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Scientists not Sponges: STEM Interest and Inquiry in Early Childhood

J. L. Jipson,[1] M. A. Callanan[2], G. Schultz,[3] and A. Hurst[3]

[1]*Department of Psychology and Child Development, California Polytechnic State University, San Luis Obispo, California 93407, USA*

[2]*Department of Psychology, University of California Santa Cruz, Santa Cruz, California 95064, USA*

[3]*Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, California 94112, USA*

Abstract. Young children are fascinated by the natural world. They explore endlessly, with both a sense of wonder and determination, usually in self-directed investigations or informal interactions with peers and adults. Capitalizing on this early period of spontaneous interest and inquiry is critical to efforts to promote lifelong STEM literacy. To inform education and public outreach efforts, it is important to consider common assumptions about how children of this age learn and consider how such assumptions influence the ways we support children's learning. Four metaphors for children learning are investigated in this paper: the young child as sponge, the young child as unlit match, the young child as scientist, and the young child as apprentice. As we critically evaluate these views on learning, we share research findings from developmental psychology that demonstrate that children's engagement with STEM begins well before kindergarten, that children between three and five years of age develop surprisingly sophisticated scientific reasoning capacities and conceptual knowledge, and that parents play an important role in structuring and supporting preschool children's learning.

1. Introduction

Attention to the potential of the preschool years to provide a foundation for STEM learning is critical to efforts to promote lifelong STEM literacy. Despite earlier assumptions that scientific thinking is not possible before adolescence, recent research in developmental psychology demonstrates that children's engagement with STEM begins well before kindergarten, and that by three years of age children develop surprisingly sophisticated scientific reasoning capacities and conceptual knowledge (Gopnik 2010). With regard to astronomy learning, specifically, research shows that preschool children are interested in astronomy-related topics and are amassing specific content knowledge (accurate and inaccurate) in this domain. They typically gain these understandings through self-directed explorations and informal interactions with others, with substantial variation in the resources and support they receive for such activities (Callanan & Oakes 1992; Jipson 2001; Kallery 2011; Maria 1997). To complement and extend these spontaneous, everyday learning moments, informal science education practitioners at the Astronomical Society of the Pacific are working with learning researchers at the University of California Santa Cruz, Cal Poly San Luis Obispo, and Penn State to develop a set of astronomy learning activities for informal science educators to use with young children and their families. To ensure that these activities are solidly grounded in research and theory in developmental psychology and early childhood education, the collaboration found it useful to explicitly examine prevailing metaphors for how preschool children learn. If left unexamined, these metaphors shape our thinking about how children learn and, as a result, influence the strategies we adopt in supporting children's learning. In the following sections, we evaluate four metaphors for children's learning: young child as sponge, young child as unlit match, young child as scientist, and young child as apprentice. We provide examples of the use of each metaphor in public and professional settings, we consider the assumptions each of these metaphors makes about the role of the child, adults, and peers in children's learning, and we examine how these metaphors hold up in light of empirical evidence on preschool children's STEM-related interests and understandings, with an emphasis on astronomy.

2. Metaphor #1: Young Child as a Sponge

Many people endorse the well-intentioned metaphor of children as little sponges, readily and rapidly absorbing information from the world around them. One example of the power that this metaphor holds over our thinking about young children's learning comes from a public service announcement (PSA) produced by First Five California, a well-respected government program that advocates for children by providing programs to "educate parents and caregivers about the important role they play in their children's first years."[1] Video images in the "Children Are Like Sponges" PSA show children imitating the behaviors of their parents, with a voice over saying: "Children are like sponges. Absorbing everything around them. Especially from you. Model good and healthy behavior. Give your child the best start in life." The goal of this campaign is clearly to promote positive developmental outcomes by helping parents reflect on how their own behaviors influence the behaviors of their children. Another striking example of this metaphor is the "Sponge School," a Seattle-based school that offers language classes to young children, where the very name of the school reflects the belief that young children are "language sponges," capable of learning with efficiency and ease.

The First Five PSA and the Sponge School explicitly endorse the common view of children as sponge-like in their learning abilities. These are but two examples of the ubiquitous use of the sponge metaphor in modern public discourse about young children's learning. Critique of this metaphor centers around the passive role assigned to children in the learning process. Children, in this view,"absorb" and "soak up" information in a manner consistent with a transmission model of education in which learners' minds are presumed to be empty vessels, knowledge is assumed to exist independently of the learner, and the educator is thought to control the learning process through the dissemination of knowledge. In schools, this model is implied when educators adopt a lecture format in which teaching and learning occurs when an expert "delivers" information to a novice who then "receives" that information.

Research in developmental psychology and early childhood education challenges the use of the sponge metaphor to describe young children's learning. In the field of

[1] `http://www.ccfc.ca.gov`, paragraph 2

language development, for example, children do go through an apparently sponge-like "vocabulary spurt" in the second year of life in which word learning accelerates dramatically. Closer investigation of even this remarkable achievement, however, shows that children's language learning is an active process in which children actively evaluate the "input" from the world around them. For example, Koenig and Harris (2005) demonstrated that children consider the source before attaching a new label to an object in the world; they resist learning words from speakers who have been wrong in the past. In addition, children under three years of age have a difficult time learning words from television (Roseberry 2009) but can do so readily during a video chat (Roseberry 2010), suggesting that mere exposure to language "input" is insufficient for word learning and that contingent interactions are essential.

Within the domain of astronomy, evidence exists that young children's thinking is more complex than a sponge metaphor might have one believe. For example, preschool children typically answer the question, "what shape is the Earth?" with responses such as "circle," "round," or "ball." Such responses could reflect children's accurate learning about the Earth's shape by absorbing the information provided in their environment (e.g., adult language, globes and satellite photos). Jipson, however, found that further questioning of preschool age children often revealed conversations like this:

> Experimenter: "What shape is the Earth?"
> Child: "A circle."
> Experimeter: "Here is a picture of a house. The house is on the Earth, isn't it?"
> Child: (nods)
> Experimenter: "How come the Earth here is flat, but you said it's a circle?"
> Child: "Well, because that's grass."
> Experimeter: "Can you explain that a little bit more?"
> Child: "Well, the Earth is up there and the world's down here."

This child seems to have a "dual earth" concept of one flat world we live on and another round earth in the sky. This way of thinking about the Earth is consistent with Vosniadou and Brewer's (1992) findings that, en route to developing an understanding of the Earth as a sphere, many children articulate alternative mental models. The alternative models reflect active effort to reconcile information obtained from everyday sensory experiences (e.g., the Earth is flat) with abstract, scientific information provided by others (e.g., the Earth is a sphere). In Jipson's research, 82% of four-year-olds expressed creative models incorporating information that the Earth is round yet looks flat into their understanding of the Earth's shape. One example is the dual earth model above. Only 12% of the four-year-old children had a spherical understanding, and only 6% understood the Earth to be a flat rectangle. The finding that children generate such creative interpretations of the Earth's shape provides evidence that children are doing more than "absorbing" information from the world around them.

3. Metaphor #2: Young Child as Unlit Match

In contrast to the Young Child as Sponge view, the Young Child as Unlit Match metaphor is rarely articulated explicitly. Rather, this metaphor emanates from a reaction to the sponge metaphor, as expressed in the following quote often attributed to William Butler Yeats: "Education is not the filling of a pail, but the lighting of a fire." This quote appears to resonate with the general public, as measured by the number and variety of products upon which it appears (e.g., coffee mugs, magnets, t-shirts). It also seems to be accepted by some early childhood educators, as evidenced by a recent Community Playthings catalog entitled "Lighting the Fire" which promotes the value of hands-on investigation, play and outdoor learning.

The quote upon which the unlit match metaphor is based argues against the transmission model of learning (education is not filling an empty vessel with knowledge), yet still attributes a passive role to children. Comparing children to unlit matches suggests that they are full of potential and just need to be "lit" by an inspiring teacher or parent. This metaphor reflects the familiar assumption that educators are responsible for initiating interest and inquiry.

Although adults likely play a role in introducing children to new content areas, the child as unlit match metaphor fails to account for the natural curiosity of early childhood. Developmental psychologists know that for young children, the spark that ignites learning is already there. Chouinard (2007) investigated children's questions and found that when actively engaged with an adult, three to four-year-old children asked an average of 76 information-seeking questions per hour. Callanan and her colleagues also examined children's questions to shed light on the topics that they found interesting. In two studies with three different demographic samples, she revealed that about 50% of children's questions were about natural phenomena, biological phenomena, and physical mechanisms (STEM-related questions) and the other 50% were about human motivation, behavior, and cultural conventions (Callanan & Oakes 1992; Callanan et al. 2013). When looking specifically for children's questions about astronomy, Callanan found that approximately 30% of children asked at least one question about such topics as the Sun, Moon, stars, planets, seasons, weather. For example, one four-year-old child asked, "How come the Moon is big and orange now but other times it is little and white?" The mother reported that after she responded with a long explanation about gases, her child asked "does it ever get green?" and "why is it sometime round and sometimes not?"

Several additional studies show that young children ask questions in order to get desired information, not to drive adults crazy. Chouinard (2007) reports that children are persistent in seeking answers to their questions, and they do not easily give up when adults do not respond satisfactorily. Similarly, Frazier et al. (2009) found that when children received non-explanatory responses to their causal questions, they were more likely to re-ask the original question. When they received explanatory answers, they asked follow-up questions (as in the Moon example above).

In sum, empirical evidence challenges the unlit match metaphor by revealing that young children are already curious about many facets of the world around them. They do not always need someone to inspire their learning. Rather, they may need support in stoking existing fires to maintain and extend their initial interests. In addition, however, sometimes educators and parents are lighting fires, perhaps because the original flames have been dampened by experiences that do not support learning. Recent research in developmental psychology suggests that adults' responses to children's efforts can influence intrinsic motivation. Dweck (2007) revealed that when adults support children by praising effort (e.g., "you worked really hard to finish making that" or "you're really concentrating on that book right now") rather than ability (e.g., "you're really good at reading" or "you're smart"), children are more likely to try difficult tasks, perhaps with less fear of losing their reputation as a "smart kid" or "good reader."

4. Metaphor #3: Young Child as Scientist

Comparisons between children and scientists are common in academic publications, educational resources, and popular media. Brewer (2008) published a chapter exploring this metaphor entitled, "In what sense can the child be considered to be a little scientist?" Other academics have used the child as scientist metaphor to bridge developmental research and theory with educational practice, such as Chaille and Britain's (2002) "Young Child as Scientist" and Gelman et al.'s (2009) "Preschool Pathways to Science." In the popular media, Sid the Science Kid entertains viewers with his curiosity and scientific approach to seeking answers.

The allure of the child as scientist metaphor lies in its appreciation of children's natural curiosity, and its recognition that children spontaneously observe and experiment as they attempt to understand the world around them. This metaphor is consistent with Piaget's constructivist theory: learning is described as an active process of evaluating and organizing new information in light of existing understandings. According to constructivist theory, an important additional motivator for learning is that children's observations and inquiries provide them evidence that puts them in a state of puzzlement. As Isaac Asimov once said, "The most exciting phrase to hear, the one that heralds new discoveries, is not 'Eureka!' (I found it!) but 'That's funny... ' " Cognitive conflict motivates learning in both scientists and children.

Empirical evidence in support of the child as scientist metaphor is abundant. Callanan and Oakes (1992) offer one notable example of children's spontaneous scientific thinking. In their study, a mother reported being asked the following question by her young child, "Why does Daddy, James, and me have blue eyes and you have green eyes?" The mother told her daughter that she got her eyes from Daddy, said goodnight and left room. After a few minutes, the child called her mother back and exclaimed, "Mom!!! I like Pee Wee Herman and I have blue eyes. Daddy likes Pee Wee Herman and he has blue eyes. James likes Pee Wee Herman and he has blue eyes. If you liked Pee Wee Herman you could get blue eyes too! Could you try to like Pee Wee Herman so we could see if your eyes turn blue?" This example is striking because, despite this four-year-old's naive understanding of the potential causes of eye color, she is sophisticated in her observations of the world, identification of regularities, and application of the scientific method. Many other studies support the conclusion that preschool children engage in scientific thinking in a variety of ways. For example, children seek explanations, categorize objects in the world, reason about cause and effect (including making assumptions about nonvisible causal mechanisms), and construct theories based on their interpretation of evidence (Gelman 2005). This body of research provides convincing support for the young child as scientist metaphor. In fact, recent research suggests that even infants have some core knowledge and processes that could support STEM learning (Carey 2011, Gopnik 2010). One limitation of the scientist metaphor, however, is that it seems to conceive of both children and scientists as engaging in individual pursuits of knowledge. The final metaphor for learning recognizes the social nature of young children's (and scientists') learning.

5. Metaphor #4: Young Child as Apprentice

An informal Internet search reveals that the apprenticeship metaphor is perhaps more often invoked in conversations about higher education and craftsmanship than in discussions of children's learning. An exception is Rogoff's (1990) book, "Apprenticeship in Thinking" in which she uses a sociocultural lens to reflect on how children's learning is supported by others more expert than themselves and by the culturally structured activities in which children engage. Inspired by Vygotsky (1978), contemporary sociocultural approaches (Rogoff 2003; Wertsch 1979), argue that accounts of children's developing understanding of the world are not complete without attention to the social context of their early learning and thinking.

Reflecting on science learning through the lens of the apprentice metaphor can help us to understand how families with young children structure their engagement in science learning activities. Studies of dinner table conversations, visits to the zoo, and other everyday activities, for example, have uncovered rich conversations on a myriad of scientific topics and demonstrate that families use scientific forms of discourse to varying extents (Blum-Kulka 1997, Callanan, Shrager, & Moore 1995). Research on how parents, specifically, support children's science learning is particularly relevant when considering preschool children's apprenticeship experiences in science-learning environments, as well as in settings not explicitly marked as related to science learning. This body of research provides evidence that supports the use of the apprenticeship metaphor. For example, Crowley et al. (2001) found that children's exploration was more extensive when young children engaged with parents than alone. Many others have discovered that although parents rarely articulate complex scientific principles, they frequently provide fragments of information that may help children's knowledge construction (Callanan & Jipson 2001; Crowley et al. 2001). Other research finds that parents are more likely to treat children "as if" they understand than to offer detailed explanations, and by doing so may be providing children with a moment of cognitive conflict that spurs on further learning (Callanan, Jipson, & Soennichsen 2002).

Examples of parent-child conversations from Callanan and Oakes (1992) and Callanan et al. (2013) demonstrate the importance of considering how children construct understandings of astronomy in the context of interactions with others. The first two examples show children's attentiveness to patterns in the sky, and curiosity about astronomical objects and events. In these examples, the children interact with an engaged parent, however the parents' responses seem to guide children away from thinking about the relevant scientific causal mechanisms.

> Child: "Why does it get dark?"
> Mom: "Because God made this world and he made it with a day and a night."
> Child: "Why is the light gone?"
> Mom: "It has to get dark because we have to sleep."
> Child: "Why is there Sun?"
> Mom: "During the day the Sun comes out because we have to go to work and go to school."

In the next example, a parent provides her curious child with an incorrect explanation, yet one that may encourage thinking about movement of the Earth as it relates to the position of the Sun:

> Child: "Why is there a day and a night?"
> Mom: "The rotation of planets. If Earth passes close to the Sun it is day, and when it goes away it is night."

In this final example, the parent adopts a clear science learning agenda in her efforts to respond to her child's interest in astronomy.

> Child: "How big is the Sun?"
> Mom: "It's very very big."
> Child: "Is it bigger than the whole world?"
> Mom: "Oh yes, many times bigger!"
> Child: "Does the Sun go around the world to keep the world warm?"
> Mom: "No the Earth goes around the Sun but at the same time the Earth rotates" (she showed him with two balls).

These conversations illustrate preschool children's spontaneous interest in astronomy, and variation in parents' responses to their questions. In designing astronomy activities for young children, this work encourages us to communicate astronomy concepts clearly to parents in ways that appear understandable for children.

6. Summary

In summary, young children are fascinated by the natural world. They explore endlessly, with both a sense of wonder and determination, usually in self-directed investigations, or informal interactions with peers and adults. Capitalizing on this early period of spontaneous interest and inquiry is critical to efforts to promote lifelong STEM literacy. To do so effectively, we argue that it is important to explicitly evaluate one's assumptions about how children learn, and to become familiar with research on children's STEM learning that can inform the selection of appropriate education and public outreach strategies.

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