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Inconsistencies in Early Science Education: Can Nature Help Streamline State Standards?

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Abstract

An analysis of U.S. preschool science standards shows persistent disagreement on what to cover during the preschool years. Such inconsistency hampers progress for science learning and pedagogy, calling for a shared foundation on how to define science in preschool. We propose that children's play in nature can provide the basis for such a shared foundation. Our proposal builds upon both theoretical and practical considerations. Specifically, we derive our theoretical argument from insights about cognitive development, positing that the complexity of natural surroundings is ideal to increase children's attention and memory. Our practical argument is derived from findings with preschool teachers. Preschool teachers were asked to rate (1) their attitudes towards science learning, and (2) their self-efficacy related to a nature-based science curriculum. Results show that teachers could easily see the benefit of science learning in preschool, but that they perceived significant challenges with classroom-based science curricula for young children. In contrast, most teachers felt very comfortable with nature-based science learning. Based on these insights, we develop a framework of science standards that starts with explorations in nature. Unique opportunities lie in *playscapes* – playgrounds to which natural elements are added strategically.

Highlights

- Three analyses are reported, guided by the overarching question about whether nature can help streamline state standards on preschool science education.
- The first analysis is on current state standards. It reveals (1) inconsistencies across states and (2) a lack of regard for learning difficulty.
- The second analysis is on key determinants of learning. It reveals the importance of (1) input variability and (2) input stability, both of which are present at ideal levels in nature.
- The third analysis is on attitudes and self-efficacy of preschool teachers regarding science pedagogy. It reveals that teachers (1) perceive some challenges with science pedagogy, and (2) would be comfortable with including nature in science pedagogy.
- Together, these insights point to an organizational framework for early science learning that is based in nature.

Introduction

"Watch nature and you'll understand everything."
("*Schau dir die Natur an und du wirst alles verstehen.*")
Albert Einstein

Science literacy is a well-defined academic subject, with consistent expectations for elementary and secondary school across the U.S. (National Research Council, 2012). Reflecting its ubiquity, science learning can start as early as preschool – long before mandatory science education is implemented (Gopnik & Wellman, 2012; Kloos, Baker, Luken, Brown, Pfeiffer, & Carr, 2012; National Research Council, 2009). Yet, expectations for what children should learn during preschool are not established uniformly across states in the U.S. The goal of this paper is to explore whether nature can serve as a guide to organize state standards for science.

Research suggests that exposure to nature can have positive effects on children. For example, exposure to residential greenness was associated with better attention, cognition, and memory in preschool- and school-aged children (Berman, Jonides, & Kaplan, 2008; Dadvand et al., 2017; Kahn & Kellert, 2002). Moreover, measures of electrical brain activity indicated that more cognitive resources were needed indoors in comparison to outdoors (Torquati, Schutte & Kiat, 2017). Thus, self-guided play in nature may provide a productive starting point for science learning among young children (Educational Development Center, 2013; Elliott, 2017; Tsunghui, 2006).

To explore how nature could help streamline the recommendations for preschool science, we report three separate analyses. The first analysis (Section A) is on existing state standards, namely to explore how science is currently defined for preschool curricula. We then focus on what nature has to offer in terms of attainable science learning, looking specifically at naturalized playgrounds and playscapes (Section B). Finally, we analyze data obtained from preschool teachers on the perceived value of nature-based science learning (Section C). While this three-prong format is arguably unusual for a research paper, it best allows for a comprehensive motivation of nature-based science standards. Following the three analyses, we will elaborate on a proposal for science standards (Section D).

A. State Standards for Preschool Science: A Time-Lag Content Analysis

Our first analysis focuses on the state standards guiding preschool science learning since 2015. Our specific questions are: (1) What are preschoolers expected to do when exploring science themes? And (2) What are preschoolers expected to learn about scientific content? The distinction between exploratory activities and learning of science content is in line with the well-known distinction between science inquiry and science truisms (cf. Zimmerman, 2000). According to this distinction, science inquiry involves the generation of scientific knowledge (e.g., through observation, description, prediction and testing, causal inferences), and scientific truisms involves the learning of already-established content.

Our method was to compile all pertinent science standards at two time points. The first wave of data on state standards was collected in December 2015. At the time, standards were publicly available in all but two states: Kentucky and South Carolina[1]. The second wave was collected two years later, in December 2017. At this point, all 50 states had put forward science standards for preschools. Appendices A and B provide details on individual states (2015 and 2017, respectively).

Notably, the mere lengths of the complied documents differed widely. For some states, the recommendations contained a small list of items (e.g., 2 bullet points for North Carolina), and for other states, the recommendations were multiple pages long (e.g., Massachusetts). The average word count of the 2015 standards was 198 (SD = 142.3 words), and the average word count of the 2017 standards was 268 (SD = 183.2). There was also inconsistency in how science is defined. Of the 48% of states that offered a definition in 2017, some definitions were very broad (e.g., "Science is about finding out how the world works"), whereas other definitions were detailed and specific (e.g., "Science is a way of understanding the physical universe using observation and experimentation to explain natural phenomena").

To get a pictorial representation of the concepts present in science recommendations, we created a word cloud of the combined standards. We first removed articles and numerals and merged related words to their most common instance (e.g., the words 'observe', 'observes', 'observed', and 'observing' were all changed to 'observe'). We then counted the frequency of each word to determine its relative size in the word cloud. As an example, Figure 1 shows an outcome from the 2015 data in a word cloud. The most common words that appeared in science standards include: 'objects', 'observe', 'use', 'explore', 'describe', 'environment', 'investigate', 'materials', 'living', 'physical', and 'earth'. A large number of words appeared in only a few state standards (e.g., 'heat', 'cause', 'generate').

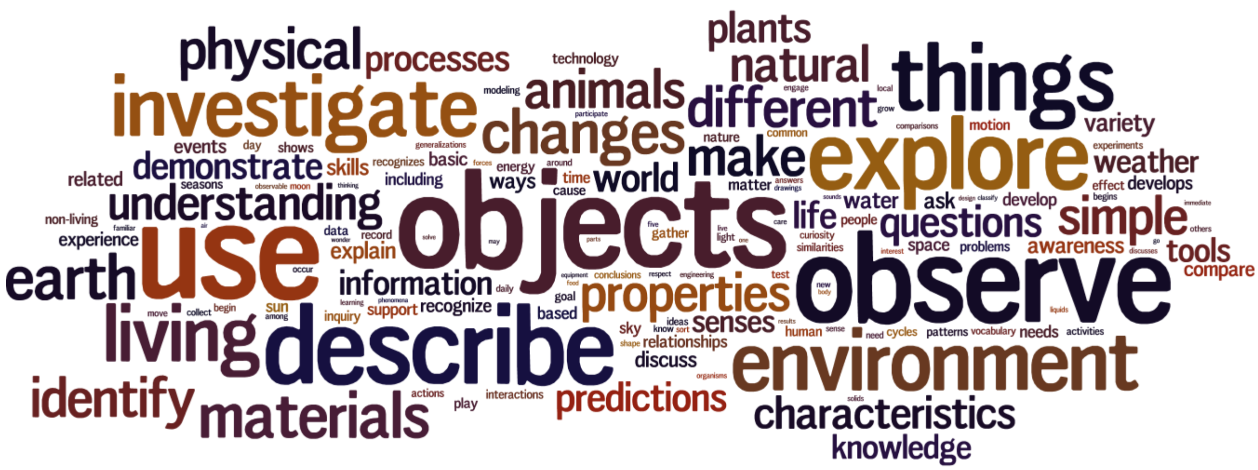

Figure 1. Word cloud obtained from the 2015 state standards, illustrating the frequency of each term across the standards. Larger font indicates higher frequency.

[1] In 2015, Kentucky mentioned science as a recommended topic in preschool alongside domains such as social studies, music, and math.

1. <u>Science Inquiry: What are preschoolers expected to do when exploring science themes?</u>

In order to quantify the level of inquiry expected for preschoolers, we devised a 4-level scale. The lowest level of inquiry merely requires children to observe, explore, or be curious about science phenomena, without creating knowledge of their own. In contrast, the highest level of science inquiry pertains to generating explanations and detecting cause-effect relations. The two intermediate levels of inquiry are to describe phenomena (Level 2) and to test predictions (Level 3). Figure 2 shows the variation in these levels across the U.S. science standards.

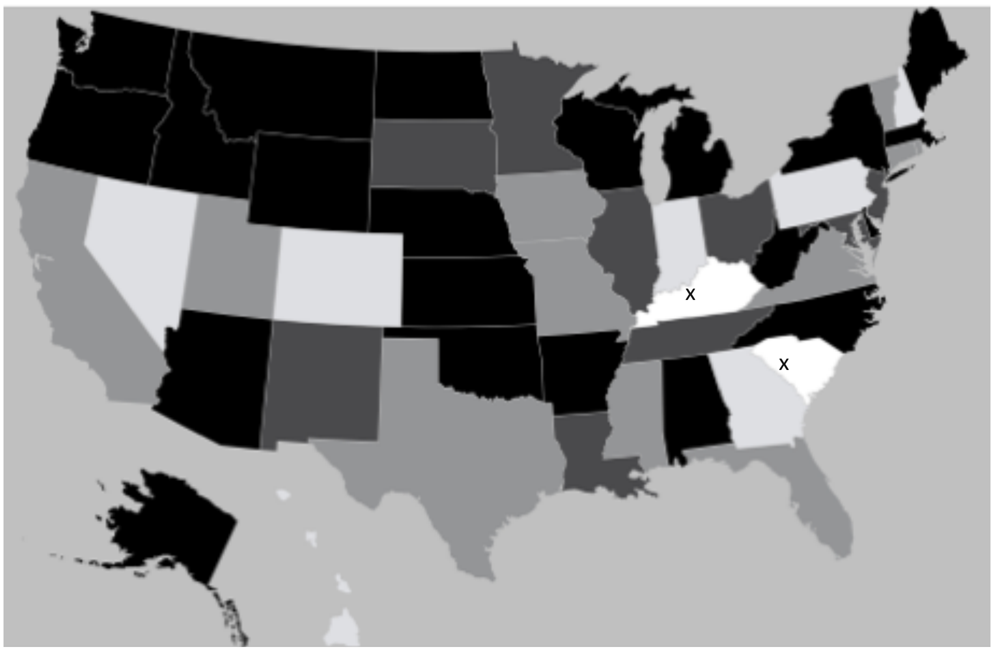

Figure 2. Level of inquiry recommended in the 2015 U.S. state standards. Level 1: Observation; Level 2: Description; Level 3: Testing Predictions; Level 4: Generating Explanations. “x” indicates the states that lacked designated science standards.

Although nearly all states (94%) mentioned some form of scientific inquiry (e.g., being curious, exploring, observing), only about half of them (58%) highlighted components of the scientific process that are central to testing predictions and drawing conclusions (Levels 3 and 4, respectively). The highest level of inquiry (to generate explanation) was recommended in 42% of the states; and the lowest level of inquiry (to explore and observe) was recommended in 16% of the states. From 2015 to 2017, the recommended levels of inquiry increased slightly. The two states without recommendations in 2015 recommended the highest level of inquiry in 2017. Eight states increased their recommendations by one or two levels (5 and 3 states, respectively). The remaining 40 states had no change in inquiry level.

2. <u>Science Truisms: What are preschoolers expected to know about science?</u>

When it comes to science truisms, there are typically three broad content domains listed: life science, physical science, and earth/space science (see Table 1). Life science is concerned with species, growth and decline, and ecosystems. Physical science is concerned with the composition of materials and the principled behavior of materials under different circumstances. Finally, earth/space science is concerned with large-scale terrestrial events, such as the water cycle, the Earth's shape, and Earth's relation to other bodies in space.

Table 1
Existing Organization of Science Domains

Science Inquiry: observation, description, prediction and testing, causal inferences		
Science Truisms: labels, patterns, rules, hidden features, associations, explanations		
Life Science	Physical Science	Earth/Space Science
Living things and their environments	States of matter (solid, liquid, gas)	Weather (hot, cold, rain, snow, sun)
Comparison of living things	Energy (light, electricity)	Day/night cycle (sun, moon)
Ecosystems	Motion and stability	Seasonal changes
Growth of organisms	Features of objects (texture, weight)	Geology (mountains, rocks, soil)

Note. The examples listed are typical in science standards. Other examples and topics, not listed here, can be found across the state standards.

The three content domains were mentioned in nearly all state standards. For example, in 2015, content from the domain of life science was listed by 84% of the states, physical science was listed by 84% of the states, and earth/space science was listed in 78% of states. Two additional content domains appeared in some states: One domain pertains to issues of technology and/or engineering, listed separately in seven state standards. Another domain pertains to issues of the environment and/or society (e.g., "environmental conservationism"), listed as a separate science domain by two states.

From 2015 to 2017, the number of states that listed the three broad content domains increased slightly. Importantly, the variability among states remained large. For example, of the 23 unique topics we identified (e.g., motion, weather, parts of the human body), no state required more than half of them (% coverage: M_{2015} = 23, M_{2017} = 28, $SD_{2015/7}$ = 18). Similarly, no individual topic in 2015 was mentioned by more than 62% of the standards, further illustrating the wide discrepancy among states.

In terms of organization by concept difficulty, there was surprisingly little done. In fact, 32% of state standards explicitly claimed that science ability is innate (e.g., "every young child is a natural scientist and engineer", "children are scientists from the moment they are born"). This implies that all science concepts can be learned equally well. Indeed, state standards list recommended topics without consideration of how they might build upon each other. Preschool teachers are left with little more than a list of topics to cover.

In sum, the analysis of state standards yielded two important shortcomings. First, there was a large discrepancy between state recommendations, whether in the definitions of science, the levels of inquiry, the organization of content into domains, or the choice of science truisms to be learned. Second, none of the standards were organized by conceptual difficulty or students' developmental progress. Instead, the typical organizational framework was based on topical distinctions, often not more than a list of unorganized topics. Overall, the findings highlight the need for a new organizational framework to guide early science standards.

B. Science in Nature: An Analysis of Learning Difficulty

As a means of addressing the problems with existing state standards, we turn to nature and its potential advantages for early science learning (Beery & Jørgensen, 2018; Lee, 2013). Two questions guide this second analysis: (1) What are the science concepts in nature that children are typically surrounded by? And (2) Why is nature ideal for learning?

1. <u>Playscapes: What type of science is available in nature?</u>

Nature comes in very different forms (see Müller & Liben, 2017). In a rural area, nature is abundantly available, whether it be as fields, forests, lakes, creeks, or swamps. In urban areas, on the other hand, nature may be confined to backyards and parks that lack natural water sources. Preschool playgrounds might have only minimal natural features; and nature inside the classroom might be limited to a pet or a plant. For our purposes, we focus on forms of nature that exist in a *playscape*: a kind of playground that includes natural elements (see Fig. 3).

Figure 3. Images of two playscapes, one located in a rural area and one located in an urban area.

Playscapes have recently received increased attention in preschool education, the emphasis being on exposing children to nature that has the safety of a playground (Carr & Luken, 2014; Elliott, 2008; Moore, 2014). Playscapes are nature-rich landscapes and ecologically-designed spaces for young children to play in (Luken, Carr, & Brown, 2011). They are bounded areas that emulate the native flora and fauna. Key features include water (e.g., streams, fountains, wading ponds), indigenous plants, unlevel topography, and gardens that are accessible to young children. Smaller playscapes could be confined to just butterfly gardens, whereas elaborate playscapes could contain entire ecosystems.

Playscapes are likely to positively affect children's cognition. For example, playscapes offer preschoolers the chance to exercise executive function skills, including goal-setting, problem-solving, self-regulation, focused attention, and cognitive flexibility (Carr, Brown, Schlembach, & Kochanowski, 2017). Similarly, preschoolers were more likely to explore materials and living things on playscapes than playgrounds, for example by looking under rocks and logs and throwing loose parts into the water (Wight, Kloos, Maltbie, & Carr, 2016). They even used science-specific language related to the proper naming of plants and animals (e.g., 'honeysuckles', 'ants', 'butterflies', 'woodpeckers'). This, in turn, might promote reflection to share with peers, parents, and teachers.

In terms of science content available on playscapes, concepts from life science are perhaps most readily accessible. For example, playscapes expose children to grass, flowers, trees, insects, spiders, worms, snails, birds, and so on. They also allow children to explore food webs and the life cycle (e.g., 'butterflies drink nectar'). At yet another level, available science content includes the chemistry of life, the functioning of cells, and growth (e.g., 'plants turn light into food'). A playscape even harbors concepts of physical and earth/space science: material composition, rocks, soil, night-and-day cycles, seasons, and weather. Thus, playscapes provide opportunities for science learning that may not be available in classrooms or on traditional playgrounds.

2. Key Determinants of Learning: Why is nature ideal for learning?

Before developing a nature-based preschool science curriculum, the issue of learning difficulty needs to be addressed. In the remainder of this section, we outline theoretical advances in cognitive development that speak to the question of learning difficulty. These advances challenge the idea that children's cognitive development occurs in fixed stages (e.g., Piaget & Inhelder, 1969). Instead, they are in line with the idea that knowledge emerges in conjunction with the surroundings children are immersed in (Barsalou, 2008; Geary, 2005; La Cerra & Bingham, 2002; Thelen & Smith, 1996). Thus, the emphasis is on describing the surrounding, more so than the child's readiness, to establish learning difficulty.

At the most elemental level, context can be described in terms of two features: (1) the amount of *variability* in the surrounding (i.e., change, difference, novelty) and (2) the amount of *stability* in the surrounding (i.e., patterns of order, symmetry, common threads from one experience to the next). To elaborate, consider a typical preschool classroom. The walls are likely to feature colorful displays, and the shelves are likely to hold objects of different shapes, sizes, functions, and materials. Many of these classroom entities remain stable over time, arranged in consistent configurations. The differences in colors, shapes, etc. constitute the variability in a child's surrounding. In contrast, the patterns and predictable events that stay the same over time constitute the stability in a child's surrounding.

Variability and stability in the surrounding are fundamental to understanding learning (Rączaszek-Leonardi, 2016; Riley & Turvey, 2002). Specifically, the presence of variability affects children's attention: The more novelty, differences, or change in a child's surrounding, the more the child's attention will be drawn to these features (e.g., Posner, Rothbart, & DiGirolamo, 1998). On the other hand, stability influences children's memory: The more obvious a repeating pattern of predictable events is, the more likely it is that children will be able to remember it (e.g., Nelson, 2005).

Incidentally, nature offers an ideal amount of variability and stability for science learning. There is relevant variability in colors, shapes, sizes, textures, sounds, and so on, without being overwhelming. And there are relevant stable arrangements, routines, and patterns without being monotone. In fact, variability and stability occur on many different scales, ranging from the details on a single entity to the global gist of an ecosystem or the weather. For example, the same amount of variability is present, whether the child explores a leaf close up or 'zooms out' to look at a tree from a distance. Known as fractality, this nested hierarchy of variability and stability can accommodate individual differences among children, promoting learning for children who differ in readiness (Stephen, Arzamarski, & Michaels, 2010).

In line with the idea of fractal richness in nature, Van Wieren & Kellert (2013) highlighted "nature's diversity, information richness, dynamism, uncertainty, multi-sensory quality, and above all aliveness" as important qualities of children's experiences of nature (p. 262). Nature also appears coherent and organized. For example, children's description of nature included "a sense of *beauty* (including the related dimensions of balance, symmetry, color, and information richness), *pattern and order* (including the related dimensions of harmony and organized complexity) and a sense of *wonder and discovery* (including the related dimensions of curiosity, imagination, and creativity)." (Van Wieren & Kellert, 2013; p. 251). Thus, it might be the presence of the variability and stability in nature that explains why humans are attracted to natural events (cf. Heft, 1988; Kellert, 2015; 2018; Kellert & Wilson, 1993; Wilson, 1984).

In sum, the human mind is equipped to pay attention to whatever changes in a surrounding, and it is equipped to remember what remains the same. This complexity of variability and stability available in nature is ideal to enhance children's learning. Indoor science centers, on the other hand, may sometimes lack the right complexity and thus can compete for attention with other areas of the preschool (Dodge, 2010). Before turning to the organizing framework that is implied by these considerations, we report on one more analysis: the perceived feasibility of nature-based science learning, as viewed by preschool teachers.

C. Feasibility of Nature-Based Science Learning: Findings with Preschool Teachers

Given insights about the key determinants of learning, we showed how nature offers unique opportunities for learning. In this final analysis, we will turn to practical considerations about science learning in nature. The thought is that a certain level of comfort level is needed for teachers to be able to support children's science learning in nature. A barrier to nature-based science learning could arise from teachers' attitudes towards science and their comfort levels with nature. Our last analysis is designed to address this issue. Two questions were of specific interest: (1) What are teachers' views on science curricula in preschool? And (2) How confident are teachers about incorporating nature in children's science learning?

Input was obtained from 23 preschool teachers, all of whom were familiar with playscapes. Teachers were recruited from four different preschools, two located in an urban neighborhood, and two located in a rural environment. One school was exclusively Head Start, one school was majority Head Start, one school offered a mix of Head-Start and tuition-paying options, and one school was exclusively tuition-based. Most teachers were women (87%) and most were Caucasian (83%). Regarding their age, 55% of the teachers were younger than 40, and 21% of the teachers were older than 50. Teachers' average number of years teaching preschool was 9.4, with a range of 0 to 24 years. All but two teachers had a college degree in early childhood education (ranging from Associate's to Master's).

Teachers were asked to complete two surveys: the Preschool Teacher Attitudes and Beliefs toward Science (P-TABS; Maier, Greenfield & Bulotsky-Shearer, 2013) and the Teacher Self-Efficacy Survey (Carr, Kochanowski, & Maltbie, in preparation). The surveys were administered as hard copies at the beginning of the academic year. The teachers were given time to complete these surveys individually within their work day. Focus groups were also conducted, recorded, and transcribed to obtain a nuanced understanding of teachers' attitudes towards science learning and play in nature. This was done in an informal setting, either at the preschool or at a nearby restaurant.

1. P-TABS: What are teachers' views on preschool science curricula?

The P-TABS survey consists of Likert-scale items on various aspects of early science instruction (see Appendix C). The *Teacher Comfort* factor (14 items) captures the degree to which teachers enjoy the planning and carrying out of activities related to various science content (e.g., "Teachers in my center feel comfortable doing science activities in the classroom."). The *Child Benefit* factor (10 items) captures teachers' attitudes towards whether science learning is beneficial for preschoolers (e.g., "Science-related activities help improve preschoolers' approaches to learning."). Finally, the *Challenge* factor (7 items) captures perceived challenges in teaching science, including amount of time, perceived skills, and science knowledge level (e.g., "Teachers in my center include some books about science during story time.")[2].

Teachers' P-TABS scores, whether in the aggregate or separated by factor, were uncorrelated with teacher age or years of teaching experience, rs < ± 0.11. Figure 4 presents average scores on the P-TABS, separated by factor. The higher the scores, the more positive teachers' reported attitudes towards science were. The highest average was obtained for the Child Benefit factor (M = 3.37, SD = 0.27), followed by the Teacher Comfort factor (M = 3.24, SD = 0.28), and lastly followed by the Challenge factor (M = 2.99, SD = 0.34). A repeated-measures ANOVA revealed a significant difference among the factors, $F(2, 20) = 3.49$, $p < 0.05$. This suggest that, while teachers easily could see the benefit of science learning to young children, they also perceived substantial challenges.

[2]Note that high Challenge scores mean less perceived challenge (i.e., items such as "Given other demands, there is not enough time in a day to teach science" were reversed). Four items of the P-TABS (#s 4, 15, 18, and 29) do not load onto any of the three factors. They are not included in our analyses.

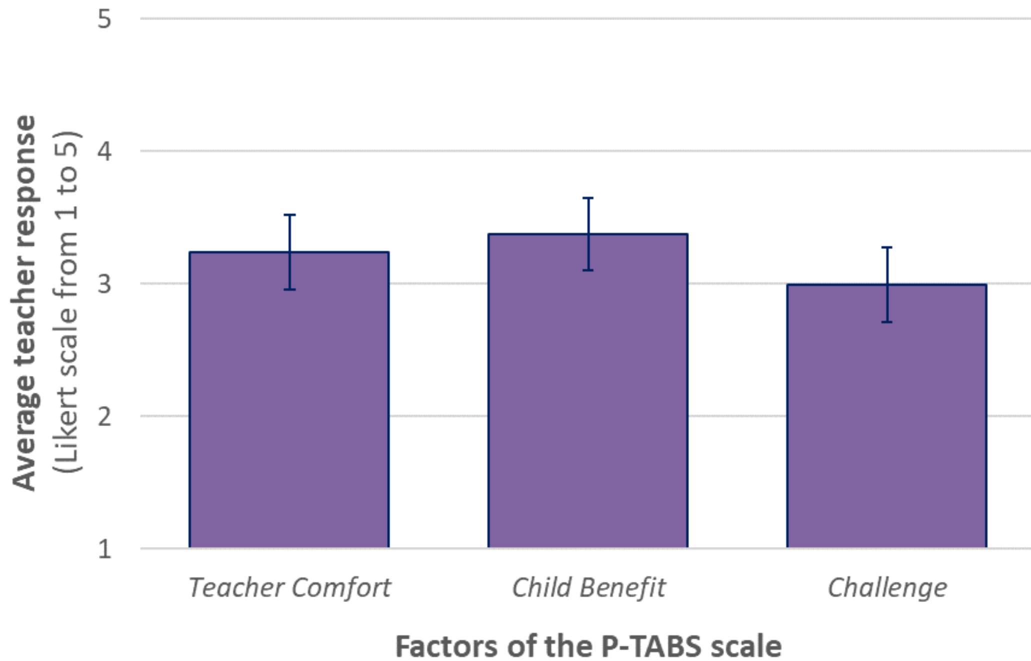

Figure 4. Average scores obtained for the P-TABS survey, separated by factor. Each item used a 5-point Likert scale, with higher values indicating positive attitudes and beliefs towards science (after reversing the coding of negatively worded items).

A similar image emerges when looking at individual items of the P-TABS. For example, while all teachers strongly agreed that "Science-related activities help improve preschoolers' approaches to learning", most teachers disagreed that "Teachers in my center use all kinds of classroom materials for science activities." The difference in scores between the two items was statistically significant, paired-sample $t(21) = 4.78$, $p < 0.05$. Focus-group data confirmed the concerns with the science education that is typically recommended by state standards.

2. <u>Self-Efficacy: How confident are teachers about incorporating nature in children's science learning?</u>

The Teacher Self-Efficacy Survey is designed to gauge teachers' perceived ability and comfort level in exploring the natural world with their students. It consists of 30 items pertaining to various aspects of teachers' experiences with nature play (see Appendix D). This includes teachers' comfort levels with nature itself, their comfort levels with children's explorations in nature, and their comfort levels with instructional materials and pedagogy related to nature. Each item is a rating scale from 0 (lowest confidence) to 100 (highest confidence).

Figure 5 shows the frequency distribution of teachers' average confidence levels. Overall, confidence levels were high: Three quarters of the teachers (74%) reported an average confidence level of 80 points or higher, with over a third (35%) reporting an average comfort level above 90 points. Only two teachers reported confidence levels below 50 points (22 and 32, respectively). Follow-up during the focus groups confirmed that these two teachers were unsure about whether they can be effective conveying science concepts in nature (for additional insights about teacher comfort with nature, see Kloos, Maltbie, Brown, & Carr, 2018).

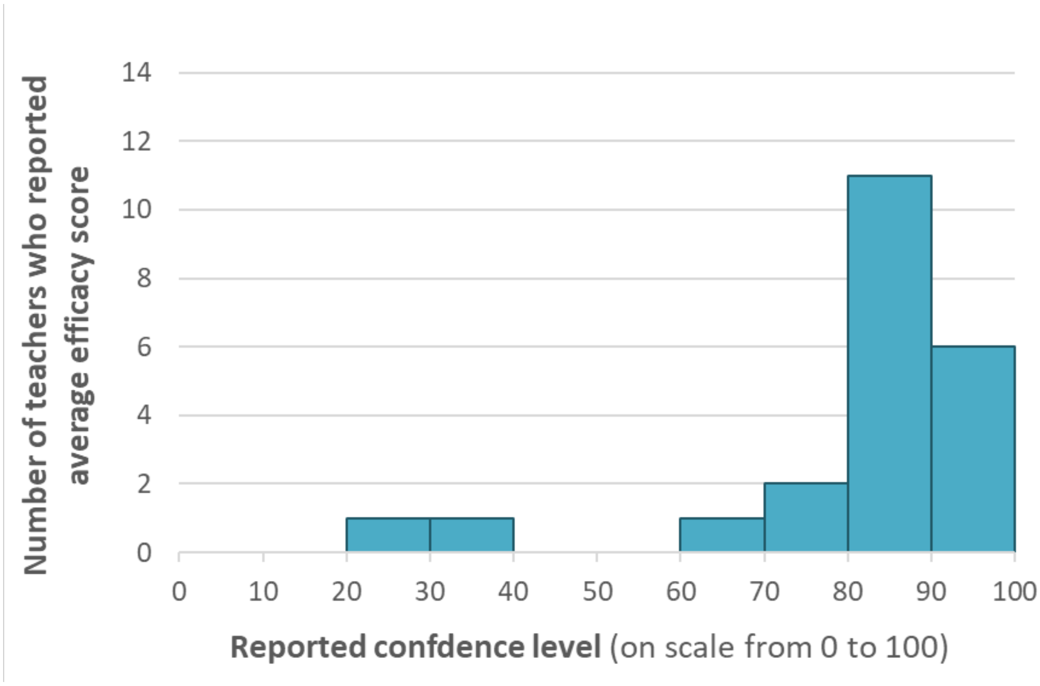

Figure 5. Frequency distribution of teachers' average confidence levels obtained from the Teacher Self-Efficacy Survey (Carr et al., in preparation)

In terms of individual survey items, the lowest averages were obtained for the items "implement sustainable practices into the preschool classroom" (71 points) and "ask open-ended questions to prompt deeper thinking about the natural world" (72 points). The highest average was obtained for the item "identify potential hazards to children and adults that exist in natural settings (89 points). Finally, the highest variability was obtained for the item "provide the proper care for live animals and plants in my classroom" (*M* = 78; *SD* = 31.3). Focus group data added to these findings: Teachers indicated that they were highly motivated to explore ways in which science learning could take place in nature. Reported challenges pertained to time constraints, safety, and concerns about how to prompt deeper thinking in children.

In sum, our results highlight a discrepancy between how preschool teachers feel about general science recommended by the state standards and how they feel about science learning in nature. Even though teachers could easily see the benefit of early science learning, they perceived significant challenges with the recommended science curricula for preschoolers. In contrast, most teachers felt very comfortable with nature-based science learning. This aligns with theoretical insights about the efficacy of nature-based experiences. Equipped with these answers, we now turn to a proposed nature-based science curriculum.

D. A Framework for Science Standards: Prioritizing Basic-Level Concepts

As discussed in Section A, the existing state standards have considerable problems. From the perspective of teachers, it is perhaps most problematic that standards often imply that children have an innate affinity for scientific explorations. This suggests – mistakenly – that science is learnable spontaneously, merely via child-guided explorations. It leaves teachers without guidance about where to start or how to build upon concepts. Moreover, it conflicts with insights about how the surrounding needs to be structured to promote learning. In this last section, we present an alternative organization of state standards that takes into account learning difficulty.

As discussed in Section B, the ideal learning context requires a sufficient amount of relevant variability in the surrounding (namely to support focused attention), and it requires a sufficient amount of relevant stability in the surrounding (namely to support lasting memory and knowledge). Nature offers such ideal levels of variability and stability for many science concepts. Our questions, then, are: (1) What nature-based science concepts can be learned spontaneously? And (2) How should an early science curriculum be structured?

1. <u>Learning in Nature: What concepts can be learned spontaneously?</u>

A first step is to organize science concepts in a way that aligns with insights about how variability and stability in the input affect learning (for a full discussion, see Kloos, Baker & Waltzer, 2019). So-called *basic-level science concepts* have sufficiently high variability and sufficiently high stability in the surrounding. In contrast, so-called *sub-ordinate level science concepts* have sufficiently high stability in the surrounding, but lack sufficiently high variability. Lastly, so-called *super-ordinate level science concepts* have sufficiently high variability in the surrounding, but lack sufficiently high stability.

Given the availability of variability and stability for basic-level science concepts, these concepts can be learned spontaneously via self-guided explorations. Incidentally, these concepts are abundantly available in nature. Examples include the distinction between animate and inanimate entities, the distinction between plants and animals, and the different types of plants or animals. Other basic-level science concepts present in nature are the states of matter (fluid vs. solid), gravity (objects falling), seasons (winter vs. summer), the day-night cycle, shadows, and celestial bodies (sun, moon).

In contrast to basic-level concepts, neither sub-ordinate nor super-ordinate level science concepts can be learned spontaneously. For sub-ordinate level science concepts, relevant features are not sufficiently attention-grabbing (i.e., relevant features do not stand out against the static background). An example is the difference between animal sub-species, such as the difference between a Monarch butterfly and a Swallow Tail. The differences between these two types of butterflies is likely to be too minuscule for many children to catch their attention spontaneously. It would require the help of a teacher to highlight the differences in wing color before unexperienced children can detect them. Otherwise, children's attention might drift to something irrelevant to science learning.

For super-ordinate level science concepts, relevant features are not sufficiently stable (i.e., they lack the necessary stability to form a lasting memory). An example from life science is the link between butterflies and caterpillars. Other nature-based examples include the difference between mammals and non-mammals, the working of cells, the life cycle, and the food web. Examples from physical science include density, buoyancy, or energy. And examples from earth/space science includes the spatial arrangements and movements of celestial bodies. These concepts, while often listed in state standards for preschools, are difficult for young children to learn without substantial support from teachers.

2. <u>From Basic to Advanced: How should an early science curriculum be structured?</u>

Based on the outcome of our analyses, our main claim is obvious: Science concepts differ in difficulty. Thus, the claims about science learning being innate are not supported across the board. Along the same lines, the pedagogy of self-guided exploration is not sufficient to learn all of the recommended science concepts. Instead, a careful look is required to determine the degree to which a child's surrounding offers enough science-relevant variability and enough science-relevant stability for a given science concept. Table 2 provides an overview.

Table 2
Proposed Organizational Framework for Early Science Standards

	Levels of Science Concepts		
	Basic Level Concepts	Sub-Ordinate Level Concepts	Super-Ordinate Level Concepts
Key Determinants of Learning			
Intermediate Variability	Yes	No	Yes
Intermediate Stability	Yes	Yes	No
Examples in Nature			
Inquiry	observation, free exploration	measurement, description	experimentation, explanation
Life Science	plants, animals,	plant families animal families	life cycle, food web
Physical Science	loose parts, states of matter	mass, volume	conservation, buoyancy
Earth/Space Science	day-night cycle, seasons	temperature	water cycle

Science activities and truisms that fall into the category of basic-level science concepts are learnable through children's self-guided explorations (Kloos & Sloutsky, 2008; Rosch, Mervis, Gray, Johnson & Boyes-Braem, 1976). Thus, states should consider recommending these types of concepts first (e.g., differences between species, states of matter, seasons). Given the abundance of basic-level science concepts in nature, it might be prudent for preschools to turn playgrounds into playscapes. Mere play in these spaces would give children an important foundation in science literacy.

Once children are familiar with basic-level science concepts, their exploratory activities can be enriched to include sub-ordinate level science concepts (e.g., different sub-groups of animals, different types of material, fluctuation in temperature). This requires teachers to explicitly interact with children, namely to draw their attention to science-relevant details that children might miss otherwise. Here is where teachers could explore nature together with children, encouraging detailed observations and discussing children's experiences.

The biggest challenge is the learning of super-ordinate level science concepts. Child-guided explorations would be utterly insufficient to learn these concepts. Even discussions and offering answers would not be enough to convey the relevant patterns of order. For example, it would help little to point out that caterpillars and butterflies are the same animals at different stages. The stable appearances of these different stages are too different to allow for an understanding of the underlying link. To learn super-ordinate level science concepts, a more strategic intervention is needed. This is when nature needs to be supplemented with learning tools that are not found in nature: books, diagrams, concept maps, and so on.

State standards that list super-ordinate level science concepts without highlighting the need for a strategic modification of the learning space are likely to do more harm than good. This is because high-variability surroundings with insufficient stability can foster misconceptions. Children's attention will be drawn to the available variability, without the right stability to encourage science-relevant memory traces. As a result, children will remember patterns or arrangements that are irrelevant to science concepts. It might be more prudent to leave super-ordinate level science concepts off the list of recommended science concepts.

Taken together, we argue that nature provides a unique opportunity for early science learning. This is because there exists a multitude of basic-level concepts in nature, concepts that can be learned through mere explorations. Nature also harbors sub-ordinate science concepts, offering opportunities for more advanced observations. Finally, nature harbors super-ordinate science concepts. Learning these latter concepts requires extensive teacher involvement, namely to circumvent misconceptions. An effective science curriculum would start with basic-level concepts, add sub-ordinate concepts next, and introduce super-ordinate concepts last.

E. Conclusion

Early science education is a busy field, fueled by technological innovations, numerous research studies, and the national call to offer science in preschool. But the field remains unorganized, as shown in our time-lag analysis of publicly listed standards for preschool science in the U.S. To derive an organizing framework, we have looked at the potentials offered by nature, using both insights about cognitive development and data from preschool teachers about opportunities and barriers. Our results point to exciting options for science learning in nature. Experiences in nature come equipped with appropriate variability and stability for basic-level concepts. Exposure to basic-level concepts in nature can lay the foundation for formal science instruction.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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Appendix A

Type of science proficiency recommended in 2015 state standards, separated by state.

	Type of Science [a]								
	A	B	C	D	E	F	G	H	I
AL	x	x	x	x					4
AK	x	x	x	x					4
AZ	x								4
AR	x								4
CA	x	x	x	x					2
CO		x	x	x					1
CT	x	x	x	x					2
DE								21	4
FL								17	2
GA	x	x	x	x					1
HI	x	x	x	x	x				1
ID	x								4
IL	x	x	x	x	x				3
IN	x	x	x	x	x				1
IA	x								2
KS		x	x	x					4
KY									
LA	x	x	x	x					3
ME		x	x	x					4
MD	x	x	x	x		x			3
MA		x	x	x					4
MI	x						x		4
MN	x								3
MS								6	2
MO		x	x	x					2
MT	x	x	x	x	x				4
NE	x						x		4
NV	x	x	x	x					1
NH	x						x		1
NJ	x	x	x	x	x				3

	Type of Science [a]								
	A	B	C	D	E	F	G	H	I
NM	x	x		x					3
NY	x	x	x	x					4
NC	x								4
ND	x								4
OH	x	x	x	x					3
OK	x	x	x	x					4
OR	x	x	x	x					4
PA	x	x							1
RI	x						x		2
SC									
SD	x	x	x	x	x		x		3
TN	x	x	x	x	x				3
TX		x	x	x					2
UT	x	x	x	x					2
VT		x	x	x			x		2
VA	x	x	x	x					2
WA								11	4
WV	x						x		4
WI	x								4
WY	x						x		4

[a] Type of science pertains to (A) Science inquiry, (B) Life science, (C) Physical science, (D) Earth/Space science, (E) Technology/Engineering, and (F) Environment/Society. Some states combined life science, physical science, and earth/space science (G). Other states had a list of science items (H). In the latter case, the number of items in the list are provided. The level of scientific inquiry (I) is listed in the final column (1 = observe, explore; 2 = describe; 3 = predict, test; 4 = explain, cause/effect).

Appendix B

Type of science proficiency recommended in 2017 state standards, separated by state. Bolded text marks changes in content from 2015 to 2017.

	Type of Science [a]								
	A	B	C	D	E	F	G	H	I
AL	x	x	x	x					4
AK	x	x	x	x					4
AZ	x								4
AR	x	**x**	**x**		**x**	**x**			4
CA	x	x	x	x					2
CO		x	x	x					1
CT	x	x	x	x					2
DE								21	4
FL								17	2
GA	x	x	x	x					1
HI	x	x	x	x	x				**2**
ID	x								4
IL	x	x	x	x	x				3
IN	x	x	x	x	x				1
IA	x								2
KS		x	x	x					4
KY	**x**								**4**
LA	x	x	x	x					**4**
ME		x	x	x					4
MD	x	x	x	x		x			3
MA		x	x	x					4
MI	x	**x**	**x**	**x**					4
MN	x								**4**
MS	**x**	**x**	**x**	**x**	**x**				**3**
MO		x	x	x					2
MT	x	x	x	x	x				4
NE	x						x		4
NV	x	x	x	x					**3**
NH	x						x		1
NJ	x	x	x	x	x				3

	Type of Science [a]								
	A	B	C	D	E	F	G	H	I
NM	x	x		x					3
NY	x	x	x	x					4
NC	x								4
ND	x	**x**		**x**					4
OH	x	x	x	x					3
OK	x	x	x	x					4
OR	x	x	x	x					4
PA	x	x	**x**	**x**		**x**			**3**
RI	x						x		**4**
SC	x								**4**
SD	x	x	x	x	x	x			3
TN	x	x	x	x	x				3
TX		x	x	x					2
UT	x	x	x	x					2
VT		x	x	x			x		2
VA	x	x	x	x					**3**
WA								11	4
WV	x						x		4
WI	x								4
WY	x						x		4

[a] Type of science pertains to (A) Science inquiry, (B) Life science, (C) Physical science, (D) Earth/Space science, (E) Technology/Engineering, and (F) Environment/Society. Some states combined life science, physical science, and earth/space science (G). Other states had a list of science items (H). In the latter case, the number of items in the list are provided. The level of scientific inquiry (I) is listed in the final column (1 = observe, explore; 2 = describe; 3 = predict, test; 4 = explain, cause/effect).

Appendix C

Preschool Teacher Attitudes and Beliefs toward Science Questionnaire
(P-TABS; Maier, Greenfield, & Bulotsky-Shearer, 2013)

Instructions:

On a scale from 1 (Strongly Disagree) to 5 (Strongly Agree), please indicate your level of agreement with each of the following statements regarding instructional practices at your center.

Items:

1. Preschool science activities help foster children's interest in science in later grades.
2. Experimenting hands-on with materials and objects is how young children learn best.
3. It is important for my classroom to have a science area that can be freely explored by children.
4. Young children are curious about scientific concepts and phenomena.
5. Science-related activities help improve preschoolers' language skills.
6. Science-related activities help improve preschoolers' approaches to learning.
7. More science should be taught in the early childhood classroom.
8. Teachers in my center feel comfortable planning and demonstrating classroom activities related to life science topics (e.g., living things, plants, animals).
9. Teachers in my center get ideas for hands-on activities from what my preschoolers do, say, and ask.
10. Teachers in my center enjoy doing science activities with my preschool children.
11. Teachers in my center feel comfortable doing science activities in my early childhood classroom.
12. Teachers in my center do not mind the messiness created when doing hands-on science in my classroom.
13. Science-related activities help improve preschoolers' social skills.
14. Teachers in my center feel comfortable planning and demonstrating classroom activities related to earth science topics (e.g., sun, moon, stars, and weather).
15. Teachers in my center use all kinds of classroom materials (e.g., blocks, toys, boxes) for science activities.
16. Science-related activities help improve preschooler' math skills.
17. Teachers in my center include some books about science during story time.
18. Teachers in my center make an effort to include some science activities throughout the week.
19. Teachers in my center collect materials and objects to use in my science teaching.
20. Teachers in my center feel comfortable planning and demonstrating classroom activities related to physical and energy science topics (e.g., force of gravity; gas, liquids, solids).
21. Teachers in my center demonstrate experimental procedures (e.g., comparing objects to see if they will sink or float) in my classroom.
22. Teachers in my center use resource books to get ideas about science activities for young children.
23. Teachers in my center use the internet to get ideas about science activities for young children.
24. Teachers in my center discuss ideas and issues of science teaching with other teachers.
25. *Preparation for science teaching takes more time than other subject areas.
26. *Planning and demonstrating hands-on science activities is a difficult task.
27. *Given other demands, there is not enough time in a day to teach science.
28. *Teachers in my center do not have enough scientific knowledge to teach science to young children.
29. *Teachers in my center feel uncomfortable using scientific tools such as scales, rulers, and magnifying glasses when teaching science lessons.
30. *Teachers in my center feel uncomfortable talking with young children about the scientific method (e.g., making hypotheses, predicting, experimenting).
31. *Teachers in my center do not have enough materials to do science activities.
32. *Teachers in my center are afraid that children may ask me a question about scientific principles or phenomena that I cannot answer.
33. *It is not appropriate to introduce science to children at an early age.
34. *Science-related activities are too difficult for young children.
35. *Young children cannot learn science until they are able to read.

*Items with reverse coding

Appendix D

Teacher Self-Efficacy Survey
(Carr, Kochanowski, & Maltbie, in preparation)

Instructions:

Rate your degree of confidence by recording a number from 0 to 100.

Items:

How confident do you feel to…

1. … locate books and other classroom materials to connect children's experiences outdoors with the classroom curriculum.
2. … explore surroundings outside of your own schoolyard.
3. … be relaxed and comfortable immersed in natural habitats (ex: forests, streams, ponds, and prairies).
4. … give feedback to preschool children in a developmentally appropriate manner that corrects common misperceptions about the natural world.
5. … observe children's interests in nature to guide the planning of learning activities.
6. … modify my lesson plans when inspired by natural encounters.
7. … tailor my expectations for children's behavior and questions in the natural world to be age-appropriate.
8. … allow for age-appropriate risk-taking behaviors in nature play.
9. … promote preschool children's sense of wonder of the natural world by allowing for independent exploration without adult interruption.
10. … provide the proper care for live animals and plants in my classroom.
11. … provide positive guidance and address any challenging behaviors when teaching in natural settings.
12. … ask open-ended questions to prompt deeper thinking about the natural world.
13. … communicate effectively the value of nature play to parents.
14. … facilitate children's inquiry through engagement, focused observations, investigation, discussions, and conclusions.
15. … respond to children's questions and observations about the natural world with factual information.
16. … help preschool children collect and analyze data.
17. … mentor children on hikes in natural habitats.
18. … respond to personal fears (ex: bugs, snakes) in a calm manner.
19. … decide what elements in natural play areas elicit science learning.
20. … implement sustainable practices into the preschool classroom.
21. … be comfortable encountering creatures in nature (ex: reptiles, amphibians, fish, or mammals).
22. … increase the amount of time my class has access to natural settings.
23. … choose or find appropriate natural materials (loose parts) to prompt play and learning.
24. … identify potential hazards to children and adults that exist in natural settings (ex: poison ivy, stinging insects, venomous spiders and snakes).
25. … find creative ways to bring a variety of natural elements to the school's outdoor facilities.
26. … create outdoor spaces for play and learning about nature.
27. … seek out resources in the community to connect children with nature.
28. … engage children in sustained, integrated class projects related to natural phenomena.
29. … use a strong working knowledge of local biodiversity and environmental science to teach preschool.
30. … knowledgably contribute to an adult conversation about biodiversity.