on these two science domains, asking questions such as *What is a cocoon?*, *What kind of food helps caterpillars and butterflies grow?*, *How does a plant soak up water?*, and *Do seeds grow faster in direct sunlight, darkness, or a mixture of both?*. Preschoolers then participated in two several-weeks-long activities, one pertaining to creating an environment for caterpillars and observing the metamorphosis, and one pertaining to planting seeds and observing the growth in different climates and environments (e.g., hot and sunny vs. cold and dark). Preschoolers were frequently engaged in conversations, allowing them to reflect on their observations and experience. Post-test performance showed remarkable improvement in science knowledge: Every child improved in their answers, and every question showed gains. For example, while none of the preschoolers knew the meaning of 'cocoon' or the conditions under which seeds grow best, all of them did so during the posttest.

Promising results for the effectiveness of science talk were also reported with the domain of electrical currents (Fleer, 1991; Fleer & Beasley, 1991). The task was to explore flashlights, find out what they are made out of and how they work, and construct their own flashlights using batteries, bulbs, and wires. With the use of guided interaction with the teachers, preschoolers and 1st-graders learned to formulate questions about the working of the flashlights, and they learned to report the findings of their own explorations. Even better results were obtained when children were given direct instruction on how the electricity

flowed around the circuit, both through the reading of factual books, and through one-on-one interactions with the teachers as children explored the materials. In particular, after direct instruction, all children could talk about how the electricity continuously flowed around a simple electric circuit, an understanding they still held 2 months later. Without such direct instruction, and despite being able to connect the circuit, children's beliefs about electricity, measured through their entries in a 'notebook' did not change over the course of three months: All children with comparison data expressed exactly the same view of 'electricity' in both interviews.

As this previous study implies, a scientific discourse is aided when children can keep track of their explorations across time, for example in science journals. This is not only because children are exposed to richer information over time (e.g., to detect a contrast in an abstract dimension that is not available in snapshot events). Science journals also provide teachers with an opportunity to engage children in a targeted and individualized way (cf., Doris, 1991; Light & Simmons 1983). Recent findings show that even preschoolers can be taught to keep a science journal (e.g., Brenneman & Louro 2008). This is might involve over-simplified drawings and an explanation written by a teacher. Nevertheless, they provide an authentic medium for teachers to encourage scientific reasoning. For example, children's drawings make it possible for teachers to convey the difference between true observations and a child's imagination, the importance of dating the entries, and the focus on hidden features (e.g., the inside of a pumpkin). The outcome was a rich interaction between teachers and preschoolers, promoting children's ability to observe objectively, to record observations with some precision, and to become aware of patterns of change..

So far, we have discussed the benefits of engaging children in science talk and encouraging them to make note of their observations. An even more targeted way of helping children generate science knowledge involves helping them organize their observations and beliefs in a systematic way. It involves the use of so-called concept maps (cf., Novak, 2010). Concept maps consist of nodes (to represent objects) and arrows between nodes (to represent events). The resulting flow charts (e.g., 'plants → go in → gardens') can be organized hierarchically to capture the relations between what children think and experience. For example, when presented with a targeted question about the cycle of growth, concepts maps make it possible for children to organize information about animals and plants in a way that yields both relevant science knowledge and an understanding of how such knowledge could be generated.

The Young Florida Naturalist Program used such a concept-map strategy with 3- to 4-year-olds from urban early childhood center children (e.g., Hunter, Monroe-Ossi, & Fountain, 2008). The goal was to increase children's knowledge about the butterfly life cycle and plant growth over the course of an eight-week instructional period. A concept map was constructed first, using a set of pertinent pictures (e.g., tree roots, leaves, caterpillars, butterflies, cocoons), to capture children's initial understandings. The concept map was then posted in the classroom as a point of reference, and to allow for modifications as children learned new information. To stimulate children's thinking, a butterfly garden was planted on the center's grounds, and children engaged in various experiments with water, sunlight,

soil, etc. to explore plant growth. At the end of the period, children's understanding was assessed in semi-structured interviews to infer a child's individual concept map. For example, children were asked to sort and organize a set of pictures, they were encouraged to talk about what they know about plants and butterflies, and they were asked about their understandings of the final class concept map (e.g., 'what do the pictures tell you about plants?"). Results document that a large majority of both 3- and 4-year-olds could make higher-order propositions, and they could recall terms and concepts relevant to parts of plants and aspects of butterfly transformation.

Taken together, these results show that young children can benefit from quite sophisticated adult support in order to generate science-relevant knowledge. That is to say, children's natural curiosity can be harnessed to help them explore their surroundings in scientifically appropriate ways. Adult support can range from merely providing children with a context for explorations to engaging them in guided discussions about their explorations, to helping them document their findings and organize their thoughts. As part of this process, young children are likely to learn the cultural norms of what is considered science, what counts as a worthwhile phenomenon, how it should be explored and evaluated, and what kind of knowledge construal would be acceptable (i.e., what can be ignored and what must be included). Open questions pertain to the relative benefit of allowing children to develop their own representations of what they observe versus working with representations provided to them in a top-down fashion.

4. Coda

Science is a rather difficult subject to teach, for several reasons. First, relevant science concepts are often far less salient than superficial aspects of an observation. In fact superficial features lead to mistaken beliefs that resist change. Second, science explorations require a level of systematicity that is difficult for young children to attain. Young children get easily distracted, failing to isolate relevant variables or to note their effect. Third, agreed upon scientific knowledge is incomplete – at least to some extent: it includes necessary simplifications to capture general rules and usable models. As such, there are choices to be made in terms of what to consider a valid science understanding. And finally, given that science understanding depends on the acquisition of a novel nomenclature and seemingly isolated facts, science learning can be dull and unmotivating.

Nevertheless, young children are equipped to learn about scientific concepts early on, as cognitive-development research shows. Most importantly, they can organize individual experiences into over-arching patterns early on (cf., Thagard, 2000) – a process that forms the basic building block of the abstract reasoning necessary in science learning. Building upon these abilities, a variety of methods and pedagogical tools have shown to support early science learning (e.g., Worth and Grollman, 2003; Chalufour and Worth, 2003, 2004, 2005). Summarizing across the available findings, the following aspects appear to play a crucial role. First, science learning is aided when children engage with scientifically literate adults who understand how to use scientifically valid representations and who anticipate

children's already existing ideas about science (cf., Davis & Krajcik, 2005). Second, science learning is aided when intentional teaching is incorporated with play, such that teaching practices not only become purposeful and thoughtful, but also engage young children with topic-specific phenomena and inquiry (cf., Bodrova & Leong, 2007; Crowley & Jacobs, 2002; Copple & Bredekamp, 2009; NAEYC, 2009). The promise is to make accessible relevant science concepts to young children – even abstract concepts and those that run counter to already existing beliefs – forming the foundation upon which young learners will construct their ideas later in life (cf., Lucas, 1993).

Research on early science learning also highlights the gaps that still remain in our understanding of children's learning (cf., Davis, 2009). In fact, existing efforts to measure early science learning might be merely a first step. A more complete understanding calls for findings on how to best organize a child's science education throughout the curriculum, how to measure their progress across science domains, how to harness individual differences among children, and what kind of early exposure leads to long-term gains in science learning. Related, empirical questions still remain about how inquiry and explorations interface with direct instructions of science concepts, and how a child's attitude towards science learning both affects and is affected by learning of science. Without research-based findings to speak to these issues, our intuitions about early science learning, while fueling arguments among various viewpoints, might nevertheless jeopardize progression the area of early science learning.

Author details

Heidi Kloos, Heather Baker and David Pfeiffer
Department of Psychology, University of Cincinnati, Cincinnati OH, USA

Eleanor Luken and Victoria Carr
Early Childhood Education, University of Cincinnati, Cincinnati OH, USA

Rhonda Brown
Educational Studies, University of Cincinnati, Cincinnati OH, USA

Acknowledgement

5. References

Acher, A., Arca, M., Sanmarti, N., (2007) Modeling as a teaching learning process for understanding materials: a case study in primary education. *Wiley InterScience*. 9, 1398-418.

Anderson, C.W., & Smith, E. (1987). Teaching Science. in V. Richardson-Koehler (Ed.), *Educator's handbook: A research perspective* (pp. 84-111). New York: Longman

Baker, H., Haussmann, A., Kloos, H., & Fisher, A. (2011). Preschoolers' Learning about Buoyancy: Does it help to give away the answer? *Proceedings of the First Joint International Conference on Learning and Development and Epigenetic Robotics.* Frankfurt, Germany: IEEE.

Bassok, M., & Holyoak, K . J . (1989) . Interdomain transfer between isomorphic topics in algebra and physics. Journal of Experimental Psychology: Learning, Memory, and *Cognition, 15*, 153-166.

Bodrova, E., & Leong, D. J. (2007). *Tools of the mind: The Vygotskian approach to early childhood education (2nd Ed)*. Upper Saddle River, NJ: Prentice-Hall.

Bremner, G. & Fogel, A. (2004). *Blackwell Handbook of Infant Development.* Oxford, UK: Backwell Publishing.

Brenneman, K. (2011). Assessment for Preschool Science Learning and Learning Environments. *Assessment, 13*(1).

Brenneman, K., Stevenson-Boyd, J., & Frede, E. C. (2009). *Mathematics and Science in Preschool: Policy and Practice* (No. 19). Preschool Policy Brief. New Brunswick, NJ: National Institute for Early Education Research.

Brenneman, K., & Louro, I. F. (2008). Science Journals in the Preschool Classroom. *Early Childhood Education Journal, 36*(2), 113–119.

Chalufour, I., & Worth, K. (2003). *Discovering nature with young children*. St Paul, MN: Redleaf Press.

Chalufour, I., & Worth, K. (2004). *Building structures with young children*. St Paul, MN: Redleaf Press.

Chalufour, I., & Worth, K. (2005). *Exploring water with young children*. St Paul, MN: Redleaf Press.

Copple, C. & Bredekamp, S. (Eds.). (2009). *Developmentally Appropriate Practice in Early Childhood Programs Serving Children from Birth through Age 8* (3rd ed.). Washington, D.C.: National Association for the Education of Young Children.

Cumming, J. (2003). Do runner beans really make you run fast? Young children learning about science-related food concepts in informal settings. *Research in Science Education, 33*, 483–501.

Crowder, E. M. (1996). Gestures at work in sense-making science talk. *The Journal of the Learning Sciences, 5*(3), 173-208

Crowley, K., Callanan, M. A., Jipson, J. L., Galco, J., Topping, K., & Shrager, J. (2001). Shared scientific thinking in everyday parent-child activity. *Science Education, 85*(6), 712–732.

Crowley, K., & Jacobs, M. (2002). Islands of expertise and the development of family scientific literacy. *Learning conversations in museums*, 333–356.

Davis, J. (2009). Revealing the research "hole" of early childhood education for sustainability: a preliminary survey of the literature. *Environmental Education Research, 15*(2), 227-241.

Davis, E.A., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 34*(3), 3–14.

DeLoache, J.S. (1995). Early symbol understanding and use. In Douglas L. Medin (Ed.), *The psychology of learning and motivation: Advances in research and theory.* Vol. 33, pp. 65–114. New York: Academic Press.

Doris, E. (1991). *Doing what scientists do: Children learn to investigate their world.* Portsmouth, NH: Heinemann.

Eshach, H., & Fried, M. N. (2005). Should Science be Taught in Early Childhood? *Journal of Science Education and Technology, 14*(3), 315-336.

Fleer, M. (1991). Socially constructed learning in early childhood science education. *Research in Science Education, 21,* 96–103.

Fleer, M., & Beasley, W. (1991). A study of conceptual development in early childhood. *Research in Science Education, 21,* 104–112.

Fleer, M., & Hardy, T. (1993). How can we find out what 3 and 4 year olds think?: New approaches to eliciting very young children's understandings in science. *Research In Science Education, 23,* 68–76.

Fleer, M. (1996). Fusing the boundaries between home and preschool to support children's scientific learning. *Research in Science Education, 26*(2), 143–154.

Glynn, S. M., & Duit, R. (1995). Learning science meaningfully: Constructing conceptual models. *Learning science in the schools: Research reforming practice*, 3–33.

Gobert, J. D., & Buckley, B. C. (2000). Introduction to model-based in teaching and learning in science education. *International Journal of Science Education, 22* (9), 891 – 894.

Goldstone, R. L., & Sakamoto, Y. (2003). The Transfer of Abstract Principles Governing Complex Adaptive Systems. *Cognitive Psychology, 46,* 414-466.

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *The Journal of the Learning Sciences, 14,* 69-110.

Gunstone, R. F., Champagne, A. B., & Klopfer, L. E. (1981). Instruction for Understanding: A case study. *Australian Science Teachers Journal, 27* (3), 27-32.

Hannust, T., & Kikas, E. (2007). Children's knowledge of astronomy and its change in the course of learning. *Early Childhood Research Quarterly*, *22*(1), 89–104.

Havu-Nuutinen, S. (2005). Examining young children's conceptual change process in floating and sinking from a social constructivist perspective. *International Journal of Science Education, 27*(3), 259.

Hickling, A. K., & Gelman, S. A. (1995). How Does Your Garden Grow? Early Conceptualization of Seeds and Their Place in the Plant Growth Cycle. *Child Development*, *66*(3), 856-876.

Hickling, A. K., & Wellman, H. M. (2001). The emergence of children's causal explanations and theories: Evidence from everyday conversation. *Developmental Psychology*, *37*(5), 668-683.

Hunter, J., Monroe-Ossi, H., & Fountain, C. (2008). Young Florida naturalists: Concept mapping and science learning of preschool children. In A. J. Cañas, P. Reiske, M. Åhlberg. D. Novak (Eds.) *Concept Maps: Connecting Educators. Proceedings of the Third International Conference on Concept Mapping.* Tallinn, Estonia & Helsinki, Finland: University of Finland.

Kafai, Y. B., Carter Ching, C. (2001). Affordances of collaborative software design planning for elementary students' science talk. *The Journal of the Learning Sciences, 10*(3), 323–363.

Kaminski, J. A., Sloutsky, V. M., & Heckler, A. F. (2008). The advantage of abstract examples in learning math. *Science, 230,* 454-455.

Kenyon, L., Schwarz, C., and Hug, B. (2008). The benefits of scientific modeling: Constructing, using, evaluating, and revising scientific models helps students advance their scientific ideas, learn to think critically, and understand the nature of science. *Science and Children, 46(2),* 40-44.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.

Klahr, D. (2005). Early Science Instruction. *Psychological Science, 16*(11), 871 -873.

Kotovsky, L. & Baillargeon, R. (1998). The development of calibration-based reasoning about collision events in young children. *Cognition, 67,* 311-351.

Kuhn, D. (1997). Constraints or guideposts? Developmental psychology and science education. *Review of educational research, 67*(1), 141.

Kuhn, D. (2010). What is scientific thinking and how does it develop? In U. Goswami (Ed.), *Handbook of childhood cognitive development.* Oxford: Blackwell. (2nd ed.)

Kloos, H., Fisher, A. & Van Orden, G. C. (2010). Situated Naïve Physics; Task Constraints Decide what Children Know about Density. *Journal of Experimental Psychology: General, 139*(4), 625-637.

Kloos, H., & Somerville, S. C. (2001). Providing impetus for Conceptual change: The effect of organizing the input. *Cognitive Development, 16,* 737-759.

Kloos, H., & Van Orden, G. C. (2005). Can a preschooler's mistaken beliefs benefit learning? *Swiss Journal of Psychology, 64,* 195-205.

Kuhn, T. (1996) *The Structure of Scientific Revolutions.* University of Chicago Press; 3rd edition

Lemke, J. L. (1990). *Talking science: Language, learning, and values.* Norwood, NJ: Ablex.

Light, P., & Simmons, B. (1983). The effects of a communication task upon the representation of depth relationships in young children's drawings. *Journal of Experimental Child Psychology, 35,* 81–92.

Linn, M. C.. & Burbules, N. C. (1988). RESPONSE to contradictions: Scientific reasoning during adolescence. *Journal of Educational Research, 80 (1),* 67-75.

Lucas, A. M. (1993). Constructing knowledge from fragments of learning?. In P. Black & A. Lucas (Eds.), *Children's informal ideas in science.* London and New York: Routledge.

Luken, E., Carr, V., & Brown, R. D. (2011). Playscapes: Designs for Play, exploration and science inquiry. *Children, Youth and Environments, 21,* 325-337.

Mantzicopoulos, P., Patrick, H., & Samarapungavan, A. (2008). Young children's motivational beliefs about learning science. *Early Childhood Research Quarterly, 23*(3), 378-394.

Muthukrishna, N., Carnine, D., Grossen, B., & Miller, S. (1993). Children's alternative frameworks: Should they be directly addressed by science instruction? *Journal of Research in Science Teaching, 30,* 233-248.

Mayer, R. E. (1989). Models for understanding. *Review of educational research, 59*(1), 43.

Mix, K. S. (1999). Similarity and numerical equivalence: appearances count. *Cognitive Development, 14,* 269-297.

Novak, J. D. (2010). *Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations (2nd. Ed)*. Mahwah, NJ: Lawrence Erlbaum Associates.

Novak, J. D., Gowin, D. B. (1984). *Learning How to Learn.* Cambridge: Cambridge University Press.

Ohlsson, S. (2011). *Deep Learning: How the Mind Overrides Experience.* NY: Cambridge University Press.

Pearl, J. (2009). *Causality: Models, Reasoning, and Inference.* 2nd ed. New York: Cambridge University Press.

Penner, D. E., Giles, N. D., Lehrer, R., & Schauble, L. (1997). Building functional models: Designing an elbow. *Journal of Research in Science Teaching*, 34(2), 125–143.

Penner, D., & Klahr, D. (1996). The Interaction of Domain-Specific Knowledge and Domain-General Discovery Strategies: A Study with Sinking Objects. *Child Development*, 67, 2709-2727.

Peterson, S. M., & French, L. (2008). Supporting young children's explanations through inquiry science in preschool. *Early Childhood Research Quarterly*, 23(3), 395-408.

Piaget, J., & Inhelder, B. (1974). The child's construction of physical quantities. London: Routledge and Kegan Paul.

Pfeiffer, D. (2012) Personal Communication.

Pramling, N., & Pramling-Samuelson, I. (2001). "It is floating 'cause there is a hole:" A young child's experience of natural science. *Early Years*, 21(2), 139–149.

Popper, K. R. (1959). *The Logic of Scientific Discovery.* New York: Basic Books.

Quinn, P.C., Eimas, S.L., & Rosenkrantz, S.L. (1993) Evidence for representations of perceptually similar natural categories by 3-month old and 4- month old infants. *Perception*, 22, 463-475.

Ratterman, M.J., Gentner, D., & DeLoache, J. (1990). The effects of familiar labels on young children's performance in an analogical mapping task. *Proceedings of the Twelfth Annual Conference of the Cognitive Science Society*, 22-29. Hillsdale, NJ: LEA.

Ratterman, M.J., & Gentner, D. (1998). The effect of language on similarity: The use of relational symbols improves young children's performance on a mapping task. In K.D. Holyoak, D. Gentner, & B. Kokinov (Eds.), Advances in analogy research: Integration of theory and data from the cognitive, computational and neural sciences (pp. 274–282). Sofia, Bulgaria: New Bulgarian University.

Schauble, L. (1990). Belief revision in children: The role of prior knowledge and strategies for generating evidence. *Journal of Experimental Child Psychology*, 49(1), 31–57.

Schilling, T.H. & Clifton, R.K. (1998). Nine-month-old infants learn about a physical event in a single session: Implications for infants' understanding of physical phenomena. *Cognitive Development*, 13, 165-184.

Schneps, M. H: (Producer, Director). (1987). A private universe (Film). Boston, MA: Harvard University and Smithsonian Institute.

Scott-Little, C., Lesko, J., Martella, J., & Milburn, P. (2007). Early learning standards: Results from national survey to document trends in state-level policies and practices. *Early Childhood Research & Practice*, 9(1).

Simons, D. J., & Keil, F. C. (1995). An abstract to concrete shift in the development of biological thought: the insides story. *Cognition* 56, 129-163.

Sloutsky, V. M., Kaminski, J. A., & Heckler, A. F. (2005).The advantage of simple symbols for learning and transfer. *Psychonomic Bulletin & Review, 12*, 508-513.

Smith, C., Snir, J., & Grosslight, L. (1992). Using conceptual models to facilitate conceptual change: The case of weight-density differentiation. *Cognition and Instruction*, *9*(3), 221–283.

Smith, C., & Unger, C. (1997). What's in dots-per-box? Conceptual bootstrapping with stripped-down visual analogs. *The Journal of the Learning Sciences*, *6*(2), 143–181.

Son, J. Y., Smith, L. B., & Goldstone, R. L. (2008). Simplicity and generalization: Short-cutting abstraction in children's object categorization. *Cognition, 108,* 626–638.

Thagard, P. (2000). *Congruence in Thought and Action.* Cambridge, MA: MIT Press.

Tytler, R., & Peterson, S. (2000). Deconstructing learning in science – young children's responses to a classroom sequence on evaporation. *Research in Science Education, 30*(4), 339–355.

Uttal, D. H., Liu, L. L., & DeLoache, J. S. (1999). Taking a hard look at concreteness: do concrete objects help young children learn symbolic relations? In L. Balter & C. Tamis-LeMonda (Eds.), *Child psychology: A handbook of contemporary issues* (pp. 177-192). Philadelphia: Psychology Press.

Uttal, D. H., Scudder, K. V., & DeLoache, J. S. (1997). Manipulatives as symbols: A new perspective on the use of concrete objects to teach mathematics. Journal of Applied Developmental Psychology, 18, 37–54.

Venville, G. (2004). Young children learning about living things: a case study of conceptual change from ontological and social perspectives. *Journal of Research in Science Teaching,41*(5), 449-480.

Vosniadou S. (Ed.), 2008. *Handbook of research on conceptual change*. Hillsdale, NJ: Erlbaum.

Vosniadou, S. & Brewer, W. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, 24, 535–585.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, 4, 45–69.

Wiser, M., & Smith, C. L. (2008). Learning and teaching about matter in grades K-8: When should the atomic-molecular theory be introduced. *International handbook of research on conceptual change*, 205–239.

Witt, S. D., & Kimple, K.P. (2008). 'How does your garden grow?' Teaching preschool children about the environment. *Early Child Development and Care*, *178*, 41-48.

Worth, K., & Grollman, S. (2003). *Worms, shadows and whirlpools: Science in the early childhood classroom.* Portsmouth, NH: Heinemann.

Zembylas, M. (2008) *Affect and early childhood science education.* Contemporary Perspectives on Science and Technology in Early Childhood Education, 65-85. Information Age Publishing.

Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental Review*, *20*(1), 99–149.