THE NATURAL WORLD AS A RESOURCE FOR LEARNING AND DEVELOPMENT: FROM SCHOOLYARDS TO WILDERNESS

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THE NATURAL WORLD AS A RESOURCE FOR LEARNING AND DEVELOPMENT: FROM SCHOOLYARDS TO WILDERNESS

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EDITORIAL
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Editorial: The Natural World as a Resource for Learning and Development: From Schoolyards to Wilderness

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Editorial on the Research Topic

The Natural World as a Resource for Learning and Development: From Schoolyards to Wilderness

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Children are increasingly losing contact with nature. Many live in highly developed settings with relatively few natural elements or views; others have access to some forms of nature but spend the vast majority of their time indoors. What are the consequences of this shift for children—their academic achievement, what they know and don't know, their values and abilities, and who they become? And what are the consequences for the rest of us?

Increasing evidence suggests that the natural world may be a powerful resource for learning and development. "Contact with nature," ranging from wilderness vacations to catching frogs in a drainage ditch to doing homework with a view of trees, is increasingly tied to positive outcomes. These discoveries raise the tantalizing potential of identifying low-cost ways to address major societal challenges: boosting academic achievement, reducing the achievement gaps between different ethnic and socioeconomic groups, and countering the rise in various mental and physical disorders.

This Research Topic expands our understanding of the natural world as a resource for learning and development. These 12 articles:

- **Capture the current state of the evidence in this area**, revealing far stronger converging evidence for the positive role of nature in learning and development than previously realized and identifying a set of mechanisms underlying the relationship between nature and learning (Kuo et al.).
- **Expand our understanding of the populations nature-based learning (NBL) can serve**—while much of the previous research in this area has focused on relatively well-off, mainstream elementary school populations, the work here extends the benefits of nature to preschool children (Agostini et al.); children from low-income and/or minority neighborhoods (Bates et al.; Kuo et al.; Kuo et al.); children with emotional, cognitive, and behavioral disabilities (Szczytko et al.); and children around the globe, including from the United States, Italy, and Denmark.

- **Expand our understanding of the many ways in which children might experience nature**. At school, children might engage in project-based learning about a living wall in their classroom (McCullough et al.), have lessons outdoors (Barfod and Daugbjerg; Kuo et al.; Szczytko et al.), or have recess in a green outdoor area (Amicone et al.). Away from school, experiences like "being in solitude in nature" or "cohabiting with a wild animal" might contribute to healthy development (Kahn et al.).
- **Expand our understanding of the potential benefits of time in and around nature**.
  - A handful of articles address cognitive and academic benefits of nature: recess that mentally rejuvenates (Amicone et al.); lessons that boost student engagement with the current lesson (Szczytko et al.) and subsequent lessons (Kuo et al.); schoolyards that may boost standardized test performance (Kuo et al.); and green outdoor settings that seem to elicit and support child-centered, inquiry-based instructional methods (Barfod and Daugbjerg), serve as an antidote to cognitive load from technology (Schilhab et al.) and boost cognitive and language development (Agostini et al.).
  - Other articles provide evidence for physical benefits including increased physical activity (Bates et al.) and improved gross and fine motor skills, body function, and awareness of the surrounding environment (Agostini et al.).
  - Finally, several articles address social, emotional and behavioral functioning, including increases in prosocial interactions (Bates et al.), reductions in disruptive behavior (Szczytko et al.), and increased play and enhanced social and emotional development (Agostini et al.).
- **Offer a roadmap for future research**, identifying some of the most important and pressing "game-changing" research questions at this time (Jordan and Chawla).

The diversity of disciplines represented in this collection illustrates the importance of diverse backgrounds and areas of expertise in understanding the role of nature in children's learning and development. The authors' affiliations here span forest and natural resources; pediatrics; parks, recreation and tourism; teacher education; informatics; social work; environmental psychology; developmental psychology; landscape architecture; environmental education; nutrition; health promotion; and future technology, culture, and learning. Perhaps not surprisingly, the methodologies are similarly diverse and offer a rich picture of nature's impact. For example, direct observation of children's play, examination of nature-based instructional sessions, teacher interviews, cognitive testing and standardized tests each offer a unique perspective that contributes to our understanding.

The work here attests to the multiple benefits of nature contact across a variety of settings and forms of engagement. These original research studies, reviews, and conceptual pieces have implications for diverse fields, including education, teacher preparation, early childhood development, design and planning, and health and mental health care, among other sectors. Taken together, this work argues for practitioners and decision makers to value nature contact as a critical resource for children's learning and development.

AUTHOR CONTRIBUTIONS

Both authors compiled information about the 12 articles. MK provided an outline and first draft. CJ provided additional text. Both authors revised and approved the manuscript for submission.

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MINI REVIEW
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Do Experiences With Nature Promote Learning? Converging Evidence of a Cause-and-Effect Relationship

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Do experiences with nature – from wilderness backpacking to plants in a preschool, to a wetland lesson on frogs—promote learning? Until recently, claims outstripped evidence on this question. But the field has matured, not only substantiating previously unwarranted claims but deepening our understanding of the cause-and-effect relationship between nature and learning. Hundreds of studies now bear on this question, and converging evidence strongly suggests that experiences of nature boost academic learning, personal development, and environmental stewardship. This brief integrative review summarizes recent advances and the current state of our understanding. The research on personal development and environmental stewardship is compelling although not quantitative. Report after report – from independent observers as well as participants themselves – indicate shifts in perseverance, problem solving, critical thinking, leadership, teamwork, and resilience. Similarly, over fifty studies point to nature playing a key role in the development of pro-environmental behavior, particularly by fostering an emotional connection to nature. In academic contexts, nature-based instruction outperforms traditional instruction. The evidence here is particularly strong, including experimental evidence; evidence across a wide range of samples and instructional approaches; outcomes such as standardized test scores and graduation rates; and evidence for specific explanatory mechanisms and active ingredients. Nature may promote learning by improving learners' attention, levels of stress, self-discipline, interest and enjoyment in learning, and physical activity and fitness. Nature also appears to provide a calmer, quieter, safer context for learning; a warmer, more cooperative context for learning; and a combination of "loose parts" and autonomy that fosters developmentally beneficial forms of play. It is time to take nature seriously as a resource for learning – particularly for students not effectively reached by traditional instruction.

Keywords: literature review, green space, instruction, teaching, environmental education, nature-based learning, green schoolyard

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INTRODUCTION

The intuition that "nature is good for children" is widely held, and yet, historically, the evidence for this intuition has been uncompelling, with a distressing number of weak studies and inflated claims. Now, however, an impressive body of work has accrued and converging lines of evidence paint a convincing picture.

This integrative mini-review (see **Supplementary Material** for methods) summarizes what we know about the role of nature experiences in learning and development. It draws on a wide array of peer-reviewed scientific evidence, ranging from research in the inner city, to the study of Attention Deficit/Hyperactivity Disorder, to neurocognitive and physiological explorations. Our overarching question was, "do nature experiences promote learning and child development?"

Throughout our review, we took care to distinguish between evidence for cause-and-effect relationships and evidence for associations; causal language (e.g., "affects," "boosts," "is reduced by") is used only where justified by experimental evidence. Where converging, but not experimental, evidence points to a likely cause-and-effect relationship, our language is qualified accordingly (e.g., "seems to increase"). **Table 1** summarizes recent advances in this area and explains how those advances contribute to our confidence in a cause-and-effect relationship between nature and learning and development.

What emerged from this critical review was a coherent narrative (**Figure 1**): experiences with nature do promote children's academic learning and seem to promote children's development as persons and as environmental stewards – and at least eight distinct pathways plausibly contribute to these outcomes. Below, we discuss the evidence for each of the eight pathways and then the evidence tying nature to learning, personal development, and the development of stewardship.

NATURE MAY BOOST LEARNING VIA DIRECT EFFECTS ON LEARNERS

Five of the eight plausible pathways between nature and learning we identified are centered in the learner. Learning is likely to improve when a learner is more attentive (Rowe and Rowe, 1992; Mantzicopoulos and Morrison, 1994); less stressed (Grannis, 1992; Leppink et al., 2016); more self-disciplined (Mischel et al., 1988; Duckworth and Seligman, 2005); more engaged and interested (Taylor et al., 2014 for review); and more physically active and fit (for reviews, see Álvarez-Bueno et al., 2017; Santana et al., 2017). Evidence suggests that contact with nature contributes to each of these states or conditions in learners.

Nature Has Rejuvenating Effects on Attention

The rejuvenating effect of nature on mentally fatigued adults (e.g., Hartig et al., 1991; Kuo, 2001) and children has been demonstrated in a large body of studies, including field experiments (Faber Taylor and Kuo, 2009) and large-scale longitudinal studies (Dadvand et al., 2015). Students randomly assigned to classrooms with views of greenery perform better on concentration tests than those assigned to purely "built" views or windowless classrooms (Li and Sullivan, 2016). Nature's rejuvenating effects on attention have been found in students going on field trips (van den Berg and van den Berg, 2011), Swedish preschoolers (Mårtensson et al., 2009), children in Chicago public housing (Faber Taylor et al., 2002), and 5 to 18-year-olds with ADHD (e.g., Kuo and Faber Taylor, 2004), using measures of attention ranging from parent and teacher ratings (O'Haire et al., 2013) to neurocognitive tests (Schutte et al., 2015).

Nature Relieves Stress

The stress-reducing effects of nature have been documented in adults in a large body of controlled experiments (see Kuo, 2015; **Supplementary Material** for review) and the available evidence points to a similar effect in children. Nature has been related to lower levels of both self-reported and physiological measures of stress in children (Bell and Dyment, 2008; Chawla, 2015; Wiens et al., 2016). Recently, an experimental study showed that a window view of vegetation from a high school classroom yields systematic decreases in heart rate and self-reported stress, whereas built views do not (Li and Sullivan, 2016). Further, students learning in a forest setting one day a week showed healthier diurnal rhythms in cortisol in that setting than a comparison group that learned indoors – cortisol dropped over the course of the school day when lessons were held in the forest but not in the classroom – and these effects could not be attributed to the physical activity associated with learning outdoors (Dettweiler et al., 2017).

Contact With Nature Boosts Self-Discipline

In adults, the effects of viewing scenes of nature on self-discipline have been demonstrated experimentally using tests of impulse control (Berry et al., 2014; Chow and Lau, 2015). In children, nature contact has been tied to greater self-discipline in children from inner city Chicago (Faber Taylor et al., 2002) to residential Barcelona (Amoly et al., 2014) and in experimental (Sahoo and Senapati, 2014), longitudinal (Ulset et al., 2017), and large-scale cross-sectional studies (Amoly et al., 2014). These benefits have been shown for neurotypical children as well as for children with ADHD (Sahoo and Senapati, 2014) and learning difficulties (Ho et al., 2017). The types of self-discipline assessed include delay of gratification (Faber Taylor et al., 2002) and parent ratings of hyperactivity (Flouri et al., 2014), and the types of "nature" include not just "greenness" but contact with horses in animal-assisted learning (Ho et al., 2017). Note that impulse control effects are not always statistically significant (e.g., Amoly et al., 2014; Schutte et al., 2015). Nonetheless, in general, impulse control is better during or after children's contact with nature.

Student Motivation, Enjoyment, and Engagement Are Better in Natural Settings

Student motivation, enjoyment, and engagement are better in natural settings, perhaps because of nature's reliably positive

TABLE 1 | Do nature experiences promote learning? Advances in methodology and evidence.

We now know that...	How this advance came about and why it matters
Nature-based instruction (NBI) is, on average, more effective than traditional instruction (TI).	Early research often compared outcomes before and after NBI, showing that students benefited from nature-based instruction but not whether there was anything particularly helpful about NBI as compared to any other instruction. More recently, studies have begun comparing outcomes for NBI vs. TI, showing that incorporating nature adds value to instruction (e.g., Ernst and Stanek, 2006; Camassao and Jagannathan, 2018).
The advantage of NBI over TI does not simply reflect a tendency for better teachers, better schools, or better students to choose NBI.	Early research often compared learning in classrooms offering NBI vs. matched classrooms offering TI. But matching does not address the likelihood that teachers (or schools) who choose to offer NBI may be more innovative, energetic, or well-funded than teachers (or schools) who do not, even if they serve similar students. Similarly, comparisons of students who choose extracurricular NBI vs. students who do not will reflect pre-existing differences in the kinds of students who sign up for extra instruction. Recently, researchers have begun using "waitlist controls" – identifying teachers, schools, or students interested in NBI and then randomly assigning some of them to NBI and the rest to TI (e.g., Wells et al., 2015). Guarding against pre-existing differences between the teachers, schools, and students being compared lends greater confidence that any gains are due to the instruction itself.
The effects of NBI on academic learning are real; they do not simply reflect the rosy assessments of biased observers.	Early research often relied on subjective assessments of outcomes by persons who believe in NBI. Advocates, practitioners, and parents or children who choose NBI may perceive benefits in the absence of any real effects, whether consciously or unconsciously. More recent research guards against such bias by employing objective measures or assessments made "blind to condition" – without knowing which students were in which condition (NBI or TI) (e.g., Ernst and Stanek, 2006*)*. In these studies, an advantage of NBI over TI cannot be attributed to wishful thinking.
NBI shows a "dose-response relationship" – as the magnitude of the treatment (the dose) increases, so does the outcome.	Early research relied on binary comparisons between learning settings with and without nature, or "low" and "high nature," leaving more room for alternative explanations. For instance, if students learn more outdoors than indoors, the difference might be due to either differences in vegetation or other differences between the settings. More recent research has compared multiple levels of nature (e.g., schoolyards with 0–40% tree cover, Sivarajah et al., 2018) or multiple levels of NBI (Wells et al., 2015). When the response is proportional to the dose, that lends confidence that the effect is attributable to the level of vegetation. Although a "dose-response relationship" does not prove causality, it strengthens the case.
The nature-learning connection holds up across topics, learners, instructors, pedagogies, places, and measures of learning.	As researchers have continued to conduct studies, the body of studies testing the nature-learning hypothesis has grown larger and more diverse (e.g., Faber Taylor et al., 2002; Maynard et al., 2013; O'Haire et al., 2013; Ruiz-Gallardo et al., 2013; Fremery and Bogner, 2014; Lekies et al., 2015; Swank et al., 2017; Kuo et al., 2018a; McCree et al., 2018; Sivarajah et al., 2018). A robust association persisting across different contexts lends greater confidence in a cause-and-effect relationship (Hill, 1965, p. 8).
The relationship between nature and learning holds up across different research designs.	Over time, a greater variety of study designs have been employed, including true experiments (e.g., Wells et al., 2015), quasi-experiments (e.g., Faber Taylor and Kuo, 2009; Benfield et al., 2015), large-scale correlational studies with statistical controls (e.g., Kuo and Faber Taylor, 2004*)*, and longitudinal studies (e.g., McCree et al., 2018). Findings persisting across diverse study designs strengthen the case for causality.
The advantages of NBI over TI may stem from both setting and pedagogy.	Previous reviews drew only upon studies examining the effects of NBI on learning. In this review, we expanded our reach to include research on both the setting and the pedagogy of NBI, respectively. Educational psychologists working in the classroom have found that active, hands-on, student-centered, and collaborative forms of instruction outperform more traditional instructional approaches (Granger et al., 2012; Freeman et al., 2014; Kontra et al., 2015). Environmental psychologists have found better learning in "greener" settings – even when the instruction does not incorporate the nature (Benfield et al., 2015; Kuo et al., 2018b). These additional bodies of evidence converge to support and perhaps explain the advantages of NBI over TI.
Nature experiences may promote learning via at least eight distinct pathways.	Again, previous reviews drew only upon direct tests of the nature-learning hypothesis – studies in which nature was the independent variable and learning was the dependent variable. In this review, we also examined studies in which nature was the independent variable but the dependent variable was a precursor to learning (for example, Li and Sullivan, 2016, examines impacts of classroom views of nature on attention, which has long been established as an important precursor to learning, e.g., Rowe and Rowe, 1992). Evidence of mechanism lends greater plausibility to a cause-and-effect relationship between nature and learning. The multiple mechanisms identified here may also help explain the consistency of the nature-learning relationship, as robust phenomena are often multiply determined.

In recent years, the evidence for a cause-and-effect relationship between nature experiences and learning has advanced considerably. Some advances can be traced to the adoption of more rigorous research methods in individual studies (in green), others can be traced to the maturation of the field (in blue), and still, others stem from broadening the kinds of evidence considered in reviews (in purple).

effects on mood (e.g., Takayama et al., 2014). In previous reviews (Blair, 2009; Becker et al., 2017) and recent studies (e.g., Skinner and Chi, 2014; Alon and Tal, 2015; Lekies et al., 2015), students and teachers report strikingly high levels of student engagement and motivation, during both student-elected and school-mandated nature activities. Importantly, learning in and around nature is associated with intrinsic motivation (Fägerstam and Blom, 2012; Hobbs, 2015), which, unlike extrinsic motivation, is crucial for student engagement and longevity of interest in learning. The positivity of learning in nature seem to ripple outward, as seen in learners' engagement in subsequent, indoor lessons (Kuo et al., 2018a), ratings of course

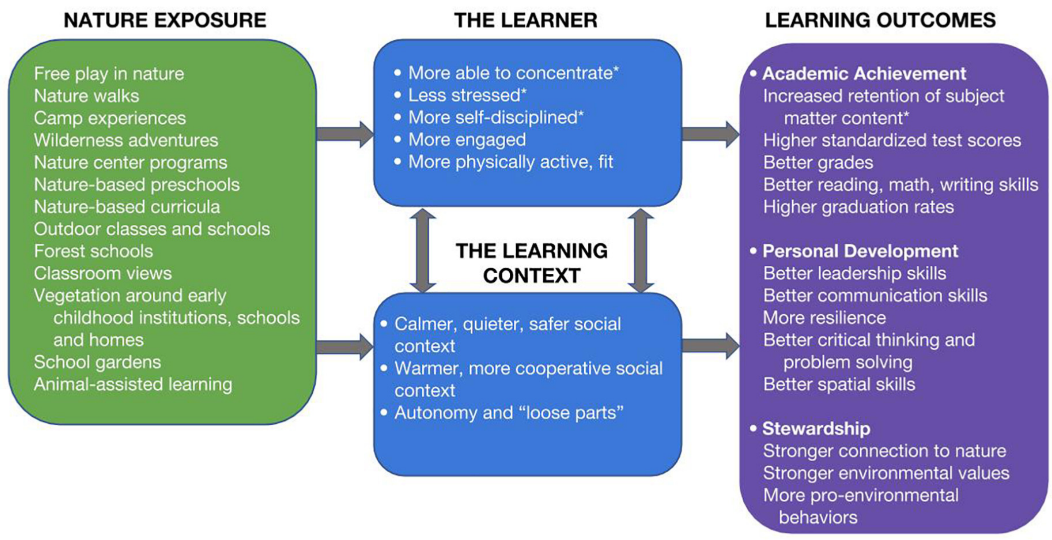

FIGURE 1 | Nature-based learning: exposures, probable mechanisms, and outcomes. This Figure summarizes the state of the scientific literature on nature and learning. The items and pathways here emerged from our review as opposed to guiding our review; thus each item listed has been empirically associated with one or more other items in the figure. Relationships for which there is cause-and-effect evidence are indicated with an asterisk; for example, "more able to concentrate" is asterisked because experimental research has demonstrated that exposure to nature boosts concentration. Similarly, "increased retention of subject matter" is asterisked because experimental research has demonstrated that exposure to nature in the course of learning boosts retention of that material. Here and throughout this review, causal language (e.g., "affects," "increases," "boosts," "is reduced by") is used only where experimental evidence (the gold standard for assessing cause-and-effect) warrants. Where converging evidence suggests a causal relationship but no experimental evidence is available, we use qualified causal language (e.g., "seems to increase"). The green box lists forms of nature exposure that have been tied with learning, whether directly (nature -> learning) or indirectly, via one or more of the mechanisms listed (nature -> mechanism -> learning). In this review, "nature" includes experiences of nature not only in wilderness but also within largely human-made contexts. Thus a classroom with a view of trees offers an experience of nature not offered by its counterpart facing the school parking lot. This review encompassed experiences of nature regardless of context – whether through play, relaxation, or educational activities, and in informal, non-formal and formal settings. The blue boxes show probable mechanisms – intermediary variables which have been empirically tied to both nature and learning. For example, the ability to concentrate is rejuvenated by exposure to nature and plays an important role in learning. Natural settings may affect learning both by directly fostering a learner's capacity to learn and by providing a more supportive context for learning. The purple box lists learning outcomes that have been tied to contact with nature. In this review, "learning" encompasses changes in knowledge, skills, behaviors, attitudes, and values. A database of articles found in the three phases of the review process (ending in 2018) is available at: https://goo.gl/FZ1CA9.

curriculum, materials, and resources (Benfield et al., 2015) and interest in school in general (Blair, 2009; Becker et al., 2017), as well as lower levels of chronic absenteeism (MacNaughton et al., 2017). Encouragingly, learning in nature may improve motivation most in those students who are least motivated in traditional classrooms (Dettweiler et al., 2015).

Time Outdoors Is Tied to Higher Levels of Physical Activity and Fitness

While the evidence tying green space to physical activity is extremely mixed (see Lachowitz and Jones, 2011 for review), children's time outdoors is consistently tied to both higher levels of physical activity and physical fitness: the more time children spend outdoors, the greater their physical activity, the lesser their sedentary behavior, and the better their cardiorespiratory fitness (Gray et al., 2015). Importantly, cardiorespiratory fitness is the component of physical fitness most clearly tied to academic performance (Santana et al., 2017). Further, there is some indication greener school grounds can counter children's trend toward decreasing physical activity as they approach adolescence: in one study, girls with access to more green space and woodlands, and boys with access to ball fields, were more likely to remain physically active as they got older (Pagels et al., 2014). This pattern is echoed in later life: in older adults, physical activity declines with age – but among those living in greener neighborhoods the decline is smaller (Dalton et al., 2016).

NATURE MAY BOOST LEARNING BY PROVIDING A MORE SUPPORTIVE CONTEXT FOR LEARNING

In addition to its effects on learners, natural settings and features may provide a more supportive context for learning in at least three ways. Greener environments may foster learning because they are calmer and quieter, because they foster warmer relationships, and because the combination of "loose parts" and relative autonomy elicits particularly beneficial forms of play.

Vegetated Settings Tend to Provide Calmer, Quieter, Safer Contexts for Learning

Both formal and informal learning are associated with a greater sense of calmness or peace when conducted in greener settings (Maynard et al., 2013; Nedovic and Morrissey, 2013; Chawla et al., 2014). Problematic and disruptive behaviors such as talking out of turn or pushing among children are less frequent in natural settings than in the classroom (Bassette and Taber-Doughty, 2013; Nedovic and Morrissey, 2013; O'Haire et al., 2013; Chawla et al., 2014). Further, in greener learning environments, students who previously experienced difficulties in traditional classrooms are better able to remove themselves from conflicts and demonstrate better self-control (Maynard et al., 2013; Ruiz-Gallardo et al., 2013; Swank et al., 2017). The social environment of the classroom has long been recognized as important for learning (Rutter, 2000). Calmer environments have been tied to greater student engagement and academic success (Wessler, 2003; McCormick et al., 2015).

Natural Settings Seem to Foster Warmer, More Cooperative Relations

Images of nature have prosocial effects in adults (e.g., Weinstein et al., 2009) and greener settings are tied to the development of meaningful and trusting friendships between peers (White, 2012; Chawla et al., 2014; Warber et al., 2015). Maynard et al. (2013) theorize that natural settings provide a less restrictive context for learning than the traditional classroom, giving children more freedom to engage with one another and form ties. Indeed, learning in greener settings has been consistently tied to the bridging of both socio-cultural differences and interpersonal barriers (e.g., personality conflicts) that can interfere with group functioning in the classroom (White, 2012; Cooley et al., 2014; Warber et al., 2015). Finally, learning in nature facilitates cooperation and comfort between students and teachers, perhaps by providing a more level playing-field wherein the teacher is seen as a partner in learning (Scott and Colquhoun, 2013). More cooperative learning environments promote student engagement and academic performance (Patrick et al., 2007; McCormick et al., 2015).

Natural Settings May Afford "Loose Parts," Autonomy, and Distinctly Beneficial Forms of Play

In his "theory of loose parts," Nicholson (1972) posited that the "stuff" of nature – sticks, stones, bugs, dirt, water – could promote child development by encouraging creative, self-directed play. Indeed, teachers' and principals' observations suggest children's play becomes strikingly more creative, physically active, and more social in the presence of loose parts (e.g., Bundy et al., 2008, 2009). Interestingly, it appears that nature, loose parts, and autonomy can each independently contribute to outcomes (see Bundy et al., 2009; Niemiec and Ryan, 2009; Studente et al., 2016, respectively), raising the possibility of synergy among these factors. Although the effects of loose parts play on child development have yet to be quantitatively demonstrated (Gibson et al., 2017), the potential contributions of more creative, more social, more physically active play to cognitive, social and physical development seem clear.

OUTCOMES FOR LEARNING AND DEVELOPMENT

In school settings, incorporating nature in instruction improves academic achievement over traditional instruction. In a randomized controlled trial of school garden-based instruction involving over 3,000 students, students gained more knowledge than waitlist control peers taking traditional classes; moreover, the more garden-based instruction, the larger the gains (Wells et al., 2015). Further, among the over 200 other tests of nature-based instruction's academic outcomes, the vast majority of findings are positive (for reviews, see Williams and Dixon, 2013; Becker et al., 2017) – and here, too, the most impressive findings come from studies employing the largest doses of nature-based instruction (e.g., Ernst and Stanek, 2006). Findings have been consistently positive across diverse student populations, academic subjects, instructors and instructional approaches, educational settings, and research designs.

Interestingly, both the pedagogy and setting of nature-based instruction may contribute to its effects. Hands-on, student-centered, activity-based and discussion-based instruction each outperform traditional instruction—even when conducted indoors (Granger et al., 2012; Freeman et al., 2014; Kontra et al., 2015). And simply conducting traditional instruction in a more natural setting may boost outcomes. In multiple studies, the greener a school's surroundings, the better its standardized test performance – even after accounting for poverty and other factors (e.g., Sivarajah et al., 2018)—and classrooms with green views yield similar findings (Benfield et al., 2015; although c.f. Doxey et al., 2009). The frequency of positive findings on nature-based instruction likely reflects the combination of a better pedagogy and a better educational setting.

In and outside the context of formal instruction, experiences of nature seem to contribute to additional outcomes. First, not only do experiences of nature enhance academic learning, but they seem to foster personal development – the acquisition of intrapersonal and interpersonal assets such as perseverance, critical thinking, leadership, and communication skills. While quantitative research on these outcomes is rare, the qualitative work is voluminous, striking, and near-unanimous (for reviews, see Cason and Gillis, 1994; Williams and Dixon, 2013; Becker et al., 2017). Teachers, parents, and students report that wilderness and other nature experiences boost self-confidence, critical thinking, and problem-solving (e.g., Kochanowski and Carr, 2014; Truong et al., 2016) as well as leadership and communication skills such as making important decisions, listening to others, and voicing opinions in a group (e.g., Jostad et al., 2012; Cooley et al., 2014). Students emerge more resilient, with a greater capacity to meet challenges and thrive in adverse situations (Beightol et al., 2012; Cooley et al., 2014; Harun and Salamuddin, 2014; Warber et al., 2015; Richmond et al., 2017). Interestingly, greener everyday settings may also boost positive coping (Kuo, 2001) and buffer children from the impacts of stressful life events (Wells and Evans, 2003).

And second, spending time in nature appears to grow environmental stewards. Adults who care strongly for nature commonly attribute their caring to time, and particularly play, in nature as children – and a diverse body of studies backs them up (for review, see Chawla and Derr, 2012). Interestingly, the key ingredient in childhood nature experiences that leads to adult stewardship behavior does not seem to be conservation knowledge (knowledge of how and why to conserve). Although knowledge of how and why to conserve, which could presumably be taught in a classroom setting, has typically been assumed to drive stewardship behavior, it is relatively unimportant in predicting conservation behavior (Otto and Pensini, 2017). By contrast, an emotional connection to nature, which may be more difficult to acquire in a classroom, is a powerful predictor of children's conservation behavior, explaining 69% of the variance (Otto and Pensini, 2017). Indeed, environmental attitudes may foster the acquisition of environmental knowledge (Fremery and Bogner, 2014) rather than vice versa. As spending time in nature fosters an emotional connection to nature and, in turn, conservation attitudes and behavior, direct contact with nature may be the most effective way to grow environmental stewards (Lekies et al., 2015).

CONCLUSION AND IMPLICATIONS

Do experiences with nature really promote learning? A scientist sampling some of the studies in this area might well be dismayed initially – as we were – at the frequency of weak research designs and overly optimistic claims. But a thorough review reveals an evidence base stronger, deeper, and broader than this first impression might suggest: weak research designs are supplemented with strong ones; striking findings are replicated in multiple contexts; the research on nature and learning now includes evidence of mechanisms; and findings from entirely outside the study of nature and learning point to the same conclusions.

Robust phenomena are often robust because they are multiply determined. The eight likely pathways between exposure to nature and learning identified here may account for the consistency of the nature-learning connection. Certainly it seems likely that increasing a student's ability to concentrate, interest in the material, and self-discipline simultaneously would enhance their learning more than any of these effects alone. Moreover, in a group setting, effects on individual learners improve the learning context; when Danika fidgets less, her seatmates Jamal and JiaYing experience fewer disruptions and concentrate better; when Danika, Jamal, and JiaYing are less disruptive, the whole class learns better. These synergies – within and between students – may help explain how relatively small differences in schoolyard green cover predict significant differences in end-of-year academic achievement performance (e.g., Matsuoka, 2010; Kuo et al., 2018b).

An important question arose in the course of our review: is nature-based instruction effective for students for whom traditional instruction is ineffective? Although this review was not structured to systematically assess this question, the benefits of nature-based learning for disadvantaged students were a striking leitmotif in our reading. Not only can nature-based learning work better for disadvantaged students (McCree et al., 2018; Sivarajah et al., 2018), but it appears to boost interest in uninterested students (Dettweiler et al., 2015; Truong et al., 2016), improve some grades (Camassao and Jagannathan, 2018), and reduce disruptive episodes and dropouts among "at risk" students (Ruiz-Gallardo et al., 2013). Nature-based learning may sometimes even erase race- and income-related gaps (e.g., Taylor et al., 1998). Further, anecdotes abound in which students who ordinarily struggle in the classroom emerge as leaders in natural settings. If nature is equigenic, giving low-performing students a chance to succeed and even shine, the need to document this capacity is pressing. In the United States, where sixth graders in the richest school districts are four grade levels ahead of children in the poorest districts (Reardon et al., 2017), this need is urgent.

Fully assessing and making use of the benefits of nature-based instruction can serve all children. The available evidence suggests that experiences of nature help children acquire some of the skills, attitudes, and behaviors most needed in the 21st century. "Non-cognitive factors" such as perseverance, self-efficacy, resilience, social skills, leadership, and communication skills – so important in life beyond school (National Research Council, 2012) – are increasingly recognized by the business community and policy makers as essential in a rapidly changing world. And for generations growing up in the Anthropocene, environmental stewardship may be as important as any academic content knowledge.

We conclude it is time to take nature seriously as a resource for learning and development. It is time to bring nature and nature-based pedagogy into formal education – to expand existing, isolated efforts into increasingly mainstream practices. Action research should assess the benefits of school gardens, green schoolyards and green walls in classrooms. Principals and school boards should support, not discourage, teachers' efforts to hold classes outdoors, take regular field trips, and partner with nearby nature centers, farms, and forest preserves. Teachers who have pioneered nature-based instruction should serve as models and coaches, helping others address its challenges and take full advantage of its benefits.

AUTHOR CONTRIBUTIONS

All authors co-wrote and edited the manuscript. MK provided leadership for decisions of content, framing, and style and led the creation of the Figure and Table. MB created the SoNBL literature database on which this review is based. CJ serves as the principal investigator of the Science of Nature-Based Learning Collaborative Research Network project; in addition to initiating this project and substantially shaping the Figure and Table, she solicited feedback from Network members.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00305/full#supplementary-material

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A Coordinated Research Agenda for Nature-Based Learning

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Evidence is mounting that nature-based learning (NBL) enhances children's educational and developmental outcomes, making this an opportune time to identify promising questions to carry research and practice in this field forward. We present the outcomes of a process to set a research agenda for NBL, undertaken by the Science of Nature-Based Learning Collaborative Research Network, with funding from the National Science Foundation. A literature review and several approaches to gathering input from researchers, practitioners, and funders resulted in recommendations for research questions and methodological improvements to increase the relevance and rigor of research in this field. Some questions seek to understand how learning in nature affects what children learn, how they learn, and how it varies based on age, gender, socioeconomic status, ethnic background, special needs, and individual differences. Outcomes of interest cover academic performance, practical skills, personal development, and environmental stewardship. Other questions seek to find causal explanations for observed outcomes. To create optimal conditions for NBL, the research agenda includes practical questions about how to prepare teachers to work successfully in nature and how to support their adoption of this approach. Not least, the research agenda asks whether learning in nature can address major societal issues by moderating the effect of socioeconomic disadvantage on children's academic achievement, personal development and wellbeing, and how these benefits might be attained at reasonable costs. A deeper understanding of how, why and for whom different forms of nature contact enhance learning and development is needed to guide practice and policy decision-making.

Keywords: nature-based learning, research agenda, children, academic outcomes, personal development, environmental stewardship

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INTRODUCTION

Although evidence is accumulating for the impact of nature-based learning (NBL) on children's outcomes, there is much we don't know (Kuo et al., 2019). A deeper understanding of how, why, for whom, and under what circumstances different forms of nature contact enhance learning and development is needed to guide practice and policy decision-making. This article presents the outcome of an initiative to define NBL and set a research agenda to advance the pace and rigor of research on its impact.

In 2015, the United States National Science Foundation (NSF) provided a 3-year grant to the University of Minnesota, the Children & Nature Network (C&NN), the North American Association for Environmental Education (NAAEE), and the University of Illinois Urbana-Champaign to establish the Science of Nature-Based Learning Collaborative Research Network (NBLR Network). On three occasions, the NBLR Network convened two dozen academic researchers from diverse disciplines, practitioners, environmental organization representatives, and funders from across the United States. The Network aimed to: (1) jointly develop a definition and research agenda to inform the rigorous development of the science of NBL, (2) disseminate research-based information, and (3) conduct collaborative research responsive to this agenda (Jordan et al., 2017). This article reports on the first aim of developing a definition and research agenda. It draws on an integrative literature review to determine and disseminate the status of our understanding of NBL impacts and explanatory mechanisms (see Kuo et al., 2019). Collaborative research that is responsive to agenda questions is currently underway.

The term "nature-based learning" was introduced in the grant application to NSF as part of an effort to coordinate research that had been scattered across multiple disciplines. NBLR Network members were sent a draft definition of this term by this article's authors, and they responded with suggestions and comments. Successive revisions were circulated until members of the network agreed on the following definition and scope for this field.

Nature-based learning, or learning through exposure to nature and nature-based activities, occurs in natural settings and where elements of nature have been brought into built environments, such as plants, animals, and water. It encompasses the acquisition of knowledge, skills, values, attitudes, and behaviors in realms including, but not limited to, academic achievement, personal development, and environmental stewardship. It includes learning about the natural world, but extends to engagement in any subject, skill or interest while in natural surroundings. NBL can occur with varying degrees of guidance or structure, across the age span, alone or with others, and in urban, suburban, rural, and wilderness settings. NBL occurs in informal, non-formal, and formal settings (La Belle, 1982).[1] With respect to children's NBL, it includes *informal* learning during children's free play or discovery in nature in their yards, near their homes, in green schoolyards, on the naturalized grounds of child care centers, or in any other natural area. It includes *non-formal* learning in nature during out-of-school programs, camps or family visits to parks or nature centers. And it includes *formal* learning when children have contact with nature during structured activities in schools, preschools, and child care centers, or during outdoor field trips.

The following section of this article reviews the methods used to develop an NBL research agenda. A subsequent section summarizes the agenda's major questions grounded in the literature and in the minds of educators, researchers, and funders, as well as recommendations for methods, measures, and designs that will be complementary and rigorous. The intent of this article is to encourage more coordination and collaboration among researchers, to promote a focus on the most pertinent research questions and most robust methods in order to advance this field, and to make a case for the importance of NBL as a field for study as well as practice. We acknowledge the boundary that participants in this agenda-setting process were drawn from the United States. They considered existing studies from around the world and intended their work to be useful internationally; yet different countries may have different research cultures, and this agenda might reflect different emphases if it were generated in another part of the world.

METHODOLOGY IN DEVELOPING THE RESEARCH AGENDA

Assembling Diverse Perspectives on NBL

This section traces the process of setting a research agenda during the 3-year period of the National Science Foundation grant that began in September 2015. The project's coordinating team from the grant's four lead institutions worked together to identify academic researchers, practitioners, representatives of environmental organizations, and funders from across the United States whose work related to NBL, with the goal of assembling a diverse membership for the NBLR Network, based on a variety of disciplines, methodological approaches, and stakeholder connections. The 23 members of the network first convened in November 2015 for a 3-day retreat to build relationships, agree on a common vision and direction for work, and discuss possibilities for interdisciplinary collaboration. In January 2016, NBLR Network members were asked to share written answers to the following questions, which guided development of the research agenda.

(1) What is the status of our knowledge about whether, how, why, under what circumstances and for whom nature impacts children's learning?
(2) What are the strengths and limitations of the research?
(3) What research questions would most effectively advance knowledge relevant to practice and policy?
(4) Are there considerations about the state of the current research that suggest methodological recommendations for the field?

After members shared their written reflections, they participated in conference calls to further elaborate and interpret responses.

Several means were used to capture the ideas of funders and practitioners, beyond representatives of these groups in the NBLR Network. The May 2016 C&NN conference provided two opportunities for group discussion—the Blue Sky Funders' Forum and an open forum for conference attendees. Both provided occasions to tap non-NBLR Network thinking regarding needs for additional research. The Natural Start

[1] In the United States, the National Science Foundation distinguishes *formal* and *informal* learning, putting *non-formal* and *informal* in one category. The three-part distinction among *formal*, *non-formal,* and *informal*, used here, which is widely used in Europe and the work of UNESCO, better reflects the diversity of practices in the NBLR Network.

Alliance nature-based preschool conference in August of 2016 and the Research Symposium associated with the October 2016 NAAEE conference offered opportunities for small group discussions with other constituencies regarding research gaps and needs. Finally, a member survey administered by NAAEE highlighted the work of the NBLR Network and collected additional input. For more details about NBLR Network strategies, processes for identifying and convening network members, members' disciplines and fields of practice, and processes to gather information from other groups, see section "Network Participants and Processes" and Jordan et al. (2017).

Network Participants and Processes

In September 2015, at the beginning of the National Science Foundation grant supporting the Science of Nature-Based Learning Collaborative Research Network (NBLR Network), the project's coordinating team worked together to assemble diverse perspectives on research to understand and apply NBL. They invited researchers to the NBLR Network whose disciplines included educational science, cognitive science, early childhood education, environmental education, developmental psychology, ecopsychology, environmental psychology, environmental neuroscience, stress neurobiology, environmental design and landscape architecture. Researchers brought expertise in qualitative and quantitative methods, field observation studies, intervention studies, neuropsychological assessment, behavioral mapping, and participatory action research. Participants from other sectors included teachers, teacher educators, leaders of professional societies, funders, and science communicators. In addition to 18 invited individuals, the NBLR Network included Principal Investigators from the lead organizations and staff from C&NN, for a total of 23 members.

Network members gathered in person on three occasions: two working retreats in November 2015 and November 2016, and as part of an expanded NBL Research Action Area that was part of the C&NN Network Leadership Summit in June 2018. Outside of meetings, members communicated through email and regularly scheduled conference calls. Agenda setting was a major focus of the November 2016 retreat and communication during 2017 and early 2018.

During the May 2016 C&NN Conference, about 40 people participated in a Funders' Forum that included representatives of organizations that might consider funding NBL research and application, along with a few members of the NBLR Network. After listening to a panel of speakers present existing evidence relevant to NBL and new areas for investigation, people broke into small groups for facilitated discussions. Discussions were guided by the questions: "What do you, as funders, feel you need to know to help make connecting kids to nature a higher priority for funding? Given the knowledge we already have, how could you support taking action to apply existing knowledge?" At each table, people began by writing down their individual responses to these questions, and then engaged in group discussions. Later in the forum, facilitators synthesized and reported back on key ideas that emerged from people's written responses and discussions. This synthesis was shared with members of the NBLR Network.

At the same conference, several members of the NBLR Network convened a "research action lab" open to anyone attending the conference. About 100 people came, including educators, staff in nature-based non-profits, advocates for children and nature, researchers, and policy makers. They divided into five groups depending on the region where they worked in the United States or their international affiliation, and discussed the following questions: "What information do you need to make your efforts to connect children to nature to enhance learning outcomes more effective? How would you use that information? In what format do you want to receive the information resulting from the NBL Network's efforts to set a research agenda for the field?" Note takers recorded participants' responses and this information was reported back to the NBLR Network.

The August 2016 Natural Start Alliance conference for educators, school directors, and advocates for nature-based preschools, followed by the Research Symposium connected with the October 2016 NAAEE conference, offered opportunities for small group discussions about information that participants would find most helpful and important questions for NBL research. These discussions confirmed the value of questions that had already been identified by the preceding larger groups.

In the fall of 2016, NAAEE sent a survey to its members that included the questions: "How do you learn about new information in environmental education?" and "What kinds of information or research would help you develop, deliver, or refine programs to connect children to nature?" A group of NAAEE researchers created, pilot tested, and distributed the survey through naaee.org, eePRO (NAAEE's online platform for environmental education professional development), mailings to NAAEE members and subscribers, and social media. The survey remained open for 3 weeks and two reminder mailings were sent during that time frame. A total of 167 respondents completed the survey. A summary of the findings was shared with the NBLR Network.

Generating a Literature Review to Guide Agenda Discussions

During the summer of 2016, three members of the network prepared a research review of nature's impact on academic functioning, personal development and environmental stewardship, as well as explanatory variables related to learners and learning contexts. This review of existing research was a necessary foundation for identifying promising directions for future research. Details about the review scope, scale and procedures, including search keywords and operational definitions of key terms, are provided in the review article by Kuo et al. (2019). The literature review consisted of three main phases, which are described here.

Phase 1

The first step was to utilize recent peer-reviewed research summaries relevant to NBL and identify major themes related to NBL at the time of their publication. Articles covered in these previous reviews were added to the review database. The purpose of this phase was to understand the previous state of the literature and the main themes in the literature at the time of past reviews' publication.

Phase 2

The second step was to collect peer reviewed journal articles that were published since the cut-off dates for previous reviews. This research was limited to articles published in English, although the research may have been conducted anywhere in the world, and it included work that addressed any aspect of learning and developmental outcomes associated with any aspect of nature, utilizing a variety of research methods. At this time, the purpose was to update and expand findings from the previous review papers, and to present the diversity of the literature as a whole.

Phase 3

The third and last step to identify relevant research was intended to extend and deepen results of the preceding steps. It included two processes. Because some topic areas yielded only a few articles during the initial searches, specific searches were conducted to determine if these were in fact little studied areas or under-sampled by the preceding searches. Additionally, foundational papers and reviews were sought that shed light on potential mechanisms that connect nature and learning, though these publications may have come from general research on topics such as learning, cognitive science, or developmental outcomes. For example, if existing studies indicated that learning in nature sparked children's curiosity, then there was a search for papers which reviewed the general role of curiosity in learning. The purpose was to create a cohesive narrative that suggested mechanisms through which nature might affect learning outcomes.

A link to a spreadsheet of the articles retrieved during these three phases of the literature review is reproduced here: https://goo.gl/FZ1CA9, as well as in the review by Kuo et al. (2019).

Identifying Directions for Future Research

A draft of the literature review was presented at the second NBLR Network retreat in November 2016. Network members considered the review, along with results of their own written reflections and the input gathered through C&NN and NAAEE. People worked in small groups to develop focal areas and questions for the research agenda. Because their goal was to advance research that can be translated into educational policy and practice, members proposed the following criteria, in addition to feasibility, as they deliberated.

Research agenda questions should do one or more of the following:

(1) Address major social issues in a compelling way
(2) Affect large populations
(3) Cross developmental stages
(4) Translate into educational policy to help teachers and school administrators enhance students' academic success
(5) Suggest how institutions can promote stewardship values and behaviors
(6) Help designers and urban planners create places where children can connect with nature in meaningful ways
(7) Achieve valued public goals in cost-effective ways, in some cases even saving public money

Applying these criteria, retreat attendees voted for questions they considered most important to advance the field of NBL.

During 2017, a report on the voting results and associated discussions was distributed to network members. Drawing on this report, reports on the C&NN conference Funders' Forum and open forum, and NAAEE survey, the authors of this article condensed and categorized the questions generated, along with methodological recommendations, and circulated them to the NBLR Network in early 2018. Feedback was gathered through email and conference calls. Questions and recommendations developed as a result of this process, vetted by NBLR Network members, are presented in the sections below.

Agenda Consensus and Challenges

Through NBLR Network discussions and input from the Funders' Forum, 2016 C&NN Conference, and NAAEE survey, more questions were generated than a research agenda could accommodate, given its goal of bringing people together in coordinated, collaborative research rather than dispersing research efforts in many unconnected directions. The challenge of gaining consensus around a few key questions was addressed in several ways. At their November 2016 retreat, members of the NBLR Network began their review of research gaps and promising research directions by generating criteria for the most productive questions. They used these criteria as they reviewed the questions that they initially suggested in individual written reflections, as well as questions proposed by the funders, C&NN conference attendees, and NAAEE survey respondents. On this basis, they drafted questions that they posted on a wall and voted on. A report was generated that contained the resulting questions and summaries of associated discussions.

The authors of this article then took this report and the reports from other groups' meetings—keeping agreed-on criteria in mind—and drafted **Tables 1**, **2** for this article. They sought to balance questions generated from the perspectives of research and practice, as the NBLR Network agreed on the importance of both sides. Reflecting contributors' diverse backgrounds, questions that invited quantitative, qualitative, action research and mixed-methods were valued equally. Questions that were raised repeatedly were included; but to be consistent with the criteria agreed to by the NBLR Network, a focused effort was made to include questions relevant to the goals of promoting healthy child development, addressing important social and environmental issues, and guiding policy and practice. When the initial draft of **Table 1** was circulated, some network members suggested that emphasis be given to questions with significant policy and practice applications by creating a second table. For this purpose, questions of this kind that network members highlighted were repeated or reworded in **Table 2**. Drafts of both tables were shared with network members, who discussed them via conference calls and email. The tables were revised and shared with the network again for final approval before inclusion in this article.

TABLE 1 | A framework for research to advance the understanding and implementation of nature-based learning (NBL).

A. Learning outcomes and differential effects

Learning outcomes

How effectively do children learn content and skills through NBL compared with instruction in classrooms where nature is absent?

- How do schools or classrooms that practice NBL compare with schools or classrooms without nature with respect to academic achievement, graduation rates, and student and parental satisfaction?
- How do nature-based preschools and kindergartens compare with conventional early childhood programs that emphasize indoor learning in terms of preparing children for school readiness?
- Are there situations when NBL is more effective and when classroom-based instruction is more effective?
- How might NBL and classroom-based instruction complement each other?

What is the range of learning outcomes influenced by nature?
*Motivation to learn/knowledge gain/skill development/creativity/curiosity/cognitive processes such as attention, encoding, retention, recall/executive skills such as behavior regulation/social and emotional learning/reduced stress, improved mood and mental health/physical health/academic performance such as test scores and graduation rates/environmental stewardship values and behaviors**

Does NBL contribute to stewardship values or conservation behaviors?

Differential effects based on age, population group, and individual differences

Learning outcomes

How do age and developmental stage influence the relationship between nature and learning?

- What are key elements of nature experiences important at different ages?
- What different forms of knowledge, skills, values, attitudes, and behaviors develop in nature at different ages?
- Are there critical windows for the development of different outcomes in nature?

To promote academic achievement, personal development and environmental stewardship, what types of nature experiences are most appropriate at different ages?

How does NBL affect special populations in terms of learning outcomes?

- How does NBL affect children from socioeconomically disadvantaged families?
- Does the impact of NBL differ based on historic relationships with nature grounded in cultural or ethnic background?
- Are there gender differences in nature's impact on children?
- How does nature exposure impact learning for children with special needs such as ADHD, autism or learning disabilities?

Are there individual differences in response to NBL? What determines why there may be different outcomes for children involved in the same experience?

B. Mechanisms of influence

What are the mechanisms that underlie the relationship between nature and learning?
*More focused attention/improved behavior regulation/increased creativity/reduced stress/greater enthusiasm for and engagement in learning/increased physical activity/improved health and wellbeing/calmer, quieter learning context/more cooperative social context/opportunities for autonomous discovery and action/self-perception/self-identity/connection between content and the child's locality/enhanced sense of purpose**

- What mediator variables explain the relationship between nature and learning outcomes, and what is the influence of different variables separately and in combination?
- Is it possible to establish that nature impacts learning and development in a causal manner?
- What moderator variables influence the strength of the relationship between nature and learning outcomes?

Do mechanisms vary for different groups, in different contexts? If NBL has such differential effects, why?

What are key elements of nature experiences that affect children?
*Type of natural features/type of activities such as unstructured play and exploration, guided inquiry and adult-led instruction/degree of manipulation of natural elements/duration/frequency/individual or group experience/type of people with the child, such as teacher, parent, naturalist, classmates, friends/degree of teacher preparation and confidence in NBL approaches**

Does nature bring associated ingredients of learning together in a distinctive way? For example, does it bring opportunities for unstructured exploration, freedom to manipulate natural materials, creativity, and social cooperation together in a unique or synergistic way?

How do interpersonal dynamics among children, parents, friends, and teachers influence NBL?

How might power hierarchies or social stereotypes based on race, ethnicity, culture, class, gender or age influence NBL?

What does nature do to the brain?

- What are the channels of nature's effects?
  *Sight/sound/smell/touch/emotion/movement**
- Does the impact of nature on the brain differ based on age?
- Does nature contact influence the development of the brain in terms of structure or physiology?

(Continued)

TABLE 1 | Continued

What is the impact on learning when access to nature is reduced?
*Removing recess in spaces with nature/no green views from school windows/more screen time**
C. Implications for policy and practice
Policy or practice
What nature-based experiences are most appropriate for different developmental stages of childhood to achieve optimal learning outcomes?
Can NBL play a role in reducing the opportunity gap and achievement gap between children from more and less advantaged backgrounds?
How does nature compare with other programs and approaches that compete for educational funding in terms of its effectiveness in enhancing learning?
What are the effects on learning of the cheapest and easiest ways of bringing nature into schools and day care centers?
What are NBL best practices in different educational contexts?
What evidence, messages, and strategies encourage increased demand for NBL and the application of NBL practices by educators, parents and other people who have influence over opportunities for children?
What determines differences in access to nature, green school grounds, and NBL?
Is NBL a social justice issue?
Preparation and professional development
What are the best strategies for teachers to use to enhance student learning in nature?
What are effective practices for preparing and supporting teachers and administrators in the adoption of NBL in their classrooms and schools?
What are barriers to teachers' and administrators' adoption?
Technology augmented learning
How does technology augment, simulate or mediate NBL? Are there costs as well as benefits?
How does nature mediated or augmented through technology impact learning compared to experiences of real nature?
Under what conditions is technology effective in enhancing nature's impact on learning?
How can we leverage technology to present nature in new ways for learning?
How would new technologies function that do not substitute for nature, or for interaction with nature, but add additional forms of interaction?

**This list is suggestive, based on current evidence, but not necessarily complete.*

A limitation of this process was that there were no opportunities to reconvene participants in the Funders' Forum, C&NN action lab, or NAAEE survey for their reviews of the draft tables. An inherent limitation is that the tables reflect the ideas of the people involved, whereas different collections of participants may have generated different results. Although contributors to the agenda setting process were composed of researchers who represented diverse disciplines, funders of child-nature related research and programming, and practitioners who provided children with nature experiences both in-school and out of school, an even more diverse group in terms of knowledge, expertise, interests, and cultural backgrounds may have provided additional perspectives on research directions. No members of the NBLR Network, for example, represented child psychiatry, social work or anthropology, and there may have been other relevant fields to consider. The network was limited to people with publications related to NBL, who were willing to commit to the considerable amount of time that network activities required, and by the funding available to bring people together. On the practical side, given the goal of creating a network of people who could hold productive whole-group and small-group discussions in person or via conference calls and email, it was necessary to contain the group to a number that enabled people to function in this way.

PRIORITY RESEARCH QUESTIONS

Table 1 presents the key research areas and questions that emerged through this agenda setting process, with three areas of emphasis: Learning Outcomes and Differential Effects, Mechanisms of Influence, and Implications for Policy and Practice. Where some contributors to the agenda approached a general question from specific perspectives, these variations on the general question are bulleted. Topics that suggest the range of areas that a question might explore are indicated in italics.

As authors of this paper, we have observed that the study of NBL reflects the convergence of two research traditions: one interested in the influence of experiences in nature on learning across the curriculum, personal development, and environmental stewardship; and the other concerned with the influence of natural settings and surroundings on conditions for learning. The first tradition has a long history. Fieldwork in nature to learn subjects like biology and geology is well established in environmental education and science education, and the resurgence of school ground greening and school gardens has created conditions for "fieldwork" immediately outside school doors (for research reviews of different forms of outdoor learning, see Dillon et al., 2006; Williams and Dixon, 2013; Stern et al., 2014; Malone and Waite, 2016; Becker et al., 2017). The use of the environment as an integrating context to engage students in math, science, social studies, language arts and other disciplines as they study the world beyond school walls, including natural areas, is the domain of place-based education (Smith and Sobel, 2010; Chawla and Derr, 2012). There is also a long history of observations of children's informal learning as they play and explore on natural school grounds and find nature in their local environment (Chawla, 2015). The questions in **Table 1** indicate that many aspects of outdoor learning still need to be better understood, but work in this area has much to build on as it moves forward.

TABLE 2 | Examples of "game-changing" research questions and justifications.

Question	Justification
Can nature reduce educational opportunity gaps and achievement gaps between children from different economic backgrounds?	Contact with nature shows an array of benefits for children across socioeconomic lines, at the same time as research shows that low-income families are more likely to live in urban neighborhoods with low levels of vegetation and smaller, less safe and less maintained parks, compared to middle- and high-income families (Jesdale et al., 2013; Chawla, 2015; Rigolon, 2017). Therefore, benefits of bringing children from disadvantaged backgrounds to nature and nature to their schools, child care centers and neighborhoods merits particular attention.
If learning in nature can enhance children's achievement and wellbeing, how do its costs compare with other approaches that compete for educational funding?	Research is needed that analyzes the economic costs of NBL practices relative to other interventions that lack natural elements. Cost accounting should include the full valuation of NBL in terms of impact on academic achievement, physical health, mental health, behavioral function, engagement in learning, use of special education services, and interaction with the criminal justice system. A compelling case for NBL can be made if educational outcomes are similar to conventional approaches but produce cost-savings in additional arenas, and an even more compelling case if NBL can narrow gaps in educational outcomes compared to conventional approaches.
What are the mechanisms that underlie the relationship between nature and learning?	Understanding how contact with nature facilitates and improves learning will permit the effective and efficient delivery of NBL experiences and the design of natural areas to best promote learning and development. For example, if research shows that nature enhances learning by reducing stress, then programs and settings should be designed to activate this pathway: and similarly with other potential pathways such as more focused attention or more cooperative and supportive social dynamics.
How does nature impact the learning of children with special needs as a result of physical health, mental health, or cognitive conditions; learning differences; or educational disadvantages due to low income?	When individuals with special needs or disadvantages in the educational setting do not benefit from education as much as they could or do not find meaningful roles in society, there are high costs to those individuals, their families, school districts, and society in terms of expenses, lost potential and reduced well-being.
What teacher characteristics and practices enhance the association between NBL approaches and educational outcomes? How can teachers be prepared and supported to adopt NBL practices?	The impact of NBL is partially dependent on the attitudes, skills and practices of teachers (Mcfarland et al., 2013). Understanding how teachers learn to value NBL, integrate it into their school day, and promote positive outcomes will facilitate effective teacher preparation and professional development programs. This information will suggest how programs of teacher education and school administrators can best support the adoption and effective implementation of NBL strategies, in both pre-service and in-service settings.
What knowledge and experiences promote people's motivation and competence to protect the integrity of natural landscapes and ecosystems? How can these experiences be integrated into NBL practices?	Information is gathering on many sides that basic systems of the biosphere that support human health and wellbeing and the survival of other species are rapidly deteriorating (Millenium Ecosystem Assessment, 2005; Intergovernmental Panel on Climate Change, 2014). An essential dimension of NBL is learning to understand and care for the natural world.
How can technology be most effectively harnessed to enhance the outcomes of NBL?	Technology is a common feature in current and future-looking educational programs; yet technology can be overused, resulting in reduced engagement in active, enriching activities (Singer et al., 2009), including those in nature and disrupting cognitive functioning and optimal mental health (Chassiakos et al., 2016). Therefore, it is important to understand how technology can be used as a tool to enhance nature experiences or to present nature while mitigating risks of overuse.

The second tradition—investigating the influence of nature on conditions for learning—has emerged recently, demonstrating that vegetation and other elements of nature in classrooms, on school grounds, and in the proximity of schools are associated with more effective cognitive functioning, decreased stress, improved health, and enhanced classroom and social learning environments—all of which can facilitate learning and higher student achievement (see reviews by Chawla, 2015; Gifford and Chen, 2016; Becker et al., 2017; Kuo et al., 2019). Many studies of this topic suggest productive directions for further investigation. Whereas the first research tradition focuses on learning in nature to enhance knowledge, skills and personal development, this second tradition involves children's basic wellbeing and capacity to learn efficiently. Recently, and partly with the assistance of the NSF grant to promote the Science of Nature-Based Learning, people from these different backgrounds have been sharing their work at conferences and other professional meetings.

The questions in **Table 1** suggest an ambitious agenda for moving an understanding of NBL forward. They seek to understand how learning in nature affects what children learn, how they learn, and how it varies based on age, gender, socioeconomic status, ethnic background, special needs, and individual differences. They investigate the relative benefits of learning in nature and through conventional classroom-based instruction, and learning in settings where there is nature in and around buildings with learning in predominantly hardscaped, built surroundings. Outcomes of interest cover academic performance, practical skills, personal development, and environmental stewardship. Other questions seek to identify mechanisms of action in NBL and find causal explanations for the outcomes observed. To create effective conditions for NBL, the research agenda includes a number of practical questions about how to prepare teachers to work successfully in nature and encourage their adoption of this approach. Possibilities for using technology to augment learning in nature also merit exploration (such as approaches identified in Kahn, 2011). Not least, the research agenda asks whether learning in nature can address major societal issues by moderating the effect of socioeconomic disadvantage on children's outcomes, and how these benefits might be attained at reasonable costs. Although these questions outline an ambitious agenda for future research, promising results of past studies suggest that further investment in this field may significantly benefit children and their societies.

In drafting this research agenda, funders, researchers who focus on school-based initiatives, and practitioners emphasized the importance of systematically investigating how to most effectively disseminate results of NBL research and encourage implementation. It is important to match growing evidence of benefits of learning in nature with outreach to teachers, school administrators, school boards, schools of education, child care center directors and people in other institutions who have opportunities to apply nature-based approaches. Effective outreach depends on understanding barriers to the integration of NBL into teacher preparation and practice, how barriers can be lowered, and the types of data and messages that will help practitioners understand the value of NBL. Similar questions need to be asked relative to reaching the public at large, in order to build public support for NBL.

Though not comprehensive, the questions offered in the research agenda have the potential to significantly advance our knowledge and ability to inform policy and practice in an array of areas. Given the wide range of subjects covered by the questions proposed for this research agenda, it is reasonable to ask where to begin or what to prioritize. In **Table 2**, we offer a set of "game-changing" questions—research questions that are most likely to yield critical information for practice and policy decision-making.

RECOMMENDATIONS FOR FUTURE RESEARCH APPROACHES

Significant scientific advances are made not only by asking the most relevant and important questions, but by utilizing approaches that will yield the most useful, valid and reliable information. What general recommendations can be made to strengthen future research in this field?

The researchers, practitioners, and funders who helped define this research agenda recommend a more coordinated approach to NBL research in the future. In part, this will require periodic syntheses of what is already known in relation to the questions in **Tables 1**, **2**, to guide further efforts to fill in gaps in understanding. To facilitate research syntheses, C&NN established an online Research Library that deposits, on an ongoing basis, lay summaries of new studies related to NBL as well as other aspects of children's relationship with nature[2]. C&NN's monthly Research Digest has begun to curate existing research on selected themes, such as equitable access to nature's benefits[3]. C&NN and NAAEE now provide a central location to access the combined resources of C&NN's and NAAEE's research libraries[4] to provide comprehensive coverage of the two traditions of investigation reflected in this research agenda.

More coordinated research will also require the consistent use of adequate descriptions of study contexts as well as consistent measures of study variables (see also Kuo et al., 2019). Qualitative and quantitative researchers need to specify learning settings and activities, including elements of nature in each setting, length of children's time in nature, and how children engage with nature—whether it is a passive view or background, or they use it actively through their own autonomous exploration or encounters facilitated by teachers, peers or other people. Complete descriptions are important for understanding and applying results and identifying potential causal mechanisms that underlie learning.

Coordinated progress in quantitative research and experimental designs will be furthered by agreement on valid, reliable measures of nature exposure, mediating variables and learning outcomes. Many measures already exist, and they need to be evaluated to understand which are most effective with different age groups and in different learning contexts. A working group is underway to do this for measures of nature connection, but similar evaluations are needed of other key variables important for this research agenda. It would be helpful to have an online bank of NBL measures that researchers can draw from, along with examples of studies where they have been applied and recommendations for their appropriate use. This would encourage more reliable comparisons across studies.

Nature-based learning research needs to move forward through complementary methodological approaches. Different methods are required to investigate questions of different kinds, and therefore the field of NBL will be advanced most effectively by different methods and mixed-method approaches. For example, to understand how NBL and classroom-based approaches compare or complement each other, it can be helpful to begin with observations and interviews with teachers and students, in order to identify similarities and differences. Qualitative results may suggest how settings with and without nature afford different opportunities for teaching and learning, which may lead to different outcomes; and these outcomes can then be tested in more controlled ways through experimental designs. Experimental designs can also investigate the mechanisms that underlie results. As experiments and correlational studies establish with increasing confidence key variables that affect learning, the case builds for investments in longitudinal research that can track the effect of key variables over time. Some objectives, such as quantifying the effect of learning in nature preschools on performance in elementary school, can be addressed with relatively short-term studies; others, such as tracing the effect of childhood learning in nature childhood learning on environmental stewardship values and behaviors in adulthood, require long-term studies.

Nature-based learning research will be advanced through collaboration between academic researchers and practitioners and through multidisciplinary and multiethnic perspectives.

[2]childrenandnature.org/research-library

[3]https://www.childrenandnature.org/learn/research-digest/

[4]naaee.org/eeresearch

In participatory research, practitioners, parents and young people themselves can help at different stages of research, including defining questions, designing and implementing studies, interpreting results, and disseminating outcomes. The audiences that researchers seek to reach are best qualified to identify the type of information that will catch their attention and resonate with their values and practical considerations. For example, the experiment reported by Kuo et al. (2018) was designed to test the validity of teachers' common fear that if they take a class to an outdoor setting in nature, students will never settle down to concentrate on lessons after they return to the school building (finding, in contrast, that students concentrated better in their subsequent indoor class). In a similar way, researchers can identify NBL outcomes that matter most to teachers, school administrators, parents and children themselves as promising directions for research efforts.

CONCLUSION

Existing research suggests that NBL has many positive outcomes for children's learning and development. It suggests promising directions for future investigation; but to move forward, NBL research will benefit from a clear definition and a coordinated agenda. This paper has attempted to provide this framework by presenting a definition and a list of priority questions that have been drafted and reviewed by academic researchers from diverse disciplines, practitioners, environmental organization representatives, and funders.

Priority questions for future research cluster into three domains: (1) learning outcomes, including understanding how learning in nature compares with learning in classrooms, preschools and child care centers, and how outcomes may vary by age, gender, socioeconomic background, ethnic background, individual differences, or special needs; (2) the mechanisms that explain relationships between nature and learning; and (3) how to most effectively apply research to policy and practice. This Research Agenda also suggests that a few questions have the potential of uncovering relationships between nature and learning that could have "game changing" effects on the practices of policy makers, educators, school administrators, urban planners, designers, staff in nature centers and parks, parents, and other people who influence children's access to nature. With the aim of enhancing conditions for children's learning and development, this agenda seeks to accelerate progress on the science of NBL.

AUTHOR CONTRIBUTIONS

CJ served as the principal investigator of the Science of Nature-Based Learning Collaborative Research Network project. She surveyed the NBLR Network members, conducted discussion sessions at conferences, and supervised the graduate student conducting the literature review. She was involved in the generation and review of research questions, co-wrote the manuscript, and solicited input from NBLR Network. LC was a member of the NBLR Network. She was involved in the generation and review of research questions and co-wrote the manuscript.

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Do Lessons in Nature Boost Subsequent Classroom Engagement? Refueling Students in Flight

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Teachers wishing to offer lessons in nature may hold back for fear of leaving students keyed up and unable to concentrate in subsequent, indoor lessons. This study tested the hypothesis that lessons in nature have positive—not negative—aftereffects on subsequent classroom engagement. Using carefully matched pairs of lessons (one in a relatively natural outdoor setting and one indoors), we observed subsequent classroom engagement during an indoor instructional period, replicating these comparisons over 10 different topics and weeks in the school year, in each of two third grade classrooms. Pairs were roughly balanced in how often the outdoor lesson preceded or followed the classroom lesson. Classroom engagement was significantly better after lessons in nature than after their matched counterparts for four of the five measures developed for this study: teacher ratings; third-party tallies of "redirects" (the number of times the teacher stopped instruction to direct student attention back onto the task at hand); independent, photo-based ratings made blind to condition; and a composite index each showed a nature advantage; student ratings did not. This nature advantage held across different teachers and held equally over the initial and final 5 weeks of lessons. And the magnitude of the advantage was large. In 48 out of 100 paired comparisons, the nature lesson was a full standard deviation better than its classroom counterpart; in 20 of the 48, the nature lesson was over two standard deviations better. The rate of "redirects" was cut almost in half after a lesson in nature, allowing teachers to teach for longer periods uninterrupted. Because the pairs of lessons were matched on teacher, class (students and classroom), topic, teaching style, week of the semester, and time of day, the advantage of the nature-based lessons could not be attributed to any of these factors. It appears that, far from leaving students too keyed up to concentrate afterward, lessons in nature may actually leave students more able to engage in the next lesson, even as students are also learning the material at hand. Such "refueling in flight" argues for including more lessons in nature in formal education.

Keywords: classroom engagement, academic achievement, teaching outdoors, lessons in nature, environmental education

INTRODUCTION

When teachers offer lessons in relatively natural settings, students may benefit in a number of important ways. Academically, some evidence suggests students retain more after lessons in nature in biology and math (Fägerstam and Blom, 2012), language arts, social studies, and science more generally (Lieberman and Hoody, 1998) than after similar lessons indoors. Lessons in nature may also offer other benefits associated with exposure to trees, gardens, parks, and wildlife, including physical activity, stress relief, and the rejuvenation of attention (for reviews see Chawla, 2015; Kuo, 2015). Furthermore, as anthropogenic climate change becomes an increasingly pressing issue, lessons in nature may help build the next generation of environmental stewards; positive childhood nature experiences appear to play a key role in fostering pro-environmental behavior in adulthood (Monroe, 2003).

Perhaps in response to these important potential benefits, many European countries are incorporating lessons in nature in their formal schooling (Bentsen and Jensen, 2012); in the U.S., however, there has been relatively little embrace of outdoor formal instruction beyond the preschool setting (Ernst and Tornabene, 2012). One reason lessons in nature have not caught on in the U.S. may be a concern on the part of teachers that outdoor lessons will leave students keyed up and unable to concentrate. In the context of high-stakes testing, even temporary losses in classroom engagement are an important concern. Classroom engagement—the extent to which students are on-task and paying attention to the material or activity at hand—is both easily disrupted and a major driver of learning and academic success (Godwin et al., 2016). If lessons in nature do leave kids "keyed up" and unable to focus afterwards, then the benefits of that time may be outweighed by the costs.

Do lessons in nature impair subsequent classroom engagement? Our review of the environmental psychology literature suggests quite the opposite. Although we found no studies directly addressing this question, the indirect evidence suggests that classroom engagement will be enhanced, not impaired, immediately after lessons in nature. Specifically, spending time in relatively natural outdoor settings has a number of positive, immediate aftereffects on individuals, each of which is likely to enhance classroom engagement. Moreover, multiple studies have found that schools with greener, more vegetated surroundings perform better academically—even when socioeconomic factors are taken into account (Kuo et al., in review). Here we review the evidence on acute doses of contact with nature and their effects on cognitive functioning, interest in learning, and stress, as well as the literature tying greener schools with better academic achievement.

Attention is an important resource in student engagement (Pekrun and Linnenbrink-Garcia, 2012). Acute doses of nature, whether through a window view of a tree-lined street or a walk in a park, have positive aftereffects on attention and working memory. Attention restoration theory suggests that natural landscapes are gently absorbing, inducing a state of "soft fascination" that allows the mental muscle underlying our ability to deliberately direct attention to rest; afterwards, our capacity to direct attention is thereby refreshed (Kaplan, 1995; for a recent review of empirical work on attention restoration theory, see Ohly et al., 2016). Experimental work has demonstrated these aftereffects for classroom window views of greenery vs. barren schoolyards (Li and Sullivan, 2016), and for walks in both forested (van den Berg et al., 2017) and relatively green urban settings (Faber Taylor and Kuo, 2009) as compared to walks in less green urban settings. Thus, both a lesson in a relatively green spot in a schoolyard and the walks between that spot and the classroom might rejuvenate students' attention, enhancing their ability to concentrate on the next, indoor lesson.

Motivation is a similarly important resource in student engagement (Deci et al., 2011), and nature-based learning has been tied to high levels of engagement and enjoyment in a number of studies. Although we found no studies examining aftereffects of acute doses of nature, children prefer and enjoy lessons outdoors over lessons indoors (Mygind, 2009; Wistoft, 2013), and there is some indication that outdoor nature-based learning fosters greater interest in school and learning generally (e.g., Ernst and Stanek, 2006). Importantly, these effects may be largest in precisely the students whose motivation in "normal" classes is most lacking (Dettweiler et al., 2015). Nature-based learning appears to foster students' intrinsic motivation (Fägerstam and Blom, 2012; Skinner et al., 2012). Collectively, this body of work suggests nature-based instruction makes learning more interesting and enjoyable; might the interest and positive affect from a lesson in nature carry over to the next, indoor lesson, resulting in greater classroom engagement?

Stress is likely to be another important (negative) factor in student engagement; high levels of stress consistently predict lower levels of academic achievement (e.g., Grannis, 1992; Leppink et al., 2016). Experimental work in adults with physiological indicators shows that contact with nature offers quick and powerful reductions in stress biomarkers (e.g., Park et al., 2010; for review, see Kuo, 2015; Supplementary Materials), and this effect appears to extend to children as well. Contact with nature has been tied to lower levels of both self-reported and physiological measures of stress in multiple studies with children (Bell and Dyment, 2008; Chawla, 2015; Wiens et al., 2016). Recently an experimental study involving high school students showed that even a mere window view of vegetation from a classroom yields systematic decreases in both heart rate and self-reported stress, whereas a classroom without windows does not (Li and Sullivan, 2016). Further, students learning in a forest setting one day a week showed healthier diurnal rhythms in the stress hormone cortisol in that setting than a comparison group that did not receive outdoor learning—and these effects could not be attributed to the physical activity associated with learning outdoors (Dettweiler et al., 2017).

Not only is contact with nature tied to important factors in classroom engagement, but greener schools and classrooms have been tied to better academic achievement. Multi-year assessments of greenness around Massachusetts public schools found positive correlations between greenness and standardized test scores, even after adjusting for income and other confounding factors, although not for all seasons of the year (Wu et al., 2014). Similarly, standardized test performance in 3rd through 9th graders was higher for District of Columbia public schoolyards with higher levels of tree cover, even after similar controls (Kweon et al., 2017), and high school graduation rates and test scores were better for public high schools across Michigan with views of greenspace from high school classrooms and cafeterias (Matsuoka, 2010). More recently, standardized test scores have been tied to schoolyard tree cover in over 300 public schools in Chicago, again controlling for socioeconomic and other factors (Kuo et al., in review). While these studies do not directly connect nature exposure with increased classroom engagement, they are consistent with this possibility; indeed, it is difficult to imagine how contact with nature could boost academic achievement while reducing classroom engagement.

Thus, exposure to nature has been tied to both the antecedents and the consequences of classroom engagement. Additional converging evidence comes from research in educational psychology not focused specifically on greenness. Generally speaking, time spent out of the classroom and in relatively natural outdoor settings is positive. Studies document (a) the rejuvenating effects of recess (e.g., Pellegrini and Davis, 1993; Pellegrini et al., 1995; Jarrett et al., 1998), (b) the positive impacts of students' physical activity—often in schoolyards—on on-task behavior and executive functioning in the classroom (Mahar, 2011; Kvalø et al., 2017), and (c) the motivational benefits of teacher-led education outside the classroom (EotC)—in schoolyards, museums, and other cultural institutions (Dettweiler et al., 2015; for review see Becker et al., 2017) and of garden-based learning (Skinner et al., 2012). All these lines of investigation lend indirect support for the hypothesis that lessons in nature might enhance subsequent classroom engagement.

At the same time, it must be acknowledged that the question here differs importantly from those lines of investigation. This study differs from the research on the benefits of recess and physical activity in that the intervention involves formal instruction—teacher-led, formal lessons, delivered as part of a larger curriculum, with all the rules against student socializing and autonomous activity typical of classroom-based lessons. Similarly, unlike most education outside the classroom (EotC) studies and the study of garden-based learning, this study holds pedagogical approach constant in comparing lessons in nature vs. in the classroom. That is, in most EotC studies, the instruction outside the classroom is designed to take advantage of the setting; as a consequence, the experimental condition differs from the control in two ways—in setting (outside vs. in the classroom) and in pedagogical approach. In this study, pedagogical approach was held constant across conditions; the lessons inside and outside the classroom differed in setting but not instructional approach.

In sum, although it appears no study has directly examined the aftereffects of lessons in nature on classroom engagement, considerable evidence in both environmental psychology and education research points to time spent in natural outdoor settings as having positive impacts. In this study, we hypothesize that *lessons in nature have positive, immediate aftereffects on classroom engagement*—that is, we expect that when children learn outdoors, their classroom engagement after returning indoors is better than it would have been had they stayed inside the entire time. To test this hypothesis, we compared classroom engagement after a teacher gave her students a lesson in nature vs. after the same teacher gave her students a lesson on the same topic in the classroom (e.g., leaves) in the same week, replicating this comparison across 10 different topics (one topic per week), two classrooms ("classroom a," with its own teacher, students, and room; and "classroom b," with another teacher, set of students, and room), and five different measures of classroom engagement.

METHODS

Setting and Instructors

The effects of lessons in nature on subsequent classroom engagement were examined in the context of a 300-student environmental magnet school in the Midwestern United States serving a predominantly disadvantaged population, with 87% qualifying for free or reduced lunch, 82% African American, 7% Hispanic, 5% White, and 6% Multi-racial. Written consent from parents of involved students was obtained prior to the study.

The indoor condition in this study comprised two typical classrooms (**Figure 1**; although they are not shown in the photo, both classrooms had windows). The outdoor condition comprised a small grassy area just outside the school (**Figure 2**). This instructional area was adjacent to a stream and woodlands, not used in the lesson. While the teacher was setting up the outdoor lesson, students occasionally visited the stream bank briefly. The post-treatment (and post-control) observation period was always conducted indoors, in each class' and teacher's regular classroom.

The two teachers in this study were highly experienced and state-certified in elementary education, with Masters in Education degrees and in-service training in outdoor and environmental education. These teachers had teamed together in lesson planning over a period of 5 years prior to this study, facilitating their coordination of lessons during this study.

The students in the classrooms were in third grade. Their age range was 9–10 years old.

Design and Procedure

At base, this study involved a mini-experiment replicated 20 times. In each mini-experiment, we examined classroom engagement after a lesson in nature vs. after a matched lesson in the classroom on the same topic, with the same teacher and students. Thus, in week 1 of our study, teacher "a" gave her students both a lesson on, say, leaf identification, outdoors, and another lesson on leaf identification in the classroom, and we compared indoor classroom engagement for that set of students after each of those two lessons. This mini-experiment was repeated across 10 different lesson topics and weeks (one topic per week), in each of two classrooms.

Figure 3 schematically depicts a mini-experiment—the fundamental unit of comparison in this study. Both the experimental condition (the lesson in nature) and the control condition (the lesson in the classroom) were 40 min long, and the observation period for both conditions was 20 min

FIGURE 1 | The two classrooms **(A,B)** used for indoor instruction in this study. Written permission for the publication of this figure was obtained from students' parents.

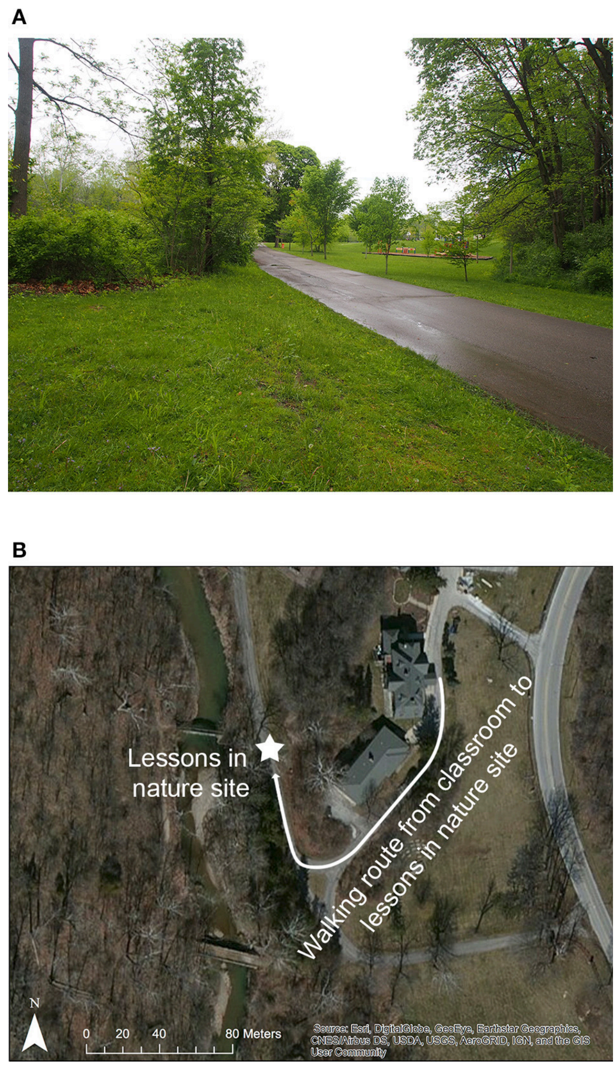

FIGURE 2 | The site of the lessons in nature **(A)** and the route students took between their classroom and the outdoor lessons **(B)**. The road in the pictures was used exclusively for pedestrian traffic and (infrequently) for maintenance vehicles.

long. Observation periods took place in the teacher's regular classroom, and included an introductory 5-min presentation by the teacher on math or language arts using a dry erase board, overhead projector, or chalkboard and 15 min of assigned individual student work completed at their desks. Before the observation period there was a water and bathroom break in both conditions.

Figure 4 shows how we replicated our fundamental unit of comparison across different instructional content, times in the school year, students, classrooms, and instructors. Each pair of lessons (one in nature, one in the classroom) was delivered in a single week. For each pair, the two teachers worked together to adapt a different theme from the Project Learning Tree (www.plt.org) environmental education lesson guide, with lessons on leaf, tree, and seed identification; organic matter decomposition; the life cycle; and pollution. These two instructors each delivered 10 pairs of lessons over 10 different weeks in the semester from September-November, under a range of weather conditions[1]. Before the study began, both instructors were open-minded as to what we might find, although one tended to think the positive effects of lessons in nature might outweigh the negative, whereas the other tended to think the opposite—that lessons in nature might leave students "too wired" afterward to engage in classroom material.

To make the lessons as comparable as possible, each lesson pair was carefully matched along numerous dimensions. In addition, where exact matching was not possible we

[1]On one occasion, a planned lesson was not given as scheduled; that lesson was made up in April instead. Analyses with and without the makeup lesson and its paired classroom lesson show the same effects of lessons in nature on subsequent classroom engagement. Findings reported here were based on the full sample.

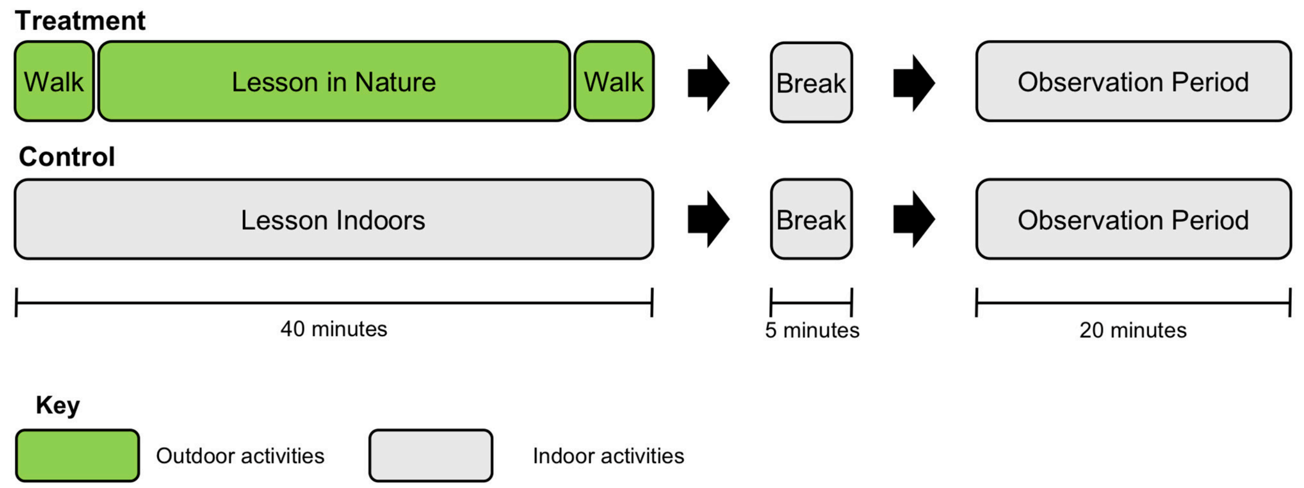

FIGURE 3 | Schematic diagram of one mini-experiment. This included a treatment (lesson in nature and with walks to lesson site before and after) or a control (classroom lesson indoors), followed by a 5-min indoor break and 20-min indoor observation period. Order of conditions was counterbalanced.

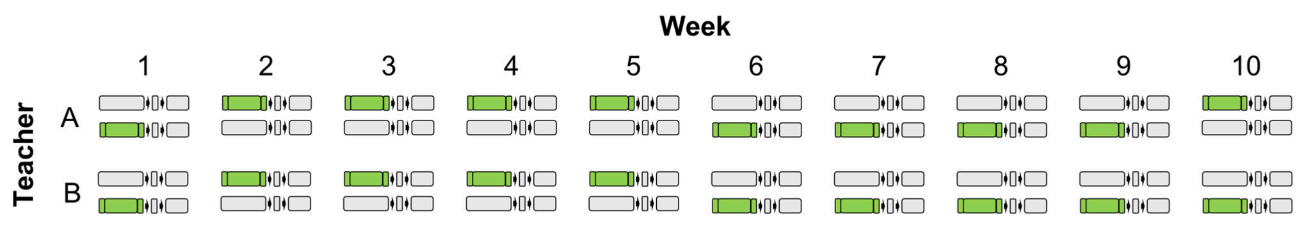

FIGURE 4 | Mini-experiments were replicated over 10 different topics and weeks, for each of two classrooms (and each of five measures). Order of conditions was counterbalanced.

counterbalanced across the study so there were no consistent differences between conditions. For one notable dimension, neither matching nor counterbalancing was possible.

Lessons were matched along the following dimensions: teacher, students and class size, topic, teaching style, week of the semester, and time of day. That is, for any given pair of lessons, both the treatment lesson (in nature) and its indoor counterpart were delivered by the same teacher to the same students, on the same topic, in the same week of the semester. Both lessons involved hands-on, experiential learning; lessons that required natural materials from the outdoor instructional site (e.g., different types of leaves) were adapted for classroom instruction by bringing these materials indoors prior to the lesson. While the pairs of lessons were offered in afternoons ($n = 12$) slightly more often than in mornings ($n = 8$), the two conditions did not differ in how often they were taught in the morning vs. the afternoon—an important consideration given that cognitive performance generally drops over the course of the day (Sievertsen et al., 2016).

We counterbalanced the order in which conditions were delivered each week over the course of the study. It is impossible to offer both a lesson in nature and its matched classroom lesson simultaneously; thus one lesson would have to precede the other and the second lesson would always be an extension of the first. So that neither condition would have an advantage over the other, we encouraged teachers to put the lesson in nature first roughly as often as they put it second. The scheduling of lessons was constrained by the scheduling of other curriculum (e.g., physical education, art, and music) as well as weather. In the end, the lesson in nature came before its classroom counterpart four times and after it six times for each teacher.

It is important to note that there was one consistent difference between the experimental and control lessons other than setting. The 40-min lesson in nature was not purely instructional time; it required the class to walk a few minutes to and from a grassy area (see Setting above) to reach the instructional site—a distance of about 200 m. Thus, the lesson delivered in nature was roughly 30 min long whereas the matched indoor lesson was 40 min long.

Measures of Classroom Engagement

We developed a battery of four measures to assess classroom engagement: (1) teacher ratings; (2) student ratings; (3) "redirects"—the number of times instructors had to interrupt instruction to redirect a student's attention to the task at-hand; and (4) independent photo ratings—ratings of classroom engagement by an independent observer based on photographs of the observation period. These four measures were then combined into a Composite Index of Classroom Engagement.

Teacher Ratings

At the end of each 20-min observation period, teachers rated classroom engagement on a −2 to +2 scale (from −2 *much worse than usual* to 2 *much better than usual*, with 0 *same as usual*). Classroom engagement was defined for teachers as students listening to instructions, looking at assigned material, and raising their hands for assistance. Teachers were asked to rate the engagement not of individual students, but of the classroom as a whole, during the observation period.

Student Ratings

Students also rated classroom engagement after each 20-min observation period. Unlike the teacher ratings, the student ratings consisted of three components. Each student rated their own engagement, the engagement of the students sitting close to them, and the engagement of the class as a whole on a 5-point scale indicating the period of engagement (from 1 *no time* to 5 *the whole time*).

Of the three types of engagement ratings—self, peer, and whole class—one turned out to be relatively uninformative and was not further analyzed: students consistently rated their own engagement highly and with little variance; perhaps as a consequence, this rating correlated relatively weakly with other measures (see Supplementary Materials). Students' ratings of the engagement of their seatmates and the class as a whole were somewhat informative in that they were not at ceiling and showed some variance; students' peer and whole class ratings were therefore used as another measure of classroom engagement. For each classroom after a given lesson, students' peer engagement ratings and whole class engagement ratings were averaged to produce an average, student-based measure of classroom engagement. This summary student-based measure of classroom engagement demonstrated high internal reliability (Cronbach's alpha = 0.869 for indoor lessons, 0.807 for outdoor lessons).

"Redirects"

Each time a teacher needed to stop instruction to redirect or correct student behavior—e.g., "sit down," "you need to be working," or "I will wait"—one "redirect" was tallied. "Redirects" reflect the number of instances tallied for a 20-min observation period. Redirects are a concrete and important indicator of how well instruction is going. High levels of redirects indicate students are not attentive to instruction or tasks assigned. Further, redirects themselves are likely to impact learning outcomes by reducing the coherence and flow of lectures and distracting students as they work on assigned tasks.

MP, an investigator on this project and the social worker for the school where this study was conducted, was stationed at the back of the classroom during observation periods to record "redirects." As the school social worker, the instructors and students in this study were already comfortable with his presence in the classroom. Pilot testing confirmed that he was able to observe the class from the back of the room without influencing class dynamics. Redirects were tallied "blind to condition"—that is, the observer assessed redirects without knowing whether the preceding lesson had been given indoors or outdoors.

Independent Photo Ratings

While teacher ratings and student ratings each provide a valuable window onto class engagement, both are inevitably subject to observer expectancy effects. That is, both teacher and student ratings of classroom engagement during a given observation period might be influenced by their knowledge of which condition (lesson in nature or lesson in the classroom) preceded that observation period and their expectations for the effects of lessons in nature on classroom engagement. Redirects were blind to condition, but we included a second "blind to condition" measure of classroom engagement, in which an independent observer rated photographs of each observation period without knowing what kind of lesson had preceded it.

Photographs were captured with a wide-angled camera (Nikon P90) positioned on a tripod in front of the classroom and programmed to automatically capture images of the class throughout the 20-min observation period. Each observation period was represented by 10 photos; hence the complete collection of photos rated by our independent observer consisted of 400 photos, with each set of 10 photos corresponding to one of the 40 observation periods in this study (one observation period per week after the lesson in nature, another observation period per week after its classroom-based counterpart, for each of two teachers, for a total of 10 weeks).

Our independent observer—an undergraduate student at the University of Illinois at Urbana-Champaign—began by acquainting herself with the entire collection of 400 photos, without knowing which observation periods belonged to which condition. This allowed her to calibrate her ratings of classroom engagement relative to both the typical levels of engagement seen in the observation periods as well as the extremes. She then rated classroom engagement for each observation period on the same −2 to +2 scale as the teachers (from −2 *much worse than usual* to 2 *much better than usual*, with 0 *same as usual*). The rater assessed classroom engagement blind to condition; that is, she made her ratings without knowing where the preceding lesson had taken place (in nature vs. the classroom).

Constructing a Composite Index of Classroom Engagement (CICE)

Each of the component measures in our battery is valuable in its own right. Teacher ratings and student ratings offer important lenses on classroom engagement. Redirects, as counted by an independent observer, provide external validation for teacher and student-ratings as well as a concrete measure of classroom engagement. Both redirects and the independent photo ratings provide measures of classroom engagement uncontaminated by knowledge of condition. **Table 1** illustrates how each of the measures in our battery address different methodological criteria for assessing classroom engagement. Together, the measures in this battery provide a multifaceted measure of classroom engagement, with the limitations of each measure countered by the strengths of another.

To create a single measure that draws on each of these different methodological strengths, we combined these component measures into a single Composite Index of Classroom Engagement (CICE), which was the average of

TABLE 1 | Measures and criteria for assessing classroom engagement.

Measure	CRITERIA FOR ASSESSING CLASSROOM ENGAGEMENT			
	Incorporates teacher perceptions	**Incorporates student perceptions**	**Provides external validation**	**Is blind to condition**
Teacher ratings	Yes	–	–	–
Student ratings	–	Yes	–	–
Redirects	–	–	Yes	Yes
Independent photo ratings	–	–	–	Yes
Composite index of classroom engagement	Yes	Yes	Yes	Moderately[a]

[a] *Two of four components of Index are blind to condition.*

TABLE 2 | Means of classroom engagement measures by classroom.

		Classroom A		Classroom B	
	Range	***M***	***SD***	***M***	***SD***
Teacher ratings (−2–+2)	−2–2	0.70	1.34	0.55	1.23
Student ratings (0–100)	62–93	81.29	8.09	79.00	7.55
Redirects (tallied)	0–8	3.70	2.62	5.10	1.86
Independent photo ratings (−2–+2)	−2–2	0.35	1.42	0.65	0.99
Composite index of classroom engagement	−1.60–1.17	0.00	0.81	0.00	0.77

TABLE 3 | Bivariate correlations between measures of classroom engagement across 40 observation periods.

	1	2	3	4	5
Teacher ratings (1)	–	0.48**	0.54**	0.87**	0.92**
Student ratings (2)		–	0.25	0.32*	0.63**
Redirect (3)			–	0.51**	0.70**
Independent photo ratings (4)				–	0.86**
Composite index of classroom engagement (5)					–

$^*p < 0.5$, $^{**}p < 0.01$.

teacher ratings, student ratings, independent photo ratings, and redirects. Because these measures are on different scales (e.g., from −2 to +2 for teacher and photo-based ratings, from 0 to 100 for student ratings), data from each measure were standardized before averaging. Thus, for example, a teacher's rating of classroom engagement for a given observation period would be expressed in terms of how that period's rating differed from the mean rating for that teacher across all observation periods, in units of standard deviations. Redirects were reverse-coded (multiplied by −1.0) so that higher values would correspond to better classroom engagement, in line with the other components of the Composite Index.

RESULTS

Descriptive Statistics and Bivariate Correlations

Descriptive statistics and bivariate correlations are presented in **Tables 2**, **3**. Teacher ratings of class engagement tended toward the positive, with average ratings falling between 0 *usual* and 1 *better than usual*. Student ratings of class engagement were quite positive, averaging roughly 80% on a 0–100% scale, with little variance. Redirects occurred with some frequency, averaging 3.7 and 5.1 in the two classrooms, respectively, in the 20-min observation window. And photo-based ratings of class engagement also tended toward the positive, with average ratings falling between 0 *usual* and 1 *better than usual*. As the CICE (Composite Index of Classroom Engagement) is based on the average of standardized scores across the four component measures for each classroom, its means for each classroom were zero by definition. In two-sided *t*-tests for group differences with an alpha of 0.05, the two classrooms did not significantly differ from each other on any of the measures of classroom engagement; thus data from the two classrooms were combined for further analysis except where otherwise noted.

As **Table 3** shows, our measures of classroom engagement were generally highly correlated. The individual components of the CICE show high concurrent validity. Teacher ratings and independent photo-based ratings were particularly highly correlated with both each other ($r = 0.87$) and with our summary measure ($r = 0.92$). Student ratings of classroom engagement were significantly correlated with teacher ratings and independent photo-based ratings, but not significantly related to the number of redirects in a given observation period.

Overall Condition Differences in Classroom Engagement

Is classroom engagement higher after a lesson in nature than after a matched lesson in the classroom? **Table 4** presents the results of paired, two-tailed *t*-tests comparing classroom engagement after lessons in nature vs. matched classroom lessons across the 10 different topics/weeks and two instructors. Lessons in nature show an advantage in subsequent classroom engagement over classroom lessons for four of the five measures. Teacher ratings of classroom engagement are roughly a standard deviation higher, on average, after a lesson in nature than its matched, classroom-based counterpart. Consistent with this, redirects were less frequent after a lesson in nature—in fact, the number of redirects after a lesson in nature was roughly half (54%) that of redirects after a classroom lesson. If we calculate the rate of redirects by dividing the duration of our observation period (20 min) by the number of redirects, the nature condition yielded a redirect rate of roughly one redirect per 6.5 min as compared to a rate of one interruption of instruction every 3.5 min in the classroom condition. The independent, photo-based ratings of classroom engagement echo the teacher ratings. And Composite Index of Classroom Engagement scores are 4/5ths of a standard deviation higher after lessons in nature than

TABLE 4 | Classroom engagement is better after lessons in nature than lessons in the classroom by most measures: Findings for each measure of classroom engagement.

	Means		Paired differences				
	Nature	**Classroom**	**Mean**	**Std. dev.**	***t*-value**	**df**	**Effect size[a]**
Teacher ratings	1.20	0.05	1.15	1.79	2.88**	19	0.74
Student ratings	81.01	79.27	1.74	6.56	1.18	19	0.60
Redirects	3.10	5.70	−2.60	2.62	4.43***	19	0.84[b]
Independent photo ratings	1.10	−0.10	1.20	1.64	3.27**	19	0.77
Composite index	0.40	−0.40	0.80	0.93	3.83**	19	0.81

[a]*Common language effect size (McGraw and Wong, 1992) also known as the probability of superiority (Grissom and Kim, 2005) expresses the effect size in percentages. In this table, it reflects the probability that the score for a given classroom engagement measure will be better after a lesson in nature than after a lesson in a classroom. Controlling for differences between classrooms in classroom engagement, the likelihood that a class will score higher on teacher ratings of classroom engagement after a lesson in nature than after a lesson in a classroom is 74%.*

[b]*For ease of interpretation, all effect sizes reflect the likelihood of better class engagement after a lesson in nature than a matched classroom lesson; because class engagement is better when redirects are fewer, the effect size reported here reflects the likelihood that redirects are fewer after a lesson in nature.* $^{**}p < 0.01$, $^{***}p < 0.001$.

after matched control lessons. Effect sizes for all measures but the student ratings are substantial, indicating that the magnitude of the difference between classroom-based lessons and nature-based lessons is not only statistically significant but practically meaningful.

Bayesian statistical analyses yield similar results. The Bayes factor is a ratio of the likelihood of two hypotheses being correct given a set of data. In this case, we compared the likelihood that classroom engagement was better after outdoor lessons than after indoor lessons (H_1) with the likelihood that it was not (H_0). There was very strong evidence that the Composite Index of Classroom Engagement was better after outdoor lessons than after indoor lessons—so much so that H_1 was 33 times more likely to occur than H_0. In regard to individual measures, redirects showed extreme evidence for H_1 occurring, indicating increased classroom engagement after outdoor lessons ($BF_{01} = 0.009$, error percent $8.07e^{-7}$), while independent photo-based ratings of classroom engagement displayed strong evidence ($BF_{01} = 0.091$, error percent $= 5.12e^{-4}$) and teacher ratings of classroom engagement presented moderate evidence ($BF_{01} = 0.18$, error percent $= 0.002$) for this outdoor lesson advantage. In contrast, student ratings of classroom engagement showed no evidence of nature lessons improving classroom engagement afterward compared with indoor lessons ($BF_{01} = 2.33$, error percent $= 0.014$).

Condition Differences in Classroom Engagement for Different Classrooms, Weeks, and Measures

Our research design involved 100 paired comparisons between lessons in nature vs. their matched, classroom-based counterparts across two different instructors, 10 different topics and weeks, and five different measures of classroom engagement. To give a more fine-grained view of our results, **Figure 5** schematically depicts the results for each of the 100 pairs of comparisons. Symbols of different colors and shapes indicate which condition, if any, showed an advantage in subsequent classroom engagement in a given mini-experiment (green checkmark = lesson in nature; purple circle = lesson in the classroom), and the number of symbols indicate the extent of the advantage (no symbols = the conditions differed by less than half a standard deviation; one = the conditions differed by between 0.5 and ≤1 standard deviation; two = between 1 and ≤2 standard deviations; three = over 2 standard deviations).

Figure 5 thus illustrates the consistency and size of the nature advantage over the entire series of mini-experiments. Of the 100 nature vs. classroom comparisons, the majority of comparisons (61) show an advantage for the lesson in nature, 25 show small or no difference (less than half a standard deviation in either direction), and only 14 show an advantage for the classroom-based lesson. Further, the size of the nature advantage is considerable: in 48 comparisons, the lesson in nature yielded classroom engagement scores a full standard deviation larger than its classroom-based counterpart; in 20 of these 48, the nature advantage was more than two standard deviations.

Visual inspection for differences across measures suggests that, of the four component classroom engagement measures, teacher ratings, redirects, and independent (photo-based) ratings are reasonably sensitive. By contrast, student ratings appear to be a relatively insensitive measure, showing fewer and smaller condition differences than the other measures.

Similarly, visual inspection reveals no obvious trends in the size of the nature advantage over the course of the semester; consistent with this, a *post-hoc*, two-tailed independent *t*-test comparing the difference between CICE scores for the first 5 weeks of the semester with CICE scores for the next 5 weeks showed no significant difference, $t_{(18)} = -0.26$, $p = 0.80$ ($M = 0.86$, $SD = 1.00$ for the first 5 weeks; $M = 0.74$, $SD = 0.91$ for the next 5 weeks). Interestingly, although one of the two teachers entered with some skepticism regarding the effects of lessons in nature on subsequent classroom engagement, the nature advantage is visible in both instructors' classes. Paired, two-tailed *t*-tests for each classroom show a significant effect of condition on classroom engagement for each instructor [$t_{(9)} = 2.27$, $p = 0.049$, for classroom *a*; $t_{(9)} = 3.07$, $p = 0.01$, for classroom *b*]. Bayesian statistical analyses confirmed there was no evidence for the first 5 weeks being different than the next

		Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8	Wk9	Wk10
Classroom a	Teacher ratings	✔✔✔	✔✔✔	✔✔			○○	✔✔			✔✔
	Student ratings	✔✔✔	✔✔	✔✔	○					○○	
	Redirects	✔	✔	✔✔✔	✔✔	✔✔✔	○○	✔✔	○	✔✔✔	✔✔
	Independent ratings	✔✔✔	✔✔✔	✔✔			○○○	✔✔		✔✔	
	Composite index	✔✔✔	✔✔	✔✔		✔	○○	✔✔		✔	✔
Classroom b	Teacher ratings	○○	✔✔✔	✔✔✔	○○	✔	✔	✔✔	✔✔	✔	✔✔✔
	Student ratings	○	✔		○○			✔			
	Redirects	○	✔✔✔		✔✔	✔✔✔		✔✔	✔✔✔	✔✔	✔✔
	Independent ratings	○	✔✔✔	✔✔✔		✔	✔✔	✔✔✔	✔✔✔	✔✔	✔✔✔
	Composite index	○	✔✔	✔✔		✔	✔	✔✔	✔✔	✔✔	✔✔

FIGURE 5 | Differences in classroom engagement after lessons in nature for different classrooms, weeks, and measures. Condition differences in classroom engagement are depicted with symbols. The color and shape denotes the condition which yielded better classroom engagement, for a particular measure, classroom, and week; when the lesson in nature outperformed its paired classroom lesson, there are green checkmark(s); when the lesson in the classroom outperformed its paired nature lesson, there are purple circle(s). The number of symbols (checkmark or circle) represents the extent to which one condition outperformed the other, with one symbol corresponding to a difference between half a standard deviation and a full standard deviation (>0.5 to ≤1), two symbols corresponding to a difference between one and two standard deviations (>1 to ≤2), and three symbols corresponding to a difference of over two standard deviations. When the difference between a lesson in nature vs. the classroom did not exceed half a standard deviation, no symbols are depicted.

5 weeks ($BF_{01} = 2.41$, error percent = $2.31e^{-5}$). Also, Bayes factors showed moderate evidence for classroom *a* ($BF_{01} = 0.20$, error percent = $3.41e^{-4}$) and anecdotal evidence for classroom *b* showing an outdoor lesson advantage ($BF_{01} = 0.56$, error percent = 0.002).

DISCUSSION

What is the effect of lessons in nature on subsequent classroom engagement? Do they leave pupils too keyed up to focus—as some teachers worry—or do they enhance a class' engagement—as indirect evidence suggests they could? In this study, classroom engagement was significantly better after lessons in nature than after matched, classroom-based lessons. This nature advantage held for four of five measures of classroom engagement: teacher ratings; redirects; independent, photo-based ratings; and our summary index of classroom engagement all showed a substantial advantage for the nature condition; student ratings did not. Further, the nature advantage held across different teachers and held equally over the initial and final 5 weeks of lessons.

The nature advantage was substantial. Common language effect size calculations (McGraw and Wong, 1992) indicate a strong advantage for lessons in nature—the likelihood that Composite Index of Classroom Engagement scores are higher after a lesson outdoors in nature than after a lesson in the classroom, in a class that receives both, is 81%. And the nature advantage is large. Out of 100 paired comparisons, classroom engagement was over a full standard deviation better in the nature condition in 48 pairs; in 20 of those 48, the nature condition bested its classroom counterpart by over two standard deviations. The rate of "redirects," or instances where a teacher interrupted the flow of instruction to redirect students' attention, was cut almost in half after a lesson in nature. Normally, these redirects occur roughly once every 3.5 min of instruction; after a lesson in nature, classroom engagement is such that teachers are able to teach for 6.5 min, on average, without interruption.

Accounting for the Advantage of Lessons in Nature: Alternative Explanations

To what might we attribute the advantage of the lessons in nature here? There are any number of other factors that might affect classroom engagement: different teachers might be more skilled at eliciting student engagement; some topics are more engaging than others; hands-on lessons might be more engaging than lecture-based lessons; one set of students might be more attentive than another; a smaller class might be more engaged than one with more students; one classroom might be exposed to more distractions than another (for example, opening onto a particularly noisy hallway); engagement might peak at the beginning of the school year and flag as the year wore on; and students might find it easier to focus on schoolwork in the morning than the afternoon. If our nature lessons differed from our classroom lessons in any of these respects, those differences could have conceivably accounted for our findings. But because we only compared pairs of lessons *matched* on all those factors—same teacher, same topic, same instructional approach, etc.—none of those factors can account for the findings here.

Nor could positive expectations have driven the nature advantage here. It is true that one of the two teachers was predisposed to think the lesson in nature might have a positive effect on subsequent classroom engagement. Those positive expectations might have led her to view classroom engagement after the outdoor lesson more positively (which might have boosted teacher ratings of engagement but would not have affected our independent photo-based ratings), or might even, in a variant of the Pygmalion effect, have inspired her to teach more effectively afterwards (which would have boosted both teacher ratings and independent photo-based ratings). At the same time, the other teacher expected the opposite pattern; on the whole, she thought that the lesson in nature might leave students too keyed up to concentrate. If the nature advantage was due entirely to teacher expectations it is not clear why both teachers showed the nature advantage.

It should be noted that teacher expectations about the impacts of nature on subsequent classroom engagement may have become more positive over the course of the study, contributing to the nature advantage. However, this begs the question, why did teachers' expectations about the impacts of nature become more positive with experience if not because they had seen the positive impacts? Thus, a change in teacher expectations may well reflect, as well as contribute to, the nature advantage.

The novelty of the setting cannot account for the nature advantage, either. If the nature advantage in subsequent classroom engagement were due to the novelty of the setting, we would expect it to decrease over the course of the semester as students habituated to having lessons outdoors. But the nature advantage, as measured by the difference between nature-based lessons vs. classroom-based lessons in composite scores of classroom engagement afterward, was relatively stable over the course of the study. The nature advantage for the first 5 weeks of the semester and when the setting was relatively new was not statistically different from the nature advantage for the second 5 weeks—when students had acclimated to lessons outdoors.

Along similar lines, novelty of topic might have accounted for differences in classroom engagement; each week in the study corresponded to a new topic, and if the nature lesson on a topic had generally preceded its classroom counterpart, students might have found the nature lesson more stimulating and been more engaged afterwards because of the change in topic and not because of the setting. But the order of indoor and outdoor lessons was counterbalanced such that the lesson in nature came before its classroom counterpart four times and after it six times for each teacher.

In the absence of other viable explanations for the systematic pattern of superior classroom engagement after lessons in nature, it would appear that the lessons in nature boost subsequent classroom engagement.

Accounting for the Advantage of Lessons in Nature: Active Ingredients

If lessons in nature boost subsequent classroom engagement, this raises another question: what *about* lessons in nature might account for this effect? That is, what is (or are) the active ingredient(s) in a lesson in nature? Previous research suggests a number of possibilities; each of these factors might contribute. First, the *relatively natural setting* of the outdoor lessons may contribute to subsequent classroom engagement. As discussed in the Introduction, exposure to nature has immediate, beneficial aftereffects on both attention and stress, and is likely to enhance motivation as well. Further contact with nature has also been shown to improve self-discipline and impulse control (e.g., Faber Taylor et al., 2002; van den Berg and van den Berg, 2011)—thus a lesson in nature might conceivably yield a quieter, less disruptive classroom afterwards. It is interesting to note that the large effect sizes here were obtained despite the fact that the classrooms both had windows and therefore afforded some limited view of greenness. This has some precedent; previous findings have tied better outcomes for children's attention from being in nature than from simply looking at it (Faber Taylor et al., 2001).

Second, the sheer *break from classroom activity* involved in the walks to and from the classroom, and the *change in scenery* involved in the lesson in nature probably contribute to students' subsequent rejuvenation. Again, although this study involved formal instruction, not recess, Pellegrini and Davis (1993) and Pellegrini et al. (1995) found that elementary school children become progressively inattentive when recess is delayed. Another experimental study (Jarrett et al., 1998) found that fourth-graders were more on-task and less fidgety in the classroom on days when they had had recess, with hyperactive children among those who benefited the most. Thus, providing a lesson in nature may provide many of the same benefits normally accrued through recess.

The education outside the classroom (EotC) literature provides converging findings. Although EotC studies examine instruction not just in nature but also in museums and other settings outside the classroom, those studies all involve a change in scenery and some break from classroom activity to get to the alternate settings. Available evidence suggests that the social and learning outcomes of education outside the classroom are almost entirely positive (see Becker et al., 2017, for review). If a brief break from classroom activity and change of scenery suffice to deliver the improvements in subsequent classroom engagement seen here, teachers might experiment with simply taking their class to the gym for a lesson, or swapping classrooms with another teacher.

Similarly, the work on school garden-based learning suggests that student interest and motivation may improve when instruction is set outdoors in green areas, perhaps because of the greater autonomy and opportunities for social connection afforded by most garden-based curricula (Skinner et al., 2012; for a review of the role of autonomy and relatedness in motivation in educational settings, see Deci et al., 2011). While the findings here echo those, it is important to note that the lessons in nature here were formal and constructed to match those offered indoors; this was not informal learning but rather teacher-led, formal learning with the usual rules against students engaging in autonomous behavior or socializing—thus any effects of increased autonomy and relatedness would have to have occurred primarily in the walk to and from the outdoor lessons.

Third, *physical activity* might also play a part: 10-min physical activity breaks during the school day have been shown to boost classroom engagement (Mahar, 2011), and the lesson in nature here included two 5 min (or less) walks between the classroom and the outdoor teaching setting, raising the possibility that the boost in classroom engagement here was due entirely to those walks. This seems unlikely; most studies in the physical activity-classroom engagement literature have examined either brief bouts of intense physical activity (e.g., Mahar, 2011), or frequent, longer bouts of moderate physical activity—for example, one study examined the effects of adding roughly 190 min per week of moderate to vigorous physical activity—running, jump rope, hopping on one foot—over the course of 10 months (e.g., Kvalø et al., 2017). The dose of physical activity here was brief, light in intensity, and infrequent (two, 5 min walks per week). It seems likely that the physical activity involved in this study contributed to some but not all of the effects seen here.

Fourth and finally, another contributing factor may have been *impacts on teachers*. Teachers, just as much as students, might benefit from all these aspects of lessons in nature—perhaps teachers are able to teach in a more engaging way after a bit of walking, a bit of a breather and change in scenery, and a dose of nature has rejuvenated their attention and interest and reduced their stress levels. If so, simply giving teachers a break, a walk, and a dose of nature while their students continued formal instruction might yield the same benefits to classroom engagement seen here.

Each of these active ingredients has, in theory, the potential to singly explain the effect of lessons in nature on classroom engagement. Given the size of the nature advantage found here, it seems likely that the effect reflects the joint impact of all these factors.

Generalizability

The lessons in nature here involved a particular "dose" (duration, intensity, and frequency) of naturalness, administered in a particular way, to a particular population of students by a particular set of teachers. Here, we consider reasons why the nature advantage might or might not generalize to other conditions, students, and teachers.

The lessons in nature in this study involved a 5-min walk from the classroom out to a grassy outdoor area with some nearby trees (**Figure 2**) for a 30-min instructional period, followed by a walk back to the classroom, followed by a 5-min break—the classroom lesson involved no walking, and a 40-min instructional period followed by a 5-min break.

In combination with the study design, the findings here suggest the nature advantage could apply in a variety of conditions. The nature advantage persisted across 10 different topics and weeks in the school year; across different times of day; across two different teachers, including one who was predisposed to expect the opposite; and across two different groups of students, each with their own dynamics.

The levels of vegetation here (**Figure 2**) do not seem entirely out of keeping with other schools; schools with similar levels of vegetation within walking distance might reasonably expect similar effects to those here. But many urban schools might have more barren schoolyards and surrounds—in those schools, we might still expect an advantage for lessons outdoors if the environment is reasonably safe, as some evidence suggests that outdoor settings without vegetation have effects better than indoor settings although not as good as green outdoor settings (Kuo and Faber Taylor, 2004). In schools with considerably greener surrounds, lessons in nature might have even larger impacts on classroom engagement; in one of the few studies including a wide of levels of nearby nature, the more natural a students' dormitory view, the better their cognitive performance (Tennessen and Cimprich, 1995).

The students in this study were predominantly low-income, students of color. In students facing challenges associated with poverty, minority status, or both, academic achievement is a pressing concern—in a comparison of rich and poor school districts, sixth graders in the richest school districts are four grade levels ahead of children in the poorest districts, and differences in socioeconomic status explain much but not all racial/ethnic differences in outcomes (Reardon et al., 2016). In this population, then, the finding of an inexpensive educational practice with a consistent, large, positive effect on classroom engagement raises exciting possibilities. As for other populations, the available evidence suggests that similar effects might obtain: in the greenspace-academic achievement literature (e.g., Matsuoka, 2010; Wu et al., 2014), schools with lower numbers of free-lunch eligible students and non-Whites show positive relations between nearby greenspace and standardized test scores.

The teachers in the study were both highly experienced, had had in-service training in outdoor and environmental education, and were open-minded as to what the study might reveal. It seems plausible that teachers without such training, and teachers adamantly opposed to lessons in nature, might show smaller effects or even none at all. Their relevant in-service training is likely to have given the teachers more confidence in offering lessons in nature, and as highly experienced instructors, they may have been more adept at recognizing the need for adjustments and making them. Thus, the effects found here might reflect these teachers' background in outdoor and environmental education. At the same time, teachers with their background might well be precisely the population of teachers most ready and willing to try offering lessons in nature.

Contributions to the Science of Nature-Based Learning

The findings here fill a gap in the previous literature on the impacts of nature on human functioning. On the one hand, previous experimental work has shown immediate aftereffects of contact with nature on basic psychological processes relevant to classroom engagement—attention, intrinsic interest in learning, impulse control, stress, and the effects of physical activity on cognitive functioning. On the other, large-scale correlational work has tied greener near-school landscapes with better school-level performance on standardized academic achievement tests—even after controlling for socioeconomic and other factors. These two lines of investigation examine different kinds of functioning, scales of analysis, and units of time. The work here bridges the two lines of investigation, pointing to a potential pathway between the two.

Boosts in classroom engagement might be a steppingstone by which nature's immediate, short-term effects on basic psychological processes might ultimately translate into boosts in long-term academic outcomes at the school level. Boosting attention, intrinsic motivation, and discipline simultaneously while reducing stress within the same individual seems likely to have synergistic effects in student-level engagement. Across pupils in the same class, boosting engagement in multiple students simultaneously is likely to result in synergies as well; when many, if not all, of the students in a class are quieter, more focused and less disruptive, classroom engagement is likely to be much fuller and more sustained. These two synergies—between different psychological processes within individual students, and between students within a class—may explain the size of the nature advantage seen here at the classroom level. Furthermore, because classroom engagement is an important contributor to long-term academic achievement (Skinner and Belmont, 1993; Godwin et al., 2016), regular episodes of exceptional classroom engagement over the course of a school year might have a surprisingly large cumulative effect on learning. Theoretically, this may help explain how relatively small differences in near-school green cover have been tied to significant differences in end-of-year standardized test performance (Matsuoka, 2010; Wu et al., 2014; Hodson and Sander, 2017; Kweon et al., 2017; Browning et al., in review; Kuo et al., in review).

For scientists interested in examining the impacts of lessons in nature on classroom engagement—or, more generally, following changes in classroom engagement over time—the Composite Index of Classroom Engagement and its constituent components may be of use. The CICE differs from other measures of engagement in two ways. First, it focuses on engagement at the level of the classroom rather than the individual student (for a review of 21 measures of individual student-level engagement, see Fredricks et al., 2011). And second, our measure is designed to provide a global assessment of classroom engagement for a class within a specified time window, and to allow tracking changes within a class over time. By contrast, the similarly titled "Classroom Engagement Inventory" (CEI) (Wang et al., 2014) was designed to quantify differences between classrooms in classroom engagement. Although our CICE can also be used to compare different classrooms, it does not separately assess the affective, behavioral, and cognitive dimensions of engagement as the CEI does; however the CICE does have the advantage of incorporating teacher's perceptions without relying entirely on teacher report.

We recommend future researchers use the measures showing the highest concurrent validity and sensitivity to the intervention here: teacher ratings, redirects, and independent photo-based ratings, and a composite measure. Although student-based ratings of classroom engagement—or more specifically student ratings of peer engagement and whole class engagement—had reasonable levels of interrater reliability and correlated positively with other measures of engagement, they were not sensitive to condition differences in engagement and may not be worth the trouble of collecting. Teacher ratings, by contrast, are quickly and easily collected, and seem an invaluable source of data as they reflect teachers' self-reflections on how easy or difficult students were to engage. Redirects—instances in which the instructor stopped instruction to redirect or correct student behavior, "sit down," or "I will wait"—are a concrete and important indicator of how well instruction is going. High levels of redirects indicate students are not attentive to instruction or tasks assigned. Further, redirects themselves are likely to impact learning outcomes by reducing the coherence and flow of lectures and distracting students as they work on assigned tasks. And the use of photo-based independent ratings allows ratings of classroom engagement to be made blind to condition and outside of the teacher's perceptions or biases, without having to introduce an experimenter in the classroom.

Implications for Educational Practice

The findings here provide some support and guidance for including more lessons in nature in formal education. For teachers who have been intrigued by the potential of lessons in nature but have been concerned about negative aftereffects on classroom engagement, the findings here directly address that concern. For environmental educators who have been shunted aside in favor of spending instructional time on drill and practice for standardized achievement tests, the findings here may offer a valuable argument for outdoor environmental lessons. The findings here also offer some encouragement for teachers interested in trying to adopt experiential approaches to education, which are particularly well-suited for lessons in nature. Such approaches allow students to actively use the outdoors to apply theoretical knowledge "in the field" and undertake problem-solving and decision-making in real world scenarios. These processes may be more effective at instilling and scaffolding long-term knowledge acquisition than other instructional strategies (Ballantyne and Packer, 2002). Curriculum that could benefit from learning styles beyond auditory and visual are also particularly well-suited for lessons in nature, because the diversity of topography and vegetation in natural landscapes also provide unique kinesthetic learning opportunities (Fjørtoft and Sageie, 2000; Auer, 2008).

While we do not know to what situations and populations the effects here will generalize, the consistency and size of the effects here suggest that lessons in nature are worth trying in a broad range of settings (for resources on how to start, see Supplementary Materials). It is worth noting that the nature advantage, while consistent, did not occur in every pair of lessons; notably, for one teacher the first classroom lesson outperformed its outdoor counterpart. Thus, we encourage teachers to try at least two or three lessons in nature before assessing their value.

More broadly, the findings here underscore the growing view that classroom engagement is at least as limited and valuable a resource as instructional time. With the advent of No Child Left Behind legislation, the vast majority of U.S. school administrators reduced or completely cut recess time and other breaks during the school day, with the primary motivation of providing more instructional time for standardized test preparation (Robert Wood Johnson Foundation, 2010). Instructional time has been viewed by many administrators as the key, limited resource for improving academic achievement; consequently, the de facto approach to increasing student learning has been to free up instructional time by cutting school activities seen to be unhelpful to standardized test preparation—recess, physical education, art, music, theater, etc. Yet increasing the number of hours in the classroom does not translate to increasing the number of hours of student are attentively learning (Gettinger and Seibert, 2002). Estimates suggest students spend 10–50% of their time at school *unengaged and off-task* (Hollowood et al., 1994). Like pouring tea into an already full teapot, giving teachers more time to deliver standardized test content is of little value if the vessels are unable to receive. Thus, classroom engagement may in fact be the key, limited resource in academic achievement. Seen in this light, the net benefits of recess, art, music, theater, and physical education for subsequent classroom engagement may easily exceed the tradeoff in instructional time—even apart from their inherent value.

Priorities for Future Research

In our view, three tasks are pressing for future research: first, mapping the dose-response curve; second, assessing the net impact of lessons in nature for academic achievement; and third, establishing the generality of the effects here.

A map of the dose-response curve would be of great practical value. How "natural" does a landscape need to be to boost classroom engagement? If a small investment in vegetation outside a school can enable teachers to teach longer periods uninterrupted, such effects might ultimately translate to greater academic achievement in students, and more job satisfaction and less burnout among teachers. Similarly, studying larger doses than those here may reveal even larger benefits. The fact that the effect of each outdoor lesson does not diminish even as such lessons become routine suggests that adding more, or longer, lessons might yield proportionately large benefits. Perhaps instead of going out for lessons once a week, students might go out once or twice a day. Similarly, more prolonged or more intense doses of nature might be worth testing, such as is typical in "all-weather schools" or "outdoor schools" in Europe (Bentsen and Jensen, 2012). The larger landscape of the school in this study included a fishing stream and 30 acres of woodlands and open space that might theoretically be resources for lessons in nature, but the teachers in this study were reluctant to sacrifice the necessary instructional time to walk to those areas. The findings here suggest that the benefits of such larger doses of nature might be well worth investigating.

In addition to mapping the dose-response curve, there is a pressing need to quantify the net impact of lessons in nature on academic achievement. Substantial evidence points to lessons in nature enhancing learning of the material in those lessons; to what extent do lessons in nature enhance learning of the material in subsequent lessons? What is the net effect on academic achievement, given that some instructional time is spent on walking to and from lesson sin nature? The large effects here on classroom engagement suggest potentially large boosts in academic achievement.

A third priority for research should be to establish the generality of the effects here. The success of this intervention in two real-world classrooms over a variety of lessons, weather conditions, and initial teacher expectations invites expanded testing. Does it matter what the subject of the lesson in nature was? In this study, the topics all fell within the general domain of biology. Might a poetry class held outdoors have similar effects? Similarly, the teachers here were experienced and highly trained; might less seasoned instructors have less success managing an outdoor class? Further, in this study the students came from largely disadvantaged, urban neighborhoods; to the extent that these populations might experience less contact with nature than others, perhaps the impact of even small doses of nature is heightened. Future research on the aftereffects of lessons in nature should incorporate students from less urban, less disadvantaged contexts, as well.

CONCLUSION

This study is the first to our knowledge to directly examine the effects of lessons in nature on subsequent classroom engagement. We found higher levels of classroom engagement after lessons in nature than after carefully matched classroom-based counterparts; these differences could not be explained by differences in teacher, instructional approach, class (students, classroom, and class size), time of year, or time of day, nor the order of the indoor and outdoor lessons on a given topic. It would seem that lessons in nature boost subsequent classroom engagement, and boost it a great deal; after a lesson in nature, teachers were able to teach for almost twice as long without having to interrupt instruction to redirect students' attention. This nature advantage persisted across 10 different weeks and lesson topics, and held not only for a teacher with positive expectations for nature-based lessons but also for a teacher who anticipated negative effects of such lessons. The findings here suggest that lessons in nature allow students to simultaneously learn classroom curriculum while rejuvenating their capacity for learning, or "refuel in flight." Because providing children with more contact with nature in the course of the school day is likely to yield a whole host of additional dividends as well, including improved physical and mental health (see Chawla, 2015 for review), the findings here argue for including more lessons in nature in formal education.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations for the Protection of Human Subjections, Institution Review Board, University of Illinois at Urbana-Champaign. Parents gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by both the University of Illinois at Urbana

Champaign Institutional Review Board and the Indianapolis Public Schools Department of Research, Evaluation and Assessment.

AUTHOR CONTRIBUTIONS

MK was involved in study design, the development of measures, data acquisition, data analysis, and manuscript writing. MB was involved in data analysis and manuscript writing. MP was involved in the study design, the development of measures, data acquisition, and data analysis, and commented on the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2017.02253/full#supplementary-material

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Potentials in *Udeskole*: Inquiry-Based Teaching Outside the Classroom

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Most research on outdoor education, including the Scandinavian concept *udeskole* (regular curriculum-based teaching outside the classroom), has focused on pupils' outcomes, whereas less has focused on teachers' practices. In this article, we described the occurrence of inquiry-based teaching in *udeskole*. To analyze practice, we extended the notion of inquiry-based education. Within science and mathematics education, a strong stepwise teaching approach formerly was established, called Inquiry Based Science and Mathematics Education (IBSME), emphasizing pupils' hypothesis testing, data validation and systematic experimentation. In this study, we broadened the IBSME-concept of inquiry in order to include a more holistic, non-linear teaching approach, but excluding teacher-instructed inquiry. Using this idea, we observed and documented by field notes how five experienced teachers practiced mathematics and science teaching in *udeskole* at primary level in Denmark. Twenty-eight outdoor days were observed. Each day was divided into separate teaching incidents with a distinct start and end. The level of teacher interference and possible choices in each teaching incidents formed the analytic background. We analyzed each of the 71 teaching incidents, and categorized each of them into one of five categories numbered 4–0. The categories designated numbers 4–2 contained the inquiry-based teaching incidents, and the categories designated 1 and 0 were categorized as "non-inquiry-based." They contained teaching incidents where the teacher was instructing the pupils (category 1), and outdoor teaching activities with no sign of inquiry, called training activities (category 0). Our results showed that about half of the analyzed outdoor teaching practice seemed to be inquiry-based, emphasizing pupils' choice and presenting cognitive challenge. This indicates that the analyzed *udeskole* had the potential to support an explorative and multifaceted inquiry-based teaching in mathematics and science, paving the way for a child-activating education. These results, albeit limited by the small number of observed teachers, supports the theoretical notion that *udeskole* is a potential way to strengthen pupils' approach to inquiry.

Keywords: inquiry-based teaching, pupils choices, teacher guidance, teaching outside the classroom, *udeskole*

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INTRODUCTION

Teaching outside the classroom (TOtC) was discussed as a powerful way to teach curricular content (Rickinson et al., 2004; Becker et al., 2017) in natural and cultural settings. This could imply open-ended problem-solving tasks, involving inquiry-based educational approaches where by pupils were given an element of free choice (Braund, 2004; Jordet, 2010). Inquiry-based teaching has be seen as a part of a historical wave in the educational system (Albrechtsen and Qvortrup, 2017), reversing science teaching from deductive to more pupil-centered teaching, emphasizing pupil activity in a constructivist learning process. Inquiry-based teaching was in this perspective both a method for learning certain content and an approach to a field, recognizing the tentative and social parts of science and mathematics (Van Uum et al., 2016).

Inquiry-Based Education in Science and Mathematics

As it was widely used in science education, discussion concerning the concept of inquiry was prevalent (Artigue and Blomhøj, 2013; Pedaste et al., 2015) and ongoing. Still, a dominant understanding of inquiry in science and mathematics education called IBSE or IBSME was connected to stepwise processes, divided and ordered in distinct phases (Bybee et al., 2006; Pedaste et al., 2015). The phases were referred to differently in the literature, but comprised orientation, conceptualization (questioning, hypothesis generation), investigating (planning, exploration, experimentation, observation and data interpretation, analysis), conclusion, and discussion (with communication and reflection). Whenever these phases were conducted as group-work, we acknowledged this tradition, and suggested that the constructivist starting point was kept, but we added an emphasis to the educational dynamics emerging from the variation in pupils' approaches to learning activities, based on their experiences, among other things.

The aim of this paper was to investigate the prevalence of inquiry-based teaching outside the classroom. First, we discuss the traditional IBSME phases as related but not ordered, acknowledging experiences and pupils' choice as inevitable parts of the inquiry. On basis of this discussion, we propose a framework for analyzing inquiry-based teaching. Second, we use this framework to provide empirical data on the level of teacher guidance during the inquiry process in *udeskole*.

Inquiry-Based Teaching

Inquiry has been defined in a broad manner (Artigue and Blomhøj, 2013). In this understanding, inquiry encompassed a variety of practices in a constructivist pedagogical tradition, accentuating pupil activity and engagement. Besides this, the epistemological starting point concerned the democratic and critical part of inquiry, as the ability to solve unknown problems by thinking and reacting autonomously was emphasized. A key feature of inquiry was to develop a problem-based culture, allowing various ways to solve problems (Artigue et al., 2012). Other researchers within inquiry-based learning also underlined how pupils had to be offered necessary and meaningful choices during the process (Bromley et al., 2013). To qualify as choice in the process of solving a task, "the learner must perceive that there are reasonable and desirable learning choices (as defined by the learner) available" (Falk, 2005, p. 747). In this understanding, inquiry was not merely a method but a pedagogical approach, aiming to drive learning through questions and curiosity (Leat, 2017). This approach could support pupils' long-lasting intrinsic motivation to learn (Saunders-Stewart et al., 2012). In our understanding of this line of research on inquiry, experience and sensory perceptions, building up silent knowledge was a key element in an "orientation" phase. Thus, non-conscious, non-cognitive impressions did build up a scaffold for learning. Considering this scaffold helped us to understand how students learn by involving sense experiences, emotions and uncertainties (Hwang and Roth, 2011). This understanding of learning opened up for more than rational scholastic processes by which teachers supported pupils' inquiry work; it also includes pupils' engagement with concrete objects and phenomena from their everyday experience of their world, supporting their curricular learning. This everydayness could constitute both the context for learning, and a resource in the learning process (Jordet, 2010; Hwang and Roth, 2011).

In short, we used the following criteria to recognize inquiry in the teaching activities as: When a sensory or action based experience offered resonance for the learning process, or when the pupils were offered significant choices (in means of process or product) during the learning process.

Teacher Guidance and Free-Choice Learning

Inquiry-based learning has been described with both a *cognitive dimension* and a *dimension related to teacher guidance* (Furtak et al., 2012). When the assignments were open-ended, the teaching offered pupils opportunities to make conscious and meaningful choices (Katz and Assor, 2007), with activities being "open to an autonomous orientation of the student, what increases the possibility of him to produce interpretations and outcomes unexpected for the teacher" (Tavares et al., 2015, p. 157). Activating the part of the *cognitive dimension* called the "procedural inquiry" (Furtak et al., 2012, p. 305) implied "the mobilization of previous knowledge and the construction of new knowledge" (Tavares et al., 2015, p. 155). Falk (2005) introduced the concept of free-choice learning as an alternative to the dichotomy of formal and informal/non-formal learning, emphasizing that it was hardly the place or institutional context that defined the type of learning, but rather the extent to which the teaching was open-ended, inquiry-based, and optional. Free-choice learning was a construct, as "The operational issue is *perceived* choice and control by the learner. To qualify as free-choice learning, the learner must perceive that there are reasonable and desirable learning choices (as defined by the learner) available, and that s/he possesses the freedom to select (or not to select) from among those choices" (Falk, 2005, p. 273). The concept recognized characteristics of learning as non-sequential, self-paced and voluntary (Falk, 2005), and the socially constructed nature of learning. Based on observation of class visits in museal settings, Bamberger and Tal (2007) identified the constituents of choice the pupils encountered at the visits. From the guided tour with no choices, to levels of limited choice with choices regarding what to work with (topic), where to go (space), what to learn about (object), for how long (time), with whom (friends, instructors, teachers), and with what kind of interactions (interactions) and in what order, tasks could be done (order). At the other end of the spectrum was the free exploration of the exhibition. Unsurprisingly, it was indicated that the effectiveness of learning, measured as the ability to give correct answers on worksheets at the museum, was enhanced by the limited choice visits. In these visits, the pupils were offered scaffolding by the teacher, enhancing the pupil's engagement, by allowing the pupils more control over their learning process (Bamberger and Tal, 2007). In inquiry-based teaching, the pupil could make a choice regarding method (Bromley et al., 2013) based on reflection on the consequences and, during the course of the work, could ask him/herself the question "What if..." (Blomhøj and Skånstrøm, 2016), which provided the tasks with elements of openness. Pind (2015) wrote, how open tasks in mathematics teaching were tasks in which there were more possible answers, tasks in which there were choices to be made because there were something not yet decided. In accord with Dewey (1938), the tasks included elements of conscious positioning, whereby the pupil reflected on the consequences of different actions (Artigue and Blomhøj, 2013; Morgan, 2014). It was not merely the choices, but the fact that "...in all the respects mentioned freedom of outward action is a means to freedom of judgement and of power to carry deliberately chosen ends into execution" (Dewey, 1938, p. 63).

It did, however, involve a balance and a cooperative enterprise whereby the teacher gave and took ideas to and from the pupils, as it was possible:

> "…to force the activity of the young into channels which express the teacher's purpose rather than that of the pupils. But the way to avoid this danger is not for the adult to withdraw entirely. The way is, first, for the teacher to be intelligently aware of the capacities, needs, and past experiences of those under instruction, and, secondly, to allow the suggestion made to develop into a plan and a project by means of the further suggestions contributed into a whole by the members of the group" (Dewey, 1938, pp. 71–72).

The second *dimension* of inquiry-based science education (Furtak et al., 2012) was then the *degree of guidance*, described as a continuum between the highly teacher-driven and pupil-oriented teaching activities. A detailed instruction for inquiry, or a scientific "kit" offering cookbook instructions, was at the left side of the scale. From these closed tasks a continuum was described, setting pupils increasingly free to make their own decisions concerning inquiry questions and working methods.

Teacher actions supporting inquiry-based learning in practice (Harlen, 2004) are thus important (Furtak et al., 2012), and may require special effort from the teacher, as the teacher is to make space for the pupils' views and suggestions (Michelsen, 2011). Among other things, the teacher must act as a supervisor supporting the pupils' self-employed work without leaving them alone, offering help in the pupils' planning so their ideas can be tested appropriately (Harlen, 2004). Through this, the pupils should be offered scaffolding that supports their ideas or presents to them possible strategies that are beyond, or at the border of, their own abilities (Hmelo-Silver et al., 2007), thus widening their perspectives by challenging their inquiry approach. We have added a fourth guidance role, "pupils' inquiry approach widened by the teacher," to the model proposed by Furtak et al. (2012), at the far right of the teacher guidance continuum in **Figure 1**. The expanded continuum provides us with an analytical approach to understand teachers' work with scaffolding pupils' work and learning in inquiry-based education.

Udeskole in Denmark

Education outside the classroom in both natural and cultural settings has been recognized to benefit pupils' cognitive, social and physical outcomes (Rickinson et al., 2004; Bamberger and Tal, 2008; Becker et al., 2017; Schneller et al., 2017), the learning outcome often being connected to pupil motivation, hands-on learning and active participation. Outcome assessment highlighted how changing the place of teaching could support pupils in connecting knowledge from school to out-of-school settings (and vice versa), accentuating the long-term nature of pupils' learning. Thus, the out-of-school experiences should not be assessed narrowly based only on the pupils' ability to give correct answers immediately after a teaching sequence, but should take into account long-lasting, adverse, and rich learning outcomes. Although it is not mentioned in the official curricular documents, *udeskole* is a growing educational practice, performed by a fifth of all Danish schools (Barfod et al., 2016). Emanating from a Norwegian tradition, *udeskole* has spread to other countries in the northern part of Western Europe (Barfod et al., 2016; Sahrakhiz, 2017). It is a distinct category of outdoor education, held regularly (rather than an occasionally occurring exception), e.g., 1 day a week (Bentsen and Jensen, 2012), led by the schoolteacher herself and not outdoor professionals (Waite et al., 2015), and with a strong curricular content (e.g., Mathematics, History, Science). Thus, the traditional outdoor learning focus shifted "from environmental, personal, social and health perspectives toward curricular perspectives" (Bentsen et al., 2009, p. 38).

Udeskole can be seen as supporting both broad life skills and curricular goals, breaking down the walls of schools, and guiding the pupils' into society (Bentsen and Jensen, 2012). *Udeskole* research suggested that it was not simply the variation in place (e.g., going outdoors) but also the accompanying variation in teaching approach that constituted the potentials of *udeskole* (Jordet, 2010). *Udeskole* was described as an outdoor practice that involved problem-solving, explorative and practical approaches, and constructive, creative and playful approaches, with a necessary connection between the indoor and outdoor lessons (Jordet, 2010; Bentsen and Jensen, 2012), whereby teachers were inspired by the experiential educational tradition (Bentsen and Jensen, 2012). Taking into account that the academic field of *udeskole* is limited, all this indicates that *udeskole* holds the potential for learning through inquiry as it opens up for pupils answering their own questions.

There is a lack of knowledge concerning teaching approaches in the outdoors, albeit descriptions of activity categories (e.g., Lindemann-Matthies and Knecht, 2011) and descriptions of how teachers' beliefs affected their teaching in the outdoors (Glackin, 2016) has been published. As teaching outside opens up for new teaching rhythms, themes and methods (Sahrakhiz, 2017), *in vivo* studies of teaching could qualify an understanding of *udeskole* practice (Bentsen and Jensen, 2012). This research intends to fill this gap by firstly discussing the understanding of inquiry-based teaching and proposing an analytic framework, secondly by

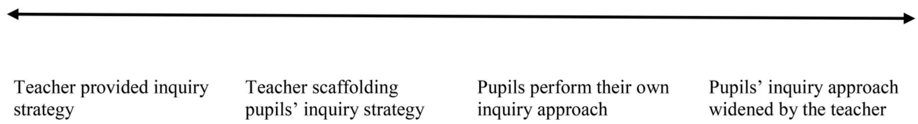

FIGURE 1 | Continuum of teacher guidance in inquiry-based teaching. Inspired by Furtak et al. (2012, p. 306).

TABLE 1 | Characteristics of participating teachers and the schools where they work.

Participant	P1	P2	P3	P4	P5
Age	40	43	44	41	45
Gender	Female	Female	Female	Male	Male
Years of teacher experience	14	15	10	14	18
Years working with *udeskole*	2	6	10	6	6
Place	SY	C	CP	SY	SY/CP
Pupil age (years)	9–10	10–11	8–9	10–11	10–11
Subjects	Ma	Ma, S	Ma, S	Ma	Ma, S
Observations, number of days	7	5	5	6	5

SY, Schoolyard and nearby surroundings; C, campsite in nature; CP, teacher choosing place according to content; e.g., Museum, Lake, Forest.Subjects taught outside. Ma, Mathematics; S, Science.

using this framework to analyze the prevalence of inquiry-based teaching conducted by five teachers in *udeskole*.

METHODS

Approach

To get in-depth insight into individual teachers' intentions and practice in teaching *udeskole*, a qualitative case study approach was chosen. Five trained teachers representing different forms of *udeskole* were studied through participant observation (Gold, 1958) over the course of a school year. Field notes observation studies and discussions gave a rich body of material that was then thoroughly analyzed.

Participants

The participating teachers represented a group of experienced professional teachers for whom *udeskole* was as an everyday working experience. See **Table 1** for the characteristics of participating teachers and the schools where they worked.

Participant 1: Taught mathematics outside in the observed class for 2 lessons lasting 45 min every week (or every second week). She had not attended any outdoor courses at all. This participant worked at a town school, with approximately 400 pupils.

Participant 2: Taught mathematics and science outside in the observed class 1 day every week. She did some work as a consultant, inspiring colleagues to teach science outside. This participant worked at a suburban school with approximately 750 pupils.

Participant 3: Taught mathematics and science outside in the observed class 1 day a week year-round in nearby natural environments, and visited the nature school with guided tours. She attended a 5-day course during her basic education 3 years prior to the observation period. This participant worked at a small rural town school with approximately 150 pupils.

Participant 4: Taught mathematics in the observed class two lessons (45 min each) every week, in the schoolyard. The participant was one of the school's two "learning by movement" consultants. This participant represented a "deviant case" (Silverman, 2013), as his urge for outdoor activities emerged from the school board enrolling in a physical activity program. This participant worked at a small town rural school with approximately 780 pupils.

Participant 5: Taught mathematics outdoors with the observed class in 2 h (120 min) lessons 2 days a week. In the years before this study, he conducted outdoor teaching one full day a week. He attended a 5-day "teaching outside with non-formal learning environments" course a few years before the data collection, and attended outdoor network meetings twice a year. This participant worked at a small town school with approximately 110 pupils.

The pupils were not formally participants in the study of the teaching, but they were the recipients of the teaching. The focus in this study was the exercised teaching actions performed by the teacher. When the pupils' reactions were illustrative in understanding the teaching, they were presented anonymized as "a pupil" in the Results section.

Data Collection

Observations were carried out as participant observation, for a total of 28 days (Gold, 1958) on outdoor lessons planned by the teacher (Silverman, 2013). Each visit lasted 120–420 min, and many of these *udeskole* days were a combination between outdoor and indoor activities. During the visits, walk-along interviews and conversations with the teachers were noted. Field notes were taken during the lessons and photos were taken to support the researcher's memory. Within two working days, all field notes were rewritten into text files and preliminarily coded into models based on Bamberger and Tal (2007) and Jordet (2010).

All participants gave their informed written consent, and all parents gave written permission to take photos. This project did not require formal ethical approval under Danish legislation.

Analysis

Prior to analysis, each teaching session was divided into separate incidents; that is, teaching activities initiated by the teacher with a purpose, a beginning, and an end. As the concept of inquiry was broadened, non-linear and explorative teaching approaches were included in the IBSE "orientation" phase and used as an analytic frame. Observational data was organized using the software NVivo QSR.

An incident was regarded as inquiry-based if it contained each of these following characteristics:

- One or more IBSE phases (Pedaste et al., 2015) leading to other phases,
- An open exploration or open-ended questions with uncertain process and results with open, multiple solution strategies,
- The presence of choices conducted by pupils, and
- The teacher's role being coded as 2–4 in the following categories.

Inspired by Furtak et al. (2012), the teachers' roles during the inquiry-based incidents were coded into the categories:

4. Teacher widening the pupils' inquiry approach
3. Teacher not interfering with the pupils' performance during the inquiry
2. Teacher scaffolding pupils during the inquiry
1. Teacher instructing pupils in the inquiry task

As the teachers could differentiate their teaching by the degree of guiding different groups of pupils, some incidents could be either "scaffolded" (Category 2) for some students, or "widened" (Category 4) by the teacher for others. The highest degree of challenge observed during the incidents were those categorized here. Activities being performed by the pupils as recurring habits (e.g., measuring weather data) was analyzed as scaffolded, as they were built upon the teacher's ideas but became a skill. As teacher-driven game-like activities did not offer the pupils any choices connected to process or result, they were categorized as non-inquiry activities (Category 0). The analytic framework is summarized in **Table 2**.

TABLE 2 | Overview of analytic categories.

Main category	Description
4: Teacher widening the pupils' inquiry approach	The teacher use productive questions to facilitate the pupils to extend their inquiry activity
3: Pupils working without teacher interference	Pupils autonomously perform their own inquiry activity
2: Teacher scaffolding pupils' inquiry	The teacher guides the pupils in their inquiry activity through instructive dialogue
1: Teacher instructing pupils	The teacher directly guides the pupils inquiry activity through instructions
0: Activities with no sign of inquiry	The teacher leaves no options for choices for the pupils

TABLE 3 | Portion of incidents coded as inquiry-based, $n = 71$.

Main category		Observed incidents *n*= 71	% of *n*
Inquiry-based	4: Teacher widening the pupils' inquiry approach	8	52
	3: Pupils working without teacher interference	6	
	2: Teacher scaffolding pupils' inquiry	23	
Non-inquiry-based	1: Teacher instructing pupils	10	48
	0: Activities with no sign of inquiry	24	

Numbers 1–4 refer to teacher guidance categories in the Methods section. Numbers 1-0 illustrates activities that are not inquiry-based.

RESULTS

Results

In this chapter, we firstly present an overview of the results as a table. Secondly, we give examples of the different categories, to open the possibility for the reader to get a deeper insight in the basic data.

The main result was, that approximately half of the observed incidents were categorized as inquiry-based. As shown in **Table 3**, 52% of all teaching incidents during the 28 observed *udeskole* days were either in category 4, 3, or 2 of the developed analytic frame.

The analytic frame we developed took into account the cognitive processes offered to the pupils by the teacher. Based on a theoretical background on inquiry-based teaching inspired mainly by Artigue and Blomhøj (2013) and Furtak et al. (2012), we developed an analytic framework only categorizing tasks as inquiry-based if the pupils were offered choices and decision-taking during the process. Even if the pupils were examining or experiencing tasks in the outdoors, but the lessons were teacher led, the activities were not designated as inquiry-based. As all tasks on the observed days were analyzed, non-inquiry activities as training activities and plays and games were observed and categorized (category 0).

Category 4. Teacher Widening the Pupils' Inquiry Approach

In this paragraph, we describe an example of a teaching incident, where the teacher was widening the pupils' inquiry approach. The teacher supported the pupils' inquiry, and asked them questions during the process to widen their exploration and understanding of their own questions.

On a windy summer day, pupils were working with distance and speed, one of the activities being "bug race," calculating invertebrates' speed in meters per second. The pupils had caught various woodlice, spiders, and earwigs to compete. But the animals were very slow, or ran in too many directions to measure. After trying this out, one pupil suggested how to make them run properly—"We could try to feed them"—and another pupil suggested "Maybe we could measure only ten centimeters?" The teacher challenged these ideas, asking "How can you calculate the speed in meters per second if you only measure ten centimeters?" and "How many centimeters do you have in a meter," and listened to the pupils' suggestions. Numbers were drawn on the ground, and decimal points shifted. Here, the teacher was widening the pupils' inquiry.

Another day, pupils had to work with symmetry, building symmetrically with materials provided by the janitor. Behind the school, there were different building materials as logs, tiles and a pile of gravel. The teacher showed with help from a pupil what the task was, to build symmetrically over a symmetry axis drawn with chalk. The children began to work—with their imagination and with symmetry. Either by dividing symmetrical things with the chalk line, or finding two identical things and putting them alike. They also used professional language: "We are building his stomach symmetrically." The janitor had offered many different things, the pupils could go in and pick up—chairs, gravel, tiles, circles, and the teacher brought a whole bag of 1 m/, ½ and ¼ m sticks the pupil had made before. Gradually all the pupils—more or less—got started. There were many professional and aesthetic discussions between the pupils. Some children build a complicated figure and the teacher draw a new symmetry axis perpendicular to the old. The pupils were discussing, they measured whether the pins were equal long, and they developed the figure, e.g., two boys began to build in height. A group builded an ant of, among other things, wooden slices, and stroke them with sticks in a rhythmic drummer. Some pupils found it difficult to work together, but when they saw how exciting the other group's products were, they got started. At the end of the lesson the teacher gathered all the pupils, asking them what a symmetry axis was—and several fingers came up, but when the explanations came, the students explained symmetry, not symmetry axis. The teacher explained: "It is the line, the white chalk line, the symmetry axis," linking the term with the pupils' own experience and actions.

Category 3. Pupils Working Without Teacher Interference

In this category, both "orientation phase" (Bybee et al., 2006) and the teachers role "pupils working without teacher interference" is merged. In this paragraph, we first describe an example of an incident, where the teacher did not interfere with the pupils' inquiry. The pupils explored relevant elements of nature, but without any questions set by the teacher. Secondly, we present an example of an incident, comprising one of the IBSE phases (Pedaste et al., 2015), and coded as "orientation phase" in terms lend from Bybee et al. (2006). The class walked to a nearby lake. After receiving safety instructions, the pupils were set free to catch water creatures. Once every 10 min, the teacher yelled "TIME!" and the waders, limited in number, was handed over to other students. The pupils worked unsystematically, but highly engaged, and experienced many different animals; without any conflicts between the pupils. No one used the identifying sheets or the books that were present. Some of the pupils wandered over to nearby trees, which they started to climb. The teacher stood in the lake, as a human border between the shallow and deep water, but did not interfere with the pupils' experiences and discoveries. Here, the pupils performed their own inquiry.

On a cold November day, the pupils had been working drawing a map of the area at a 1:100 scale. The teacher called the pupils; it was now to prepare soup over the bonfire, the bonfire being lit by today's fire team. "Who's going to cut the carrots?" the teacher asked, and the pupils volunteered to contribute to the common project in different ways. As the soup was ready, the pupils lined up and one started to ladle the warm soup into the cups being held out. Only a heeltap was left over for seconds (**Figure 2**).

FIGURE 2 | Example from category 3, pupils assesing quantety by sharing the soup.

When soup was made for the whole class, there had be enough for everyone and at the same time no food waste. The pupils worked with quantities and fractions without explicitly hypothesizing or questioning, instead doling it out by eye. There was a task to be solved involving a rough assessment of quantity, which could serve as a resonance ground for the development of further work with fractions. Here, the pupils performed their own experience-based inquiry.

Category 2. Teacher Scaffolding Pupils' Inquiry

In this paragraph, we describe an incident, where the teacher did frame the pupils work by scaffolding their inquiry process. The teacher did set the questions to be worked with, but left openings for the pupils to make their own choices during the process.

Before working with mathematical equations, pupils were asked to balance wood blocks in the sandbox. The teacher explained the task: "You have to make an equilibrium with these blocks; maximum 10 blocks." The children worked together—there was a great deal of cooperation involving, for example, placing blocks on the plank simultaneously (**Figure 3**). The pupils build huge and beautiful balanced structures, and the teacher provided the groups with supplementary challenges like "Can you make an equilibrium with two blocks on one side and three on the other?," encouraging the pupils to work with the size and placement of the blocks. In this situation, the teacher was scaffolding the pupils' inquiry.

On a cold winter day the teacher entered the classroom with thermometres. The engagement in the class was very low, the air bad and the pupils lethargic. "What do you use these for?" she asked the class. A forest of hands rose: "To measure hot and cold with" is one of the answers. The teacher sat the framework for the activity outside, the task was to measure the temperature at least four different places outside, and at least one place inside. She did not hand out the thermometers, the pupils should pick them up at her desk and bring paper and pen. The pupils immediately started measuring when they came out. Many comments showed how committed they were: "We need to find a place where we can write—we found water there were zero degrees hot," "We have a ball with a hole we can measure in." "We will measure in a dogpooh." A girl wondered what the temperature would be high up in the air, and crawled at the top of the play tower.

The pupils seemed to appreciate getting out, they played in the mud, jumped and crawled, and used their bodies in many ways. Compared to the non-energy that was inside, this was completely different. The pupils had to write down their measurements, but some pupils forgot their paper and pen inside. After an hour, the teacher called the pupils in, and in front of the blackboard a teacher centered summation was done. Where did the groups measure? What did they find?

This day, the teacher had a defined aim with the outdoor lesson, and sat the frames for it—the pupils should measure temperature. But there were still room for the pupils to inquire and choose where to measure, and under which circumstances. By this, the teacher scaffolded the pupils inquiry.

Categories 1 and 0. Activities Not Categorized as Inquiry

In this paragraph, we describe a teaching incident, where the teacher asked the problem to be examined, and instructed the pupils on how to work. We categorized this group of activities as *teacher instructing pupils in the inquiry task*. There was no choices left to be taken by the pupils. Activities of this kind is not categorized as inquiry-based in our analysis. In this case, the pupils have to collect data for a bar graph illustrating running time, each pupil running one defined roundtrip in the nearby environment. The teacher started them off by counting down, and asked them to read their own time on the iPad. When they got their time they had to take the stone that represented them and place it on the correct bar. The pupils were instructed exactly what to do, and had no choices regarding the inquiry outcome beyond running quickly or slowly.

On some occasions, teachers chose work involving the repetition of subject-related content, e.g., letting the pupils play a game with given rules, with the tasks instructed by the teacher. We categorized these as *training activities*. Running around trying to catch a matching card (e.g., I have a card with the value ¼ and you have one with 0.25, so we need to find each other and match up), challenging the pupils' ability to work together, to run, and to figure out game-related strategies. This instructive practice was specifically the most abundant with participant four, the "movement in learning" consultant (results not shown). In the observations it was evident that a tail of pupils pestered the

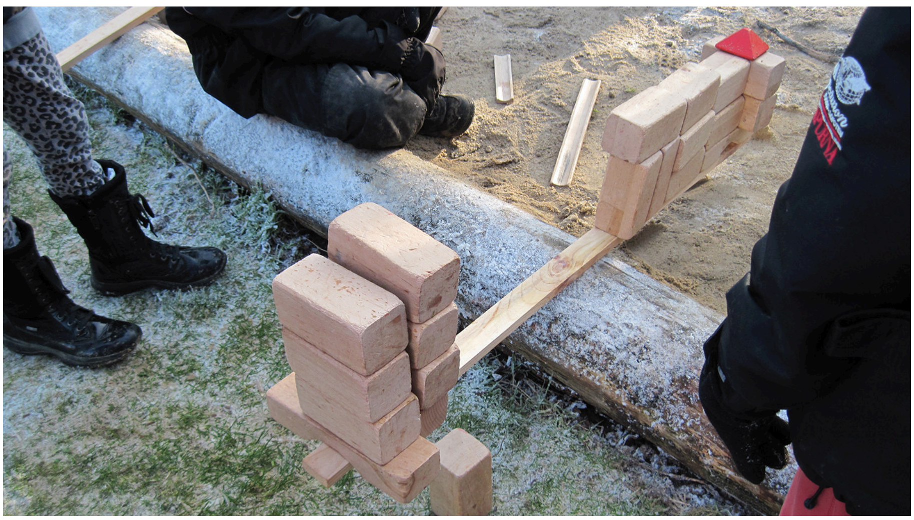

FIGURE 3 | Example of category 2, pupils balancing wooden blocks.

teacher during the closed tasks, asking "What should I do now?" and "Is this good enough?," paying attention to the only one correct answer. On the occasions when visits to the nature center were observed, the nature guides, although they were genuinely good storytellers, did not develop the children's ability to figure out problem-based solutions, but mostly either told them how to do the tasks or simply told them good stories.

DISCUSSION

This study seems to indicate, that for the studied five teachers, about half of the teaching in *udeskole* involved non-instructive, inquiry-based activities for pupils aged 8–11 years. Observations of naturally occurring outdoor science and mathematics lessons by these 5 teachers exposed both closed training tasks and open-ended, inquiry-based tasks. We developed a framework to analyze *udeskole* practice, inspired both by IBSME and free-choice learning. Firstly, we added experience and sensory perceptions to the orientation phase in IBSME. Secondly, we excluded the teacher-instructed, non-choice teaching sessions from the inquiry category. This gave us two main categories of teaching practice outside the classroom: inquiry-based and non-inquiry-based. The framework for analyzing the teaching as inquiry-based took into account:

> "[...] the development of problem-solving abilities and inquiry habits of mind; the autonomy and responsibility given to pupils, from the formulation of questions to the production and validation of answers; the guiding role of the teacher and teacher–pupil(s) dialogic interactions; and [...] the critical and democratic dimensions of IBME" (Artigue and Blomhøj, 2013, p. 809).

This is in agreement with Nesbit and Qing (2014) emphasizing not only the questioning part of pupils' inquiry, but also the experiences and explorations as a base for their construction of knowledge. Still, we did not count incidents in which the teacher instructed as inquiry, as these left pupils with few or no options for making choices. In contrast to the BSCS 5E system launched by Bybee et al. (2006), the incidents analyzed here were much shorter in duration, and the inquiry was often reduced to one or two lessons. The strength in this is that it was manageable for the teacher to teach outdoors on a daily school day, without having to break the schedule up for a longer period, while still retaining some of the qualities of inquiry. By doing this, we acknowledged the structured inquiry approach in IBSME and the BCBS 5E system, but widened it by recognizing explorative investigations as inquiry while also narrowing it by excluding closed, teacher-instructed tasks.

Udeskole (Bentsen et al., 2009) does not necessarily imply inquiry-based teaching, even if this small-scale study points to a great deal of this approach. Assessing the effect of *udeskole* must take into account the actual performed approach to teaching, taking care to closely examine the teaching performed, while not taking for granted that the place of teaching automatically implies a specific teaching approach. Indeed, teachers frequently needed training in order to give their pupils the freedom to build their own knowledge (Tavares et al., 2015). This was supported by the notion, that inquiry-based programs based on scientific kits had no effect on science achievement measures. This was likely because the teacher expended more effort on using the kit than on developing inquiry habits of mind, compared to programs developing teachers' generic competences in engaging and motivating pupils working with collaborative tasks, conceptual challenges, and inquiry approaches (Slavin et al., 2014).

Whenever teachers opened for methodological pluralism, pupils could continue to experience excitement at solving a question or problem on their own, or as part of a team (Tavares et al., 2015). In *udeskole*, there were many approaches to inquiries with curricular aims. In the presented cases, the pupils worked independently of the teacher during non-instructed tasks, and the teachers' role and communication with the children were less judging. By taking a more listening attitude to the proposals from the children, and discussing their solutions with them, the teacher could manage to encourage them to pursue their own interests and challenge them cognitively. This is the case in our "widening" category 4, where it was the teacher's challenging questions that stimulated the pupils to elaborate on their inquiry activity. In our "autonomous" category 3, the pupils worked without teacher interference, presumably driven by their own ideas and intrinsic motivation (Saunders-Stewart et al., 2012), but also limited by it. In our "scaffolding" category 2, the pupils needed the teacher's assistance and support in order to work purposefully with the inquiry activity.

In our analyzed cases, a common activity was allowing the pupils to get experiences with materials in order to create a foundation for understanding. In the equation-balancing blocks task, the pupils activated a common human experience with balance and the teacher later used this to work with equations, thereby connecting the pupils' experience with school mathematics content (Bamberger and Tal, 2008).

This study concerns teaching options outside the classroom, in *settings* that offered more than classic scholastic sensory perceptions from, e.g., nature or everyday objects. Teachers must be aware of how this expansion of educational place and experience should make learning coherent, since:

> "as an individual passes from one situation to another, his world, his environment expands or contracts [relational experiences]. [...] What he has learned in the way of knowledge and skill in one situation becomes an instrument of understanding and dealing effectively with the situations, which follows [continuity of experiences]" (Dewey, 1938, p. 44).

The reference to personal environment here refers to relational experiences—e.g., learning with others—and the reference to a following situation refers to the continuity of experiences—e.g., addressing formerly acquired learnings in preparing, or during, the inquiry.

LIMITATIONS

This study is limited in several ways, one of which is the periodic nature of the observations. As mentioned by Bybee et al. (2006), an inquiry process can take several weeks; however, the observations in this study were only conducted on approximately a monthly basis. That is, in some cases the observations may only show one phase, or part, of the educational process. Conversations with the teachers during the sessions and email correspondence contextualized the incidents, leading to the coding category "the incident contains one or more phases leading to more phases" being included as part of the inquiry process. Still, we acknowledge even shorter incidents containing, e.g., open-ended tasks with uncertain process and result with open, multiple solution strategies such as "the development of problem-solving abilities and inquiry habits of mind" (Artigue and Blomhøj, 2013, p. 809).

The same researcher performed the observations and analysis in this study. This can be seen as both a strength and a weakness: a strength, as the analyzer worked closely with the teachers and teaching, so that the field notes and photos were not the only source of information; and a weakness, as bias—due to the data being seen from only one angle, that of the observer—can hide blind spots. This was addressed by thoroughly discussing the analysis between the two authors, and examining the photos and examples during the writing process.

The significance of the philosophical and traditional underpinnings of the educational context varying between countries limits our ability to generalize. Still, this contextualized study can contribute to an extended discussion of the educational value of pupil-centered teaching approaches outside the classroom; in this case, *udeskole*.

CONCLUSION

In this article, 28 days of naturally occurring *udeskole* lessons were observed, and all 71 teaching incidents outside the classroom were analyzed in relation to inquiry-based teaching. We found three categories of teaching supporting pupils' inquiry in *udeskole* and their choice options in the inquiry process. These categories were when the teacher scaffolded the pupils during the inquiry; when the teacher did not interfere with the pupils' performance during the inquiry; and when the teacher widened the pupils' inquiry approach. Beside this, the concept of inquiry-based teaching used here acknowledged how an inquiry process could be started in multiple ways, including experience-based approaches. In this understanding, about half of the observed teaching incidents in *udeskole* were categorized as inquiry-based. The results showed that teaching outside the classroom in *udeskole* has the potential to let pupils work inquiry-based (in our understanding of the term inquiry), thus paving the way for a child-activating education in science and mathematics.

AUTHOR CONTRIBUTIONS

KB has contributed to the design of the study, collected all data, and contributed significantly to the analysis and the draft of the manuscript. PD has taken part in the analysis, and contributed substantially to the interpretation of the data and to the final writing. Finally, both authors have approved the manuscript for consideration, and account for all aspects of the presented work.

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Green Schoolyards in Low-Income Urban Neighborhoods: Natural Spaces for Positive Youth Development Outcomes

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Children from low-income families are increasingly growing up in urban areas with limited access to nature. In these environments, strategies that promote access to natural outdoor spaces, such as green schoolyards, may enhance positive youth development outcomes by promoting physical activity (PA) and prosocial behavior, as well as increasing perceptions of safety. The current study examines children's PA and social interactions, as well as caregiver and teacher perceptions of safety, injuries, teasing/bullying, and gang activity on three newly renovated green schoolyards in low-income urban neighborhoods. A multi-method strategy, including behavioral mapping and caregiver- and teacher-reported surveys, was utilized at three time points to examine positive youth development outcomes and maintenance of effects over time. Analyses revealed that children evidenced a range of PA on the green schoolyards and demonstrated significant decreases in sedentary activity over time. The majority of children were engaged in social interactions with peers on the green schoolyards when observed. Less than 3% of interactions were negative and follow-up analyses found significant increases in positive interactions on the green schoolyards up to 24 months post-renovation. Caregivers and teachers reported increased perceptions of safety, fewer injuries, less teasing/bullying, and less gang-related activity on the renovated green schoolyards in comparison to the pre-renovation schoolyards, and these effects were maintained up to 32 months post-renovation. Overall, the study suggests that green schoolyards may promote positive development outcomes among youth living in urban, low-income neighborhoods by providing natural and safe spaces for PA and prosocial behavior.

Keywords: green space, schoolyards, urban, child development, prosocial behavior, physical activity

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INTRODUCTION

Rates of urbanization have reached unprecedented levels with over half of the world's population living in urban areas. This number is expected to continue to climb, resulting in more than two thirds of people living in urban settings by 2050 (World Health Organization [WHO], 2010; United Nations Department of Economic and Social Affairs Population Division, 2014). Although urbanization has been associated with important economic and social transformations, other effects such as increased crowding, industry, and infrastructure can lead to individual and societal problems, including higher rates of crime and limited access to nature (Shelley, 1981; Frumkin, 2002). Further, urbanization has led to significant social and health inequities in low-income communities compared to more affluent communities (Mitchell and Popham, 2008). Although the specific effects of urbanization on children's development are not well-understood, research suggests that children growing up in low-income urban environments with limited access to green space may have fewer opportunities to engage in positive behaviors, including physical activity (PA) (Gomez et al., 2004; Weir et al., 2006), and may be at risk for increased rates of behavior problems, including oppositional and conduct disorders (Leventhal and Brooks-Gunn, 2000; Manly et al., 2013; Markevych et al., 2014). Research suggests that increased access to nature may buffer these effects by promoting positive development outcomes among urban youth (Wells, 2000; Wells and Evans, 2003), and may reduce health inequalities in low-income communities (Mitchell and Popham, 2008).

Two recent reviews evaluated literature examining the impact of nature on health and well-being in urban settings (Haluza et al., 2014; Gascon et al., 2015). Haluza et al. (2014) conducted a narrative review (N = 17 studies) of nature's impact on physiological outcomes (i.e., brain activity, cardiovascular system, endocrine system, and immune functioning) in college students and adults and concluded that exposure to nature had a harmonizing effect on physiological stress reactions across body systems. However, most of the reviewed studies were cross-sectional, highlighting the need for longitudinal research examining exposure to nature over time. Gascon et al. (2015) systematically reviewed the long-term mental health benefits of residential green and blue spaces (N = 28 studies) and concluded that there was evidence for a causal relation between surrounding greenness and mental health in adults, but the data were less conclusive in child samples. In summary, these studies highlight the need for additional work to examine the impact of exposure to nature on physical and mental health in urban settings, particularly among children.

One way to examine the effects of nature among children in urban areas is through studies of renovated green schoolyards. Green schoolyards are multi-purpose, environmentally beneficial spaces that incorporate natural elements, such as gardens, wooded areas, and green spaces, with traditional play features, and often include outdoor classrooms or learning components as well (Plovnik and Strongin, 2015; Healthy Schools Campaign and Openlands, 2016). Bell and Dyment (2008) narratively reviewed literature examining the impact of green schoolyards on physical, mental, social, and spiritual health of students. The authors concluded that preliminary evidence for such relations was promising, but that studies had been largely exploratory to that point and that the field was in need of additional work utilizing more sophisticated study designs for substantiation.

Several subsequent studies have implemented greater methodological rigor to examine the impact of schoolyards on positive developmental outcomes in youth. By providing natural spaces for activity, schoolyards may reduce daily sedentary behavior and promote PA, both of which have been associated with positive physical and developmental outcomes among youth (Janssen and LeBlanc, 2010; Tremblay et al., 2011). Brink et al. (2010) and Anthamatten et al. (2011) used a quasi-experimental design and the System for Observing Play and Leisure Activity in Youth (SOPLAY) observation methodology to examine elementary school children's utilization and PA on six renovated green schoolyards and three non-renovated schoolyards in Denver, CO, United States. Across both studies, renovated green schoolyards were more highly utilized than non-renovated schoolyards. Brink et al. (2010) observed that students at renovated schools had higher overall levels of activity, regardless of when the schoolyard was renovated (e.g., 1- or 2-years prior to the evaluation). Upon further examining PA in the same sample, Anthamatten et al. (2011) found that the percentage of students who were active on the green schoolyards was not significantly different between renovated and non-renovated schoolyards. Andersen et al. (2015) examined children's PA in the context of differing surface materials within green schoolyards among a sample of Danish children ages 10–15. The study observed that children engaged in higher levels of PA on the grass and playground areas of the schoolyard, in comparison to the blacktop or hard surface areas (Andersen et al., 2015). Finally, in another quasi-experimental study, Cohen et al. (2015) used the System for Observing Play and Recreation in Communities (SOPARC) observation methodology and surveys to assess pre- and post-renovation utilization, energy expenditure, and perceptions of safety at four community parks in San Francisco, CA, United States (i.e., two non-renovated and two undergoing renovation). In comparison to the non-renovated parks, coders observed greater utilization of the renovated parks and higher overall energy expenditure by users at the renovated parks. Based on analysis with the baseline and follow-up data, users from the renovated parks reported significant increases in perceptions of park safety, which may have positively impacted utilization and activity levels (Cohen et al., 2015). To summarize, several studies have established that renovated parks and green schoolyards promote increased utilization and may support positive PA outcomes. However, few studies have followed these effects longitudinally and in predominantly low-income urban communities to examine the maintenance of schoolyard utilization and PA over time.

In addition to promoting positive physical development outcomes through increased utilization and PA, renovated green schoolyards may encourage prosocial behaviors among youth. Chawla et al. (2014) conducted interviews and ethnographic observations of early elementary through high school students on a variety of schoolyards across urban and suburban settings to examine the impact of nature on socio-emotional well-being. Students at schools with renovated green schoolyards demonstrated prosocial behaviors (e.g., forming supportive groups) in addition to low levels of stress, anger, and problem behaviors (Chawla et al., 2014). In a quasi-experimental study, Carrus et al. (2015) observed 39 Italian preschool children (ages 18 months–3 years) attending green or non-green daycare centers. Children at green daycare centers displayed more positive affect and prosocial interactions than children at non-green daycare centers, but only after free play in outdoor green spaces. Thus, the authors concluded that contact with nature may promote more positive affect and social interactions among youth (Carrus et al., 2015). In a quantitative cross-sectional study that surveyed 172 urban children from Spain, Corraliza et al. (2012) found that children who reported having greater access to nature in the home and school settings (e.g., green school grounds, neighborhood green spaces, and views of nature through windows) also reported lower levels of perceived stress than children with lower access to nature, despite reporting similar exposure to adversity. Additionally, exposure to nature buffered the association between reported adversity and perceived stress, and authors suggested that exposure to nature may have promoted positive coping (Corraliza et al., 2012). Another cross-sectional study of green space and stress among 10-year-old German children found that children living within 500 m of an urban green space had fewer parent-reported behavior problems than children living a greater distance from green space. When stratified by sex, the result was only significant among males (Markevych et al., 2014). Together, these studies provide preliminary evidence for associations between exposure to nature and positive social development, including prosocial behaviors, but more rigorous methodologies are needed to confirm these associations as well as considering the benefits among youth living in low-income urban neighborhoods.

Renovating green schoolyards in low-income urban neighborhoods may impact perceptions of safety in these areas, and this may be beneficial to positive development by supporting schoolyard utilization, PA, and prosocial behavior. A study by Farley et al. (2007) demonstrated that providing safe schoolyard settings in urban areas resulted in increased PA and decreased sedentary behavior among youth in that neighborhood. Similarly, a recent study showed that among renovated urban schoolyards, those perceived to be clean and safe receive the greatest amount of utilization and PA by children and adults (Colabianchi et al., 2011). In Chawla et al. (2014) ethnographic study, students attending a school with a green schoolyard reported that this natural space was a haven from teasing and bullying that occurred inside the school walls, and this coincided with positive social-emotional outcomes at these schools. Increased perceptions of safety may also support schoolyard utilization, PA, and positive social outcomes. Indeed, these studies highlight that green schoolyard renovations may impact several components of safety, including the overall condition of the schoolyard (e.g., risk of injury during play), the surrounding community (e.g., gang activity), and student interactions (e.g., teasing and bullying), and each of these may enable children to best utilize and benefit from green schoolyard renovations. Parents and teachers' perceptions of schoolyard safety may be of particular importance for student's positive development because of parent and teacher influence on access and utilization. Children's access to schoolyards during the school day is dependent on teacher's utilization of the schoolyard for recess, physical education, and classroom instruction. During outside of school time, children's access to the schoolyard is influenced by parental rules around traveling to and utilizing the schoolyard. Therefore, it is important to assess not only children's positive development outcomes in the context of renovated schoolyards, but also parent and teacher perceptions of the safety, which may provide indications of whether schoolyards are being utilized to their greatest potential, or if there are remaining barriers.

The current study aims to expand the literature by examining the impact of nature, specifically renovated green schoolyards, on children's positive development outcomes over time in the context of low-income urban neighborhoods. The study considers two positive development outcomes – PA and social interactions – as well as perceptions of student safety, injuries, bullying, and gang activity in the context of three recently renovated green schoolyards and examines the longitudinal course of these outcomes to investigate the maintenance of effects. The effects of age, gender, and race/ethnicity are examined to understand whether positive development outcomes in the context of green schoolyards differs among various subgroups. The study aims to contribute a novel perspective on the benefits of green schoolyards on youth growing up in low-income urban neighborhoods and support the prioritization of green infrastructure in high-density urban areas.

MATERIALS AND METHODS

Schools and Participants

Data were collected at three public elementary schools in Chicago, IL, United States that had recently undergone a green schoolyard renovation through the Space to Grow (STG) initiative (see **Figures 1–3**). STG is a multi-sector, public-private partnership managed by Healthy Schools Campaign and Openlands (two non-governmental organizations) that seeks to support health, education, and a connection with nature in underserved urban communities across Chicago by renovating schoolyards to meet the needs of the respective schools and communities (Healthy Schools Campaign and Openlands, 2016). Schools were pre-selected by the capital and managing partners and invited to apply. Schools were required to demonstrate two key needs: (1) a surrounding community that lacked access to safe, well-maintained green space, and (2) community issues with storm water control and flooding. The application was completed by school staff and required demonstrating support from the Local School Council and alderman. Each school was also required to commit to keeping the schoolyard open to the public and to maintain the space following the renovation. Each STG school community took part in a planning process during which school staff, students, caregivers, and other community members provided a vision for their schoolyard through open houses and planning meetings held at the schools. Based on the input gathered at these meetings, the schoolyards were designed and constructed to meet the unique needs and visions of each community. The three schools in the current study were located in three distinct neighborhoods across the south and west sides of Chicago and enroll a high percentage of low-income, minority students (see **Table 1**). All schools enrolled children from pre-kindergarten through eighth grade. Two schools were renovated during the summer of 2014, and one school was renovated during the summer of 2015.

FIGURE 1 | Before and after photos of schoolyard renovation at School 1. Photos courtesy of Space to Grow.

FIGURE 2 | Before and after photos of schoolyard renovation at School 2. Photos courtesy of Space to Grow.

FIGURE 3 | Before and after photos of schoolyard renovation at School 3. Photos courtesy of Space to Grow.

Data were collected using a multi-method procedure, which included observational assessments and survey administration. Observational data were collected on two schooldays and one weekend day at each time point. Schoolyard observations (total observations N = 7,025) occurred during the spring and fall of 2016 (i.e., T1 and T2; see **Table 2**), and surveys were collected during the spring of 2016 and spring of 2017 (i.e., T1 and T3; see **Table 2**). Observational data were collected 6-months apart (i.e., in spring and fall) to allow for variation based on seasonality, whereas survey data were collected 1-year apart to provide a robust longitudinal examination of differences in perceptions of safety. Staffing needs and minimizing study burden were also major determinants of data collection timing. The institutional review board of Loyola University Chicago, the University of California, Davis, and the research review board of Chicago Public Schools approved all study procedures.

Measures

Behavioral Mapping

Children's behaviors on the schoolyard were objectively assessed using behavioral mapping methodology (Cosco et al., 2010, 2014). Behavioral mapping is a design-sensitive measurement system allowing for the objective observation of PA and associated schoolyard components and attributes. Using this approach, each renovated schoolyard was divided in advance into 10–14 observation zones with the purpose of providing data collectors with a designated space that was easily scanned from a

TABLE 1 | Demographics of study schools.

	School 1	School 2	School 3
Neighborhood	Chicago Lawn	Hegewisch	East Garfield Park
Student population	753	368	397
Demographics	39% Black, 60% Hispanic, 1% White	76% Hispanic, 18% White, 5% Black, 1% Other	97% Black, 2% Hispanic, 1% Other
Low income students*	96%	58%	90%
Date of schoolyard renovation	Summer 2014	Summer 2014	Fall 2015

**Low-income status is measured by eligibility to participate in free or reduced-price school meal program.*

TABLE 2 | Study time points and measurement strategies.

	Time 1 (Spring 2016)	Time 2 (Fall 2016)	Time 3 (Spring 2017)
Behavioral mapping *(i.e., physical activity and social interactions)*	X	X	
Surveys *(i.e., perceptions of safety, injuries, teasing/bullying, and gang activity)*	X		X

specified observation point. Two data collectors simultaneously followed a prescribed sequence of observation zones to circumnavigate the schoolyards. Data collectors employed a visual scanning protocol for each observation zone in a clockwise direction from the designated observation point, observing a single individual at a time. Upon observation of an individual, the data collector recorded the location of the person on a map of the schoolyard using GIS technology, and immediately recorded observational information on each variable of interest relating to that individual. The data collector then returned to the scanning protocol to collect information on other individuals in the observation zone (Cosco et al., 2010). Because behavioral mapping observes a single individual at a time, the amount of time that data collectors spent in each observation zone varied based on the number of individuals in the zone, as did the amount of time spent on a full circulation of the schoolyard.

Data collectors used behavioral mapping to code PA using the Child Activity Rating Scale (DuRant et al., 1993), which categorizes level of PA on an objective five-point scale: (1) stationary/motionless, (2) stationary with movement of limb(s) or very easy movement of trunk, (3) translocation (slow speed/easy), (4) translocation (medium speed/moderate), (5) translocation (fast or very fast/hard). Observations of social interactions used codes from the System for Observing Children's Activity and Relationships during Play (SOCARP; Ridgers et al., 2010), which included categorizing observed interactions as positive (e.g., smile, high five, hug, positive statement to another individual), negative (e.g., grimacing, fighting, shoving, negative statement to another individual), neutral (i.e., in contact with another individual but no observable physical or verbal sign of valence), or no social interaction (i.e., not interacting with another individual). Data collection occurred at specific times during the school day (i.e., before school, during recess, during gym, and after school) and on the weekends. Behavioral mapping was also used to record observable characteristics of persons utilizing the schoolyard space, including gender (i.e., male and female), and race/ethnicity (i.e., African–American, Latino, Caucasian, Asian, and unknown/other). The approximate age of persons utilizing the schoolyard was also coded. Because many classrooms/grades often utilized the schoolyard at the same time, age was coded in groupings: toddler/preschool, kindergarten-4th grade, 5th–8th grade, high school or adult. School recess and physical education class schedules were utilized to assist data collectors in accurately coding the age of children on the schoolyard.

Surveys

Caregivers and teachers retrospectively reported on changes in student safety, injuries, teasing/bullying, and gang activity following the green schoolyard renovation via self-administered surveys. Survey respondents were asked to report on safety, injuries, and teasing/bullying using the following prompts "In your opinion since the schoolyard was redesigned:

(i) has the safety of the schoolyard changed?
(ii) has the number of injuries on the schoolyard changed?
(iii) has the amount of teasing or bullying between students on the schoolyard changed?
(iv) has gang-related activity on the schoolyard (e.g., threats, bullying, and gang presence) changed?"

Survey respondents were given a Likert scale of five answer choices ranging from "much more [safe, injuries, teasing and bullying, or gang-related activity] to much less [safe, injuries, teasing and bullying, or gang-related activity].

Analyses

Descriptive analyses, including means and standard deviations, were used to characterize study variables. Independent samples *t*-tests and analyses of variance (ANOVAs) were utilized to test for significant differences in PA between sub-groups of individuals observed (i.e., age, gender, and race/ethnicity), by time of day, and to evaluate significant changes in observed PA and reported student safety, injuries, teasing and bullying, and gang-related activity over time, whereas chi-square analyses were used to examine differences in social interactions by subgroups and examine significant changes in social interactions over time.

RESULTS

Children observed via behavioral mapping ranged in age from pre-k through 8th grade (median = middle school). The majority of children observed were African/American (44.7%) or Latino/Hispanic (39.2%) and males (55%). Survey data were collected from teachers, administrators, and school staff (n = 33 at T1; n = 40 at T3) and caregivers (n = 64 at T1; n = 61 at T3). Only 23 of 97 T1 participants (24%) completed surveys at T3 (n = 9 caregivers; n = 14 teachers). As such, data were treated as independent samples for analytic purposes. Descriptive analyses showed a wide range of PA on the schoolyards. Nearly one-third of the children observed were engaged in light, moderate, or vigorous PA (e.g., walking or running), whereas another third were stationary with some upper or lower body movement (e.g., swinging, kicking, and throwing; **Table 3**). Sub-group analyses found a significant impact of age on PA [$F(4, 3250) = 21.83$, $p < 0.001$]. Specifically, children in grade k-4 were significantly more active than children in grades 5–8 ($p < 0.01$), and adults were less active than all other age groups on the schoolyard ($p < 0.05$). Analyses by gender revealed that males were more active than females on the schoolyards [$t(3316) = 7.59$, $p < 0.001$]. There were no significant differences in level of PA by ethnicity or by time of day. Follow-up analyses revealed that there was a significant increase in overall PA on the schoolyards over time [$t(7024) = -2.84$, $p < 0.001$]. The greatest change in PA between time points resulted from a decrease in children who were stationary/motionless from T1 to T2 coupled with an increase in children who were stationary with some limb or trunk movement (**Table 3**), indicating that children were less sedentary at T2 when compared to T1.

Regarding observed social interactions, 63% of children observed were interacting with others at T1, with approximately 33% engaged in neutral interactions, 27% engaged in positive interactions, and less than 3% engaged in negative interactions (**Table 4**). Females ($x^2 = 11.85$, $p < 0.01$), African–American children ($x^2 = 15.18$, $p < 0.01$), and children in grades 5–8 ($x^2 = 29.11$, $p < 0.001$) were more likely to be interacting with others on the schoolyard. There was a significant impact of ethnicity on the valance of social interactions ($x^2 = 14.64$, $p < 0.01$), with a greater proportion of negative interactions than expected among African–American and White children, and a greater proportion of positive interactions than expected among Latino/Hispanic children. There was also a significant impact of age on social interactions ($x^2 = 17.56$, $p < 0.01$), such that there was a greater proportion of positive interactions than expected among children in grade k-4, and a greater proportion of neutral and negative interactions than expected among children in grades 5–8 and adults. There was no significant impact of gender on the valence of observed social interactions. Additionally, there were significant changes in observed social interactions on the schoolyards over time ($x^2 = 98.80$, $p < 0.001$), such that a greater percentage of children were interacting socially with each other on the schoolyards at T2. Based on the observed social interaction data, a greater percentage of children were interacting with others on the schoolyard at T2 when compared with T1, with increases in positive and neutral interactions. Negative interactions remained stable at T2 when compared with T1 (**Table 4**).

Caregivers and teachers retrospectively reported that compared to pre-renovation, the schoolyards were safer, students experienced fewer injuries, and there was less teasing/bullying and gang-related activity on the schoolyards at T1 (**Table 5**). Analyses demonstrated that caregivers and teachers maintained these perceptions at 1-year follow-up, with no significant changes in reports from T1 to T3 ($p > 0.05$; **Table 5**).

DISCUSSION

Given the increasingly high rates of global urbanization and potential impact on health, particularly among low-income communities, it is important to identify effective and scalable ways to promote positive development outcomes among youth in urban areas. Evidence suggests that green schoolyards may positively impact youth development outcomes including PA and prosocial interactions. The present study builds on current literature by examining systematic observations of PA and social interactions on renovated green schoolyards in urban, low-income neighborhoods, as well as the maintenance of these outcomes over time to evaluate the stability of effects.

Children observed in this study engaged in a wide range of activity on the renovated green schoolyards. The most frequent type of PA observed was stationary with some trunk or limb movement (e.g., kicking, throwing, or bending), which neither qualifies as sedentary time nor an episode of acute PA. However, studies have demonstrated that this type of movement, especially in the context of the school day, can interrupt bouts of sedentary time to mitigate physical health risks and promote classroom engagement (Saunders et al., 2013; Hinckson et al., 2016). Moreover, nearly one-third of children were moving when observed, and most of these children were observed to be engaging in light PA. The overall level of activity did not vary significantly between the before-, during-, and after-school, suggesting that schoolyards served as a resource for PA across the entire day when school was in session. Although pre- and post-renovation data was not available for the current study, evidence suggests that park renovations in underserved urban communities promote increased utilization and PA among community members (Tester and Baker, 2009; Cohen et al., 2015). Two recent reviews concluded that acute episodes of PA benefit children's cognitive functioning, and may facilitate engagement, attention, and learning in the classroom (Lees and Hopkins, 2013; Donnelly et al., 2016). Additionally, PA may benefit psychosocial health, including mood and perceived competence (Sallis et al., 2000; Lees and Hopkins, 2013). Based on these findings, the use of the schoolyards throughout the entire school day is advisable in order to give students opportunities to interrupt sedentary time and participate in PA.

Consistent with national developmental trends in PA (Belcher et al., 2010), younger children (i.e., grade k-4) and males were more active on the schoolyard than older children (i.e., grades 5–8) and females. Studies have identified several possible reasons that PA may decrease during adolescence, including

TABLE 3 | Physical activity (PA) observed on renovated green schoolyards at T1 and T2.

	Stationary	Stationary w/limb movement	Light PA	Moderate PA	Vigorous PA
T1 (n = 3,345)	33.98%	29.41%	29.50%	6.31%	0.78%
T2 (n = 3,710)	21.71%	45.40%	29.12%	4.08%	0.68%

TABLE 4 | Social interactions observed on renovated green schoolyards at T1 and T2.

	Negative	Positive	Neutral	No interaction
T1 (n = 3,345)	2.80%	27.10%	32.70%	37.00%
T2 (n = 3,710)	2.50%	35.20%	35.60%	26.70%

TABLE 5 | Reported changes in student safety, injuries, teasing/bullying, and gang activity following green schoolyard renovation.

	Caregivers			Teachers		
	T1 (n = 64)	T3 (n = 61)	t-Value	T1 (n = 33)	T3 (n = 40)	t-Value
Safety[1]	0.77	1.03	−1.39*	1.24	1.21	0.15*
Injuries[2]	0.80	0.90	−0.58*	0.77	0.69	0.37*
Teasing/bullying[3]	0.66	0.65	0.07*	0.53	0.53	0.03*
Gang-related activity[4]	0.68	0.86	−1.07*	0.57	0.77	−0.83*

Significance of changes tested using independent samples t-tests.
[1]Scale: −2 = much less safe, −1 = less safe, 0 = no change, 1 = more safe, 2 = much more safe. [2]Scale: −2 = many more injuries, −1 = more injuries, 0 = no change, 1 = fewer injuries, 2 = many fewer injuries. [3]Scale: −2 = much more teasing/bullying, −1 = more teasing/bullying, 0 = no change, 1 = less teasing/bullying, 2 = much less teasing/bullying. [4]Scale: −2 = much more gang-related activity, −1 = more gang-related activity, 0 = no change, 1 = less gang-related activity, 2 = much less gang-related activity.
*Non-significant ($p > 0.05$).

reduced social support for PA engagement, lower perceived athletic competence, and decreased access to organized activities (Bélanger et al., 2011). Although schoolyards provided space and opportunity for PA, additional strategies may be warranted to combat these developmental trends and encourage PA among older children and females. Structured before- and/or after-school programs have been shown to be effective in increasing PA in these groups (Mears and Jago, 2016), and may be useful to increase the effectiveness of green schoolyard interventions for promoting PA among older youth. One study by Black et al. (2015) found that although 50% of children were active on urban schoolyards in the absence of any programming, the percent of children who were active increased to 99% when participating in a structured walking program. Moreover, research has shown promising outcomes—including significant increases in PA—from structured community programming that specifically targets early adolescent urban minority girls (Bohnert et al., 2014, 2017), increasing both access to organized activities and social support among urban youth. Thus, future studies may consider testing organized activities as an adjunctive strategy to promote increased PA among higher risk groups of older adolescents and females, being attentive to promoting positive social support and increases in perceived athletic competence for optimal success.

Overall, students on the renovated green schoolyards engaged in high rates of positive or neutral social interactions, and very low rates of negative social interactions. This is promising given the context of the schools in urban, low-income neighborhoods. Other literature has suggested that green schoolyards may promote positive interactions among diverse samples of youth, perhaps by providing opportunities for diverse cooperative play, promoting positive affect (Chawla et al., 2014; Carrus et al., 2015), and increasing ability to cope with stress (Corraliza et al., 2012). Another promising finding in the current study was that there were no significant differences in negative interactions between males and females. Higher rates of negative social interactions among older students were observed though highlighting the need for continued social-emotional curriculum to facilitate positive social dynamics and problem-solving strategies among early adolescents. Higher rates of negative social interactions among African–American and White students as compared with Latino students may have been an artifact of the different types of activities engaged in on the schoolyards (e.g., structured and cooperative play, such as soccer, among Latino youth, versus unstructured play among African–American and White youth), but warrants further investigation.

Positive development through PA and prosocial interactions on green schoolyards can only occur when schoolyards are utilized by students. Studies have shown that utilization of renovated schoolyards can be negatively impacted by a number of factors, especially perceptions of safety in high-crime urban areas (Colabianchi et al., 2011). Thus, it was encouraging to find that caregivers and teachers perceived the renovated green schoolyards in the current study to be safer, with less teasing, bullying, and gang activity than the pre-renovation spaces. The positive caregiver and teacher perceptions observed in the current study may have been impacted by the STG community-engaged planning process, which focuses on engaging the caregivers, students, teachers, and community members in the design of the schoolyard with the goal of meeting the specific needs and desires of the school and surrounding community (Healthy Schools Campaign and Openlands, 2016). Indeed, more work is needed to understand the best practices for renovating schoolyards and other green spaces to facilitate community investment and utilization of the renovated space. Efforts to increase community cohesion and neighborhood safety may help to overcome barriers caused by negative perceptions and promote optimal benefits from built environment interventions.

A final encouraging result of the study was the overall maintenance of beneficial outcomes over time. Few studies have longitudinally assessed PA, social interactions, and changes in student safety, injuries, teasing/bullying, and gang-related activity in the context of renovated green schoolyards. Observational data from the current study demonstrated that the renovated green schoolyards were highly utilized throughout the school day at both time points. Results suggest that green schoolyards maintained their status as zones of PA and primarily positive social interactions over time, and showed decreases in sedentary time, as well as increases in overall social interactions and positive social interactions over time. Furthermore, caregiver and teacher reports of high levels of student safety, few injuries, and low levels of teasing/bullying and gang-related activity on the schoolyard did not change significantly over time, indicating that these positive perceptions remained stable up to 32-months post-schoolyard renovation.

The study is not without limitations, most notably that the current schoolyards were only assessed post-renovation, thereby precluding our ability to infer causality. The study examined green schoolyards in diverse low-income communities in Chicago that recently underwent renovations by the STG initiative, so results should be considered in this context and may not be generalize to other cities or other initiatives. Further, renovations involved updates to both green spaces and play facilities, which may have impacted results. Rigorous experimental studies are needed to understand the unique impact of added green space, play facilities, and structured programming to positive developmental outcomes. Seminal behavioral mapping literature notes that because this method focuses on coding within a predetermined setting rather than specific children, fast-moving children may not be coded if they vacated an observation zone before being coded, whereas stationary children may be coded more than once if they do not move between observation rounds (Cosco et al., 2010). We were not able to gather self-report data from students due to restrictions implemented by the school district and the timing of data collections. Finally, we were unable to examine perceived safety as a mechanism underlying schoolyard utilization and PA due to sampling strategy. Despite limitations, the study makes a unique contribution to the literature by being the first to longitudinally investigate positive development outcomes and perceptions of safety in the context of renovated green schoolyards in low-income urban neighborhoods.

The current study builds on existing literature that has shown benefits of green schoolyard renovations to PA, prosocial behavior, and safety, and provides additional evidence that renovated green schoolyards in low-income urban areas serve as a beneficial context of development for at risk youth. Furthermore, our study supports that the observed benefits of green schoolyards are maintained long-term, and that positive development outcomes on green schoolyards may even increase over time. Both PA and social interactions saw improvements over a 6-month period, up to 24 months post-renovation, and perceptions of safety remained stable over the course of a year, up to 32 months post-renovation. Taking these results in the context of other literature leads us to conclude that investing in built environments, particularly green schoolyards, may be an effective and enduring way to promote positive development outcomes among school-age youth, especially those living in low-income urban neighborhoods with limited other resources.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Loyola University Institutional Review Board and the Chicago Public Schools Research Review Board. The protocol was approved by Loyola University of Chicago and Chicago Public Schools. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

AB is the principal investigator of the current study and DG is a co-investigator. They designed the study and oversaw data collection, entry, analysis, and manuscript writing. CB is the project coordinator and managed data collection and entry, ran study analyses, and was the primary author of the manuscript.

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Modeling Child–Nature Interaction in a Nature Preschool: A Proof of Concept

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This article provides a proof of concept for an approach to modeling child–nature interaction based on the idea of *interaction patterns*: characterizations of essential features of interaction between humans and nature, specified abstractly enough such that countless different instantiations of each one can occur – in more domestic or wild forms – given different types of nature, people, and purposes. The model draws from constructivist psychology, ecological psychology, and evolutionary psychology, and is grounded in observational data collected through a time-sampling methodology at a nature preschool. Through using a *nature language* that emphasizes ontogenetic and phylogenetic significance, seven keystone interaction patterns are described for this nature preschool: *using one's body vigorously in nature, striking wood on wood, constructing shelter, being in solitude in nature, lying on earth, cohabiting with a wild animal,* and *being outside in weather*. These 7 interactions patterns are then brought together with 13 other patterns published elsewhere to provide a total of 20 keystone interaction patterns that begin to fill out the model, and to show its promise. Discussion focuses on what the model aims to be in terms of both product and process, on what work the model can currently do, and how to further develop the model.

Keywords: nature preschools, interaction, interaction patterns, modeling, wild nature, proof of concept, nature language, environmental education

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INTRODUCTION

Nature preschools and forest kindergartens have been increasing in number: from around 25 programs in 2012 to more than 250 in 2017 in the United States alone (North American Association for Environmental Education [NAAEE], 2017). Thus questions in research communities have emerged about these programs, such as how they compare to indoor classrooms on traditional metrics of language development, physical development, executive function, and academic preparation for K-5 schooling. While these questions are important, in our view a complementary line of research is also needed, one that is perhaps even more foundational: to characterize what exactly goes on in nature schools, especially in terms of how children interact with nature. After all, nature is the central environmental feature of nature schools.

To date, many such characterizations have focused on different forms of children's play in nature (Ginsburg, 2007; Brown and Kaye, 2017; Morrissey et al., 2017). For example, Sobel (2008) postulated the existence of seven universal play motifs: going on adventures, descending into fantasies, shaping small worlds, developing friendships with animals, following paths and figuring out shortcuts, making forts and special places, and playing hunting and gathering games. This is valuable work, and it follows a growing awareness, with roots to Vygotsky (1978), that children's play in nature is not only diverse, but that it provides the mechanism for many important developmental outcomes.

That said, we believe there is much to be gained by expanding our understanding of children's engagement with the natural world beyond the scope of play. After all, there are many types of interactions, such as when a child splashes water on her face from a creek to cool down on a hot summer's day, or retreats to a solitary spot in nature and sits under a tree to regain composure after a conflict, which do not seem well characterized in terms of a play motif.

Thus in this article we bring forward an approach to modeling child–nature interaction – based on the idea of *interaction patterns*. We first provide a psychological basis for our model, drawing on psychological constructivism with roots to Jean Piaget, ecological psychology with roots to James Gibson, and evolutionary psychology with roots to E. O. Wilson. Next we discuss what interaction patterns are, how they can be enacted along a continuum from wild to domestic, and the idea of keystone interaction patterns. From there we specify the form of scientific model that we are proposing. Then we move into the empirical part of this article as we seek to provide a proof of concept for modeling child–nature interaction. We do so by analyzing observational data that we have collected in a nature-based preschool, and provide an account (what we call a nature language) of 7 keystone interaction patterns at this preschool. We then synthesize our keystone interaction patterns with 13 other such patterns (recently published elsewhere) to show that child–nature interaction can be successfully modeled in this way, leading to characterizations with prima facie validity and testable hypotheses for future experimental research.

To be clear, in this current research we do not test a hypothesis. Rather, we offer a proof of concept based on qualitative analysis of original empirical observational data. Thus stylistically we do not have the traditional "methods/results" sections in this article, but sections that we believe provide an effective exposition of our proof of concept.

THE PSYCHOLOGICAL GROUNDING FOR INTERACTION PATTERNS

Our model is based on the idea of interaction patterns. Before discussing interaction patterns, it is useful to delineate briefly the psychological grounding for them, which is based on constructivist psychology, ecological psychology, and evolutionary psychology.

Constructivist Psychology

A large body of evidence shows that the child's developing conceptual knowledge of the physical and logical world is neither simply a product of innate biological programming (endogenous theories) nor simply a product of cultural learning (exogenous theories); rather it requires the child constructing the knowledge for herself through repeated interactions with the physical and social entities of the world (Piaget, 1952/1963; Langer, 1969; Piaget, 1983; Turiel, 1983).

According to Piaget (1983), the mechanism for the construction of knowledge involves the coordination of two complementary cognitive processes: of assimilation and accommodation. Assimilation is the process that seeks to fit new information into existing cognitive schemas, perceptions, and understandings, while accommodation is the process that adjusts, reorients, and revises those schemas, perceptions, and understandings to account for aspects of the new information that is not readily assimilated. This process is motivated by what is called the mechanism of disequilibration (Kohlberg, 1969, 1971; Piaget, 1983). In other words, through interaction with the environment the child comes to recognize – in daily minor and sometimes major ways – that her current understandings of the world are not able to take into account her previous understandings, and she becomes unsettled. The disequilibrated state is not a comfortable state. Thus the child seeks to construct a more adequate and conceptually sophisticated understanding that solves the problems at hand.

Ecological Psychology

Along complementary lines, in the theory of ecological psychology, Gibson (1979/1986) postulated that the world is perceived by the individual not only in terms of shapes, spatial relationships, and logical properties, but also in terms of possibilities for action. Gibson proposed that it is our direct perception of information specifying the environment in relation to ourselves – the *affordances* of the environment – that guides our understanding of our surroundings. Affordances are dependent on a reciprocal relationship between the environment and the being interacting with it (Turvey, 1992; Stoffregen, 2003). For example, for an active young child a sapling tree's thin, close limbs might afford climbing, but that would not be the case for an infant who is unable to climb or for an adult who might break the branches. Thus affordances can guide and constrain action (Harrington, 2008, unpublished). According to Gibson (1979/1986, p. 143), "the possibilities of an environment and the way of life of an animal go together inseparably."

One of the issues discussed within the field of ecological psychology is whether an affordance exists as a property of the environment or as a property of the animal-environment system (Turvey, 1992; Stoffregen, 2003). In our view, the theory-driven answer can be different from the pragmatic answer. In theory, an affordance is a property of the animal-environment system. After all, the exact same physical attribute in the environment will often provide an affordance to one type of person but not another. But having said that, we think it is often pragmatically useful to hold a specific category of person as a constant – for example, to hold constant the referent of a child – and then to talk about affordances of the landscape itself, as we did for the sapling tree with thin branches. Both perspectives have merit. We will come back to these ideas later.

Evolutionary Psychology

Decades ago, Wilson (1984) coined the term biophilia to refer the genetic predisposition that humans have to affiliate with biological life. The mechanism for this nature affiliation is, according to Wilson (1993), that "a certain genotype makes a behavioral response more likely, the response enhances survival and reproductive fitness, the genotype consequently spreads through the population, and the behavioral response grows more frequent (p. 33). In other words, genes that lead to behaviors that enhance survival tend to reproduce themselves (since they are in bodies that procreate more rather than less), and thus these genes and correlative behaviors grow more frequent. For empirical support (see Kahn, 1999, 2011 for summaries), studies have shown that even minimal connection with nature – such as looking at it through a window – can increase productivity and health in the work place, promote healing of patients in hospitals, and reduce the frequency of sickness in prisons. Other studies have shown that when given the option humans choose landscapes that fit patterns laid down deep in human history on the savannas of East Africa. Direct contact with animals has been shown to greatly benefit a wide range of clinical patients: from adults with Alzheimer's disease to autistic children.

In terms of its theory and empirical support, biophilia has in recent times largely merged with and provided further momentum to the field of evolutionary psychology, which seeks to show that the properties of human social life are the result of evolved adaptations, and thus deeply rooted in our ancestral heritage (Barkow et al., 1992). This theory does not propose that such properties are immutable, or that they are not substantively shaped by culture. But it does mean that to understand the origins and significance of properties of human social life one needs to go back tens of thousands years in our evolutionary history, and sometimes longer.

In this article, as we articulate our model of child–nature interaction patterns, we will be seeking to show that the patterns are ontogenetically and phylogenetically significant. For ontogenesis, we draw on constructivist psychology and ecological psychology to speak about developmental mechanisms, and direct potential outcomes and developmental endpoints that promote human health, mental wellbeing, and human flourishing. For phylogenesis, we draw on evolutionary psychology to show that some of the patterns gain particular meaning because they go far back in our evolutionary heritage, and sustain us still.

INTERACTION PATTERNS

Think about an interaction in nature that you have had that was meaningful. Now characterize it in such a way that you could imagine many such examples of it happening, and even though each example would be at least a little different from the others you would not have a problem recognizing each one as essentially the same form of interaction. If possible, in describing your interaction, include a verb of what you are doing and a noun for the nature that you are doing it with. At that point you probably have an interaction pattern. For example, you have likely enjoyed *watching the sun set* many times in your life. Each time is at least a little different: the weather and colors are never identical; one time you might be on flat land watching the sun set over the hills in the distance, and another time you might be *watching the sun set* over the ocean (**Figure 1**). But no matter the differences, you know it when it's happening. You can say, "yes, I'm *watching the sun set* now." That's the idea of a "pattern" – not in the sense of a cookie-cutter pattern where each form (cookie) is identical, but that of a unified underlying structure of human–nature that can be enacted in an endless number of unique ways. In brief, interaction patterns refer to characterizations of essential features of interaction between humans and nature, specified abstractly enough such that countless different embodied versions of each one can be uniquely realized given different types of nature, people, and purposes. To date, Kahn and his colleagues have generated over 150 human–nature interaction patterns, with photos and descriptions for many of them (Kahn et al., 2010, 2012, 2018a,b; Kahn and Weiss, 2017).

Our pattern work draws on the work of Christopher Alexander and his colleagues (Alexander et al., 1977; Alexander, 1979) who generated 253 patterns in the built environment that they believe engender meaningful human living. According to Alexander, a "pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice" (p. 10). For example, one of their patterns is titled "Light on two sides of every room." They write: "The importance of this pattern lies partly in the social atmosphere it creates in the room" (Alexander et al., 1977, p. 748). There is now a body of work that has extended Alexander's idea of patterns into the fields of ubiquitous computing (Chung et al., 2004), software engineering (Gamma et al., 1995; Gabriel, 1996), interaction design (Borchers, 2001), human–computer usability (Graham, 2003), and human–robot interaction (Kahn et al., 2008).

Granted, there are other ways that researchers have used the idea of patterns, often with a more experimental or at least quantitative focus, often involving sequential analysis and observational methods across different populations, including infants, married couples, and non-human primates (Sackett, 1978; Bakeman and Gottman, 1987; Magnusson, 2000). But what we offer here is more along the lines of Alexander in terms of the robust qualitative nature of the patterns. We emphasize this point so as to establish that there are different ways that fields have conceptualized and used the idea of patterns, and explored interaction, and that one way does not preclude another.

The Continuum of Interaction Patterns: Wild to Domestic

Wildness refers to that which is untamed, unmanaged, not encompassed, self-organizing, and unencumbered and unmediated by technological artifice (Shepard, 1982, 1998; Rolston, 1989; Foreman, 1991; Kahn and Hasbach, 2013a,b). We can love the wild. We can fear it. We are strengthened and nurtured by it (Rolston, 1989; Turner, 1996).

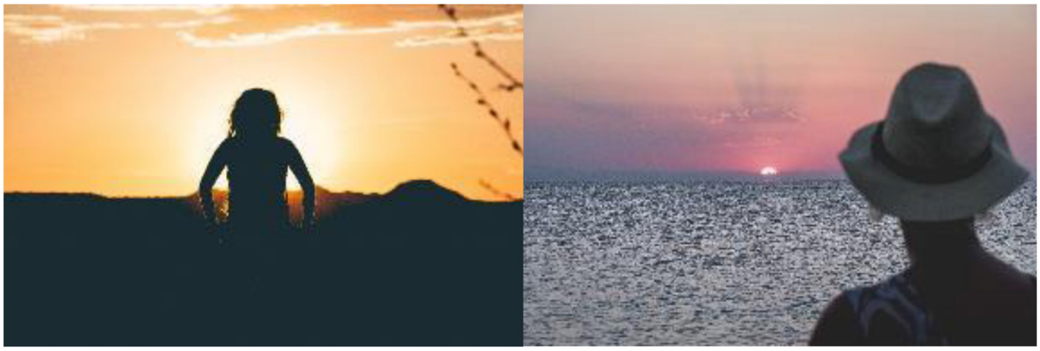


FIGURE 1 | Interaction pattern: *watching the sun set.*

One important feature of interaction patterns is that not only can they be instantiated (enacted) in endlessly unique ways, but those instantiations are themselves usually along the continuum of wild to domestic forms of human–nature interaction. For example, there is the interaction pattern of *movement away from human settlement, and the return*. In Paleolithic times, hunters would leave nomadic campsites and go out in search of animals, and gatherers would leave in search of roots, tubers, nuts, berries, and other plant life. The further out they went, the more they left the safety of the larger group. Both hunters and gatherers would then return, hopefully (but not always) with their bounty, looking forward to the re-union with their group, and greater safety. When a person now hikes for an afternoon into the mountains, it is a less wild form of this interaction pattern; and more domestic still when a person hikes for 20 min out on a park trail.

Granted, wildness is a contested construct. One line of scholarship, for example, has shown how wilderness is largely a cultural construction (Cronon, 1995). From this perspective, it is not the case, for example, that when Europeans began to inhabit North America that they encountered a pristine, untouched wilderness. Rather, the land was an inhabited landscape by Native Americans, and a partly managed landscape at that. Or the Wilderness Act of 1964 in the United States created a legal definition of wilderness, and then partitioned off 9.1 million acres of federal land that was then called "wilderness." This scholarship has merit; but our position is that there is a good deal of difference between the idea of wilderness and wildness. Wildness, as defined above, has properties – such as an entity or agent being untamed, unmanaged, not encompassed, and self-organizing – that may often be found in designated wilderness areas, but is not synonymous with it. For example, all, a weed growing up through a crack in urban concrete in Tokyo has an aspect of wildness about it that is not embodied in a bonsai plant that may be right next to it. Thus in our view, our focus on wildness (as opposed to wilderness) is not so vulnerable to cultural critiques of this literature.

Keystone Interaction Patterns

There is no limit to the unique ways that human language can be spoken. It is endless, infinite. That said, much of what we say uses common words, and even phrases: "See you there." "It's good to meet you." "I'll text you when I leave." "I'm happy for you." "I love you." "What's the weather tomorrow?" "Let me check." Some of these phrases can be understood as particularly important not only because they are common but because they play important roles in facilitating human–human interaction. For example, the common phrase "Hello, how are you?" initiates an introduction between two people, and demonstrates an initial (if perfunctory) concern of the person initiating the contact.

Interaction patterns have a somewhat similar structure. On the one hand, there is no limit to the number of interaction patterns that can be characterized. In part, this is because interaction patterns can be characterized into smaller and more discrete forms. For example, there is the interaction pattern of *walking into a body of water*. You can *walk into an ocean, walk into a lake, walk into a river,* and *walk into a swimming pool*. If you're *walking into the ocean*, you can *walk in over one's ankles, walk in over one's knees, walk in over one's waist*, *walk in over one's chest,* or *walk in over one's head.* For most people, each of these interaction patterns lead to different experiences of the human body in the water. So for most people, it can be useful to use language to make these distinctions. But anybody can say "well, for me, I notice a distinction between getting my toes wet and then wading above my ankles." Many of us would say, "oh, yes, that makes sense to me, too." We could call that interaction pattern, *getting toes wet in the ocean.* But at some point the distinctions may get idiosyncratic to a particular person. If someone says "I notice a distinction in going into the ocean just at my knee cap and 1/10th of an inch above my kneecap," it seems likely that most of us do not experience that distinction as important. But if someone thinks the interaction pattern is important to them, then that's fine. It is not an issue of right or wrong.

On the other hand, some interaction patterns play more important roles than others, and that can depend on the people involved and their sensibilities, vulnerabilities, and goals; and the nature involved at a specific time. For example, if you are supervising young children who are playing at the seashore, and the waves are breaking at around a height of two feet, you might tell the children "don't get into the water higher than your knees unless I'm with you!" The key distinction you are making is *getting into ocean at knee-level*, for that is what you believe is the safety spot for these children with their capabilities with these specific waves. Or let us say you are designing a city that seeks to develop an urban region with a lake within it. You might well argue that a particularly important interaction pattern is *walking along the edges of water and land*, or casting it more narrowly for this specific context: *walking around the edge of a lake*. This might well be the critical interaction pattern that you need to design for, which means keeping houses and development away from the edge of the lake itself, and creating a pathway around the lake, so that people can *walk around the lake*. Knowing that this interaction pattern is a particularly important one helps to provide the language for urban design and urban sustainability (Hartig and Kahn, 2016; Kahn et al., 2018b). Such interaction patterns have been referred to as *keystone* interaction patterns.

A keystone interaction pattern is any interaction pattern that plays a disproportionately large role in human–nature interaction because (a) it occurs frequently, (b) it is itself hugely beneficial or meaningful, (c) it engenders dozens or even hundreds of complementary, subsidiary, or overlapping interaction patterns, and/or (d) its loss leads to the subsequent loss of dozens or even hundreds of complementary, subsidiary, or overlapping interaction patterns (cf. Kahn et al., 2018b). This use of the term *keystone* partly mimics the term *keystone species* in conservation biology, which refers to a species (such as a top predator) that has a disproportionate benefit to its environment relative to its abundance (Mills et al., 1993; Paine, 1995). For example, if the wolf (a keystone species) is removed from such areas as Yellowstone National Park, then elk grow more abundant and stationary, overgrazing vegetation, which leads to the loss of habit, increased erosion, and the loss of biodiversity (Eisenberg, 2013).

On occasion, it is possible that several interaction patterns are themselves combined and then elevated to the level of a keystone interaction pattern, or that some other aspect of the interaction is important enough to append to the core verb/noun structure of a keystone interaction pattern. An analogy can be made to the naming of different types of soup. Some soups are named by their main ingredient, or at least for their distinctive taste. There is, for example, potato soup, lentil soup, chicken soup, carrot soup, leek soup, split pea soup, and miso soup. But sometimes a soup is named based on two of its ingredients. For example, chicken noodle soup usually has many ingredients other than chicken and noodles (e.g., carrots, celery, onion, garlic, and olive oil), but it is not called “chicken celery soup” or “chicken garlic soup” but chicken noodle soup because the chicken and noodles structure its main flavor and the experience of eating the soup. Something similar can occur with interaction patterns. This point will become clear when we discuss the interaction pattern *lying on earth in solitude*.

A Nature Language for Interaction Patterns

Interaction patterns can be thought of as a little bit like words in a dictionary. Words can be defined as individual entities, but they exist in our lives mostly in relation to one another, just as you are reading the words on this page. Similarly, interaction patterns can be defined as individual entities, but are experienced with many other interaction patterns in often overlapping and sequential ways with semantic coherence. For example, you can be *walking a trail* and *stepping over a log* while *seeking to get to a desired bluff top spot* so that you can then *look out to the snow-capped mountains*, and while you do so you might be enjoying the *sun shining on your skin, feeling a light wind,* and decide to *pick some wild blueberries* and then while you’re *kneeling on the ground* you might catch a quick look and *watch a Cooper’s hawk chase down a quail*, as you *swat a mosquito that has landed on your arm.* Human interaction with nature is endlessly varied, endlessly deep. In such ways, interactions can be combined in human discourse, and help form a *nature language* — a way of speaking about patterns of interactions between humans and nature, their wide range of instantiations, and the deeply meaningful and often joyful feelings that they engender (Kahn et al., 2012).

But there is another and perhaps more substantive way that a nature language can be used. It is to use language to speak about any specific interaction pattern, especially about a keystone interaction pattern, in order to help others understand how the interaction can be enacted, and what it feels like to experience.

This is important because in current times the natural world is getting destroyed quickly, across generations; and as we lose nature, we lose the knowledge of how to interact with nature and how wonderful it feels to do so; in turn, that loss leads to our loss of language of how to speak about interacting with nature. The anthropologist Davis (2007) writes that when indigenous cultures lose their language their indigenous way of life dies; that language needs to be spoken, it needs to be “lived” in order for a culture to survive. Similarly, we need to help revive a diverse and deep *nature language* if we are to help reverse the course of environmental destruction. Thus it is important not only to characterize interaction patterns, but to provide a rich narrative for many of them, especially keystone interaction patterns. Such narratives can draw from personal experiences, accounts of indigenous peoples, the historical record, nature writing, evolutionary psychology, and empirical studies. Each narrative helps to make interaction patterns “alive” through words so as to help others know what is possible. For this reason, when we – in the latter part of this article – characterize 7 keystone interaction patterns in a nature preschool, we will be using a nature language to help articulate the patterns themselves.

Modeling Child–Nature Interaction Through Interaction Patterns

In its basic sense, a model is a simplified description of the information of a phenomenon in the world with the objective of making the phenomenon understandable. There are many types of models, including “probing models, phenomenological models, computational models, developmental models, explanatory models. . .theoretical models, scale models, heuristic models, caricature models, didactic models. . .mathematical models. . .formal models, analog models and instrumental models” (Frigg and Hartmann, 2012).

In our work here, we are seeking to model human–nature interaction through the heuristic of interaction patterns. Interaction patterns represent a simplification of the world with the goal to make the world more understandable. Our model incorporates attributes of what is called a phenomenological model insofar as it seeks to represent observable properties of their targets, while incorporating principles and laws associated with scientific theories (Frigg and Hartmann, 2012). In our case, our model incorporates principles, as discussed earlier, from theories of constructivist psychology, ecological psychology, and evolutionary psychology.

Validation of the model occurs in several complementary ways. Given its phenomenological stance, there is face validity based on one's own direct experience. One can ask, "does this interaction pattern make sense to me based on my own experience in nature?" If it doesn't, then while it could still be an interaction pattern, it may not be an important interaction pattern. Then there is the question: "Is the interaction pattern within the realm of human possibility?" For example, there is the possible interaction pattern which has an appropriate linguistic structure of a relevant verb and nature noun, *stepping over an ocean*, which is just not physically possible. Thus *stepping over an ocean* is not a valid interaction pattern. Validation of interaction patterns is further established the more parsimoniously they correspond with the theories of constructivist psychology, ecological psychology, and evolutionary psychology. In addition, the idea of keystone interaction patterns involves an empirical claim that they occur frequently in a specified population and/or are particularly important and meaningful to that population, and/or engender dozens or even hundreds of complementary, subsidiary, or overlapping interaction patterns, and/or if lost leads to the subsequent loss of dozens or even hundreds of complementary, subsidiary, or overlapping interaction patterns. These are empirical claims that can be used to test the validity of a keystone interaction pattern. Finally, part of the validity of our model lies in whether it can lead to testable hypotheses – not for the model itself (as in a climate change model), but in terms of leading to predictions of the world using the interaction patterns.

In what follows, we seek to provide a proof of concept that human–nature interaction can be modeled using the heuristic of interaction patterns, supported with a nature language. This is a beginning venture, not an end. We focus on what seem to us keystone interaction patterns, and begin to validate our model based on the above epistemological criteria.

THE PROOF OF CONCEPT

Over a period of 7 months, we have been filming children interacting with nature in a nature preschool in Seattle, WA, United States. The school is Fiddleheads Forest School, at the University of Washington Botanic Gardens, directed by one of us (Harrington). The children (ages 3–5 years old) and teachers spend all of their time outside, in a matrix of trees, in one of two classrooms located in the University of Washington Botanic Gardens. These botanic gardens are open to the public in this fast-growing city. We divided each of the two outdoor areas into five different filming zones, and through a randomized time-sampling methodology are filming children. Our analysis is based almost entirely on the observed digital video footage; though our videos did capture diffuse sound, and so occasionally we had faint child language to work with, too, in interpreting the behavior. One of the strengths of this method is that it is minimally intrusive in the children's interactions with nature, and is highly systematic in randomly covering all of the landscape. One of the limitations is that we did not interview the children about how they themselves understood their interactions (Turiel, 1983; Kahn, 1999), which itself could become a future study.

As a step forward in characterizing child–nature interaction in a nature preschool, we offer here seven keystone interaction patterns that have been emerging from our data.

This study was carried out in accordance with and with the approval of the Institutional Review Board at the University of Washington, the Human Subjects Division. The parents of all the child participants gave written informed consent in accordance with the Declaration of Helsinki. For those parents who did not give permission for their child to participate, we then explicitly kept them out of all of our video footage, either by zooming in on only the children for whom we had permission (in our time-sampling methodology), or if that was not possible given their close proximity to other children we were filming, we stopped filming all of the children for that duration. Occasionally a parent gave permission for their child to participate but if the child's image was to be used in a publication, such as this one, they requested the child's face be blurred, which we did.

Using One's Body Vigorously in Nature

In the United States, about 75% of children ages 5–10 do not get enough exercise (Hendrick, 2011), which increases to over 90% for adolescents (Li et al., 2016). Exercise strengthens the heart, lungs, and bones, decreases the likelihood of developing obesity, decreases the risk factors for diseases like type 2 diabetes and heart disease, can reduce anxiety and depression, and promotes positive mental health (Youth Physical Activity, 2009).

From an evolutionary perspective, such outcomes are not at all surprising (Wilson, 1984; Kellert and Wilson, 1993; Kahn, 1999, 2011). For tens and hundreds of thousands of years, we as a species came of age using our bodies vigorously in nature. That was a requirement for survival. For example, in her ethnography based on living with Ju/Wa bushmen in the Kalahari desert in the early 1950's – at a time when their way of life may well have embodied much of the hunter-gatherer life from 50,000 years earlier – Thomas (2006) documents that the Ju/Wa women she went foraging with would sometimes carry home 50–80 pounds of tubers, roots, and nuts. The Ju/Wa women themselves weighed about ninety pounds. Thomas estimates that these women walked about 1,500 miles a year. Hunting, too, was physically strenuous. One method of hunting a bull eland was especially demanding. The mature bull eland, in particular, with large amounts of body mass, could be overcome on especially scorching days by a runner who kept at him mile after mile. The runner could not match the eland for speed, for the eland sprints at 35 miles an hour. But eventually, after many hours of being chased in the heat, the eland overheats and can run no more. "Then the hunter, with the last of his strength, can catch up and grab him by the tail, then kill him with a spear if he brought one, or he can push the eland over and lie on his neck to keep him from struggling and clamp his hands over the eland's nose and mouth to stop his laboring breath" (Thomas, 2006, p. 32). Thus from this evolutionary perspective, our bodies and minds are optimally programmed to thrive through using our bodies vigorously in nature, which as modern people we have now reduced to what we call "exercise."

Because *using one's body vigorously in nature* can be instantiated in so many different ways, and plays such a critical role in human health and wellbeing, it is a good keystone interaction pattern to start with here. The ways this interaction pattern is enacted in Fiddleheads are not so surprising. For example, **Figure 2** shows children *running on uneven ground*, *kicking at a wheelbarrow, lifting a stump,* and *hitting a tree with a heavy branch*.

Our point here is not to describe all of the ways that these children use their bodies vigorously in their nature preschool (though that is a worthwhile future goal), but to provide the keystone interaction pattern by which anyone can then begin to characterize subsidiary interaction patterns whenever they see it occur with children. For example, if you see children *dancing on the ground* or *swinging on a tree limb*, *tumbling down a hill, running up a hill, chasing butterflies,* or *moving heavy rocks* – you can say "ha, within a very broad framing of child–nature interaction, there's something common and important to all of it: they are *using their bodies vigorously in nature*.

With this keystone interaction pattern in hand, one can then generate important hypotheses. For example, it is possible that children in a nature preschool are more "active" than children in a traditional preschool with inside classrooms. However, such differences in children's activity may or may not show up if it is measured by a pedometer for steps walked. Rather, a more specific hypothesis is that children in a nature preschool use their bodies more vigorously than in a traditional preschool as measured by the total number and duration of engagement of the subsidiary interactions patterns of this keystone interaction pattern.

FIGURE 2 | Interaction pattern: *using one's body vigorously in nature.* Signed informed consent was obtained from the parents of all the children as shown in the photos in this manuscript.

Striking Wood on Wood

The previous keystone interaction pattern – *using one's bodies vigorously in nature* – is framed at a very broad level in the sense that it hierarchically encompasses at least hundreds of more specific forms of interactions that themselves constitute interaction patterns. We mentioned a few above: *running up a hill, chasing butterflies, and moving heavy rocks*. Given a specific population, landscape, situation one is trying to model, and audience that one is speaking to, a subset of a keystone interaction pattern can also constitute a keystone interaction pattern. We think that is the case for *striking wood on wood.* It is shown being enacted at the bottom of **Figure 2** where a girl with a club-like piece of wood is in the process of using it to strike the trunk of the large tree.

As a more complex instantiation of this interaction pattern, consider an event we observed where a boy (**Figure 3**) jumps off of a stump and with a stick in hand slams his stick repeatedly into the wood structure. In turn, a girl (also in **Figure 3**) initially watches him, and then decides to try out something similar. She picks up a stick and starts striking it, with increasing vigor, against other wood. If you were watching this video data, you would see how the initial affordance of striking wood on wood appears to lead the girl to new perceptions of affordances, such that she understands that she can strike harder. Our impression is that she is not so much trying to destroy something but trying to figure out the properties of *striking wood on wood*: how to strike, and how increased

FIGURE 3 | Interaction pattern: *striking wood on wood.*

FIGURE 4 | Interaction pattern: *constructing shelter.*

force leads to different outcomes. Sometimes when children enacted this interaction pattern, they struck with a light branch, heavy branch, or club-like branch. Sometimes they extended this interaction pattern beyond wood on wood, and struck with a tool, such as with a garden hoe or shovel. Sometimes what was being struck was a live tree, live branches, logs, stumps, or the ground.

Why do children enact this interaction pattern in play? Perhaps it is because that this form of interaction lies deep within our evolutionary history. It is primal. It is the woman gatherer 50,000 years ago, kneeling on the African desert sands, using a hefty digging stick to dig 10 or even 18 inches deep for tubers, striking the earth again and again (Thomas, 2006) for survival. It is the hunter striking an animal's body with a spear, seeking to pierce the animal's heart (Marshall, 2002). It is the woodsman chopping wood, and striking the wood round again and again, to split it, so as to have the pieces by which to build and sustain a fire. What we are likely seeing enacted here, then, are the ontogenetic origins from our phylogenetic past.

Constructing Shelter

This interaction pattern also goes far back in our evolutionary heritage. As humans, we have constructed shelter for perhaps as long as we have been a species. During Paleolithic times, the constructions would have modified natural affordances of the landscapes, such as caves; or used materials in hand, and led, for example, to light thatched huts on the savannahs of Africa, easily constructed and easily left behind in nomadic hunter-gather life (Thomas, 2006).

This form of children's interaction overlaps with what is referred to in the literature as place-making (Sobel, 1993; Nabhan and Trimble, 1994; Chawla, 2002; Sampson, 2012, 2015). For example, in **Figure 4**, the child is modifying the hollow of a tree by leaning branches up outside the hollow, thereby creating a little more protection and privacy. Then he engages in another interaction pattern: *leaning against tree*, and thereby finds respite.

Being in Solitude in Nature

In Milton's (1674/1978) epic poem *Paradise Lost*, he writes "For solitude sometimes is best society, /And short retirement urges sweet return" (book IX). He was writing of Adam going off alone for a while in the Garden of Eden. Others emphasize that *being in solitude in nature* leads to deep experience. Muir (1976, p. 314) put it this way: "Only by going alone in silence, without baggage, can one truly get into the heart of the wilderness. All other travel is mere dust and hotels and baggage and chatter." Of course

FIGURE 5 | Interaction pattern: *being in solitude in nature.*

solitude is relative to person and place. For Muir it might mean hiking a week in the Sierras without meeting another person; for a child it might mean spending a few minutes alone next to a favorite tree.

The girl in **Figure 5** had just been involved in an altercation, and went into this enclosed tree area. One of us (Weiss) was already filming in this general area and continued filming. The girl noticed the researcher, and could not seem to find the peace she needed. She fidgeted, for example, with various sticks and leaves in her hand. After several minutes, she got up and approached the researcher and politely asked if the filming could stop so as to give her some alone time. She then went back to her spot and sat by the large tree. The researcher stopped filming and moved a little ways away. Children at Fiddleheads often take advantage of the privacy that more wild or secluded parts of the landscape affords. As in this instance, it sometimes appears to be an effective mechanism for self-regulating and regrouping: processing something difficult that had just occurred with other people. Other times the solitude seems to afford some of what Muir was writing about: it allows children to get more into the heart of nature itself, as when a girl at Fiddleheads went alone into a more wild part of the landscape and stood still for a bit and then started to enact the interaction pattern *calling the birds*.

Lying on Earth

Modern people are losing direct physical contact with the earth. That loss is likely due to ignorance and happenstance. Ignorance in that we have forgotten how good it feels to have one's body in contact with the earth. Happenstance in that the urban world is increasingly paved such that there is little ability to lie on earth; and even when there is opportunity, we often design nature areas to prevent this interaction pattern under the guise of comfort. For example, it is likely that many times you have arrived at a beautiful resting spot in a park or nature preserve, perhaps alongside a creek, or on a bluff top overlooking a beautiful view, and there is a bench there for you to sit on. So you sit on it. That is an affordance of the bench. But in doing so you have passed over the affordance of the earth itself. It is an enjoyable feeling to place one's body in contact with the earth. You feel its contours, its heat or cold. Perhaps you place your hands in the earth. Or on a hot summer's day, perhaps you take your shoes off and place your feet into the soil. There is emerging scientific literature that shows the cognitive and health benefits of skin in contact with soil. For example, a strain of bacterium found in soil, mycobacterium vaccae, appears to improve cognitive functioning, and triggers the release of serotonin, which in turn elevates mood and reduces anxiety (Lowry et al., 2007). There is also emerging thought that contact with the ground helps to balance the body's electrobiochemical system (Adams, 2012). For example, Chevalier (2014) writes:

> The body is a highly intelligent electrobiochemical system that is strongly influenced by its internal electrical environment. Countless electrical charges within this system regulate countless biochemical reactions, including enzymatic transformations, protein formation, and pH (acid/alkaline) balance. In this complex arrangement, the Earth's surface electric potential serves as the body's stabilizing reference point or ground…[direct] contact with the surface of the Earth maintains the body's electrical stability and normal functioning of its self-regulating and self-healing mechanisms. (p. 255)

FIGURE 6 | Interaction pattern: *lying on earth.*

Both girls in **Figure 6** are enacting this interaction pattern of lying on earth. In addition, the girl in the first photo is enacting what could be called a combinatorial keystone interaction pattern insofar as she is also *being in solitude in nature*. Specifically, this girl had just had an altercation with another child and, in our interpretation, she wanted to regroup. She walked to this area and seemed a little agitated, and then wandered around a little, almost as if she was trying to find the right spot where she felt most comfortable to lie down. And then she did. And then it is as if the earth helped ground her emotionally. This form of interaction – *lying on ground in solitude* – could itself be elevated to a keystone pattern because it seems to us especially powerful as a form of communion with nature.

Cohabiting With a Wild Animal

It has been said that one of the overarching problems of the world today is that we see ourselves as dominating over nature, rather than cohabitating, coexisting, and affiliating with it (Kahn, 2009, 2011; Kahn and Hasbach, 2013a,b). Perhaps the basis for cohabitating grew out of necessity in Paleolithic times. For example, Thomas (2006) recounts an experience one evening when she was living with the Bushmen of the Kalahari desert in the early 1950's when four lions walked into the Bushmen camp. The Bushmen had no way of killing a lion. One of the men took a flaming branch from the fire and in a firm tone, without ever taking his eyes off the lions, talked to the lions, and then ended by telling the lions respectfully but firmly that they could not be here, and to go! The lions watched the person, and "then gracefully they turned and vanished into the night" (p. 151). Of course, for the most part the lions were not interested in eating or harming people; lions and humans coevolved together for hundreds of thousands of years in that landscape. There was enough space for both of their species to live and to thrive. As our species then evolved, and we gained the ability to control, use, and destroy more and more of our environment, and created the technological tools to do so faster, and populated faster, our wellbeing if not our very existence on the planet now comes under threat. One solution is to rediscover how to cohabit with the wild (Kahn and Hasbach, 2013a,b). It becomes a necessity again, no longer because of our limited ability to control nature but because of our seeming inability to control ourselves.

A subset of the interaction pattern *cohabiting with the wild* that we think speaks powerfully to what occurs at Fiddleheads Forest School is *cohabitating with a wild animal*. They are not wild animals like lions, obviously. But the animals such as birds, spiders, and worms are wild insofar they are autonomous, self-regulating, and not depending on the care of humans to live.

Here is an illustrative case in point of this interaction pattern. A few children were digging and moving earth in a wheelbarrow when the girl in **Figure 7** noticed a worm in the soil. The boy had come close to running it over as he was moving quickly with the wheelbarrow in hand. The girl initially displayed aversion to the worm, but that soon changed to fascination. A teacher noticed what was going on and then kneeled down and picked up the worm, placed it in her palm, and showed it first to the girl, who began to get comfortable being in the presence of the worm. The boy saw what was happening and, in our interpretation, wanted to get on with his construction without harming the worm, so he walked over and without hesitation took the worm out of the teacher's hand and placed the worm some feet away, out of the construction area. He then got back to work. Both children were cohabitating with this animal: the girl by being in its company, and learning to appreciate and take delight in it; the boy by being able to find a way to continue with his life while allowing the animal the space to continue with its life. Notice, too, how the teacher was able to foster this interaction by bringing the animal to the attention of the children, demonstrating that the animal was not harmful (by having it in the palm of her hand), and then giving children the space to figure out what would happen next.

FIGURE 7 | Interaction pattern: *cohabiting with a wild animal.*

FIGURE 8 | Interaction pattern: *being outside in weather.*

Being Outside in Weather

Some interaction patterns are so pervasive that they can escape notice, even if they are important for humans to enact. *Breathing air* is an example. We hardly think of it as a form of interaction – that is, until it becomes hard to breathe. Then we might emphasize the adjective *clean* as in *breathing clean air*. There are cities in this world where *breathing polluted air* has equivalent health impacts of inhaling 2–5 dozen packs of cigarettes a day.

One such pervasive interaction pattern, and a defining characteristic of nature schools in general, is *being outside in weather*. The children at Fiddleheads have no inside space. It rains a lot in Seattle. Occasionally it sleets or even snows. Sometimes in late Spring the sun shines and it is hot. Children spend all of their time *being outside in weather*. **Figure 8** shows a child enacting this interaction pattern on a January day of heavy rain. She is well dressed!

Being outside in weather is not only pervasive, but helps make possible many of the interactions that occur in a nature preschool. This is worth naming, and keeping in mind, when discussions occur about whether it is important to balance outside time with inside time in any specific nature school. It is also the case that this interaction pattern helps connect children with perhaps the wildest parts of nature that they have access to if the school is in an urban environment. For weather by definition is wild insofar as you do not control it: it is self-organizing, and it is big nature, some of the biggest, and while it can be nurturing and healing, it can also be fierce, and if you are not careful it can kill you. In this sense, children learn to respect nature, and to cohabit with the wild.

ADDITIONAL KEYSTONE INTERACTION PATTERNS

We have characterized seven keystone interaction patterns that have emerged from our observing children at Fiddleheads Forest School, and provided a nature language about them: *using one's body vigorously in nature, striking wood on wood, constructing shelter, being in solitude in nature, lying on earth, cohabiting with a wild animal,* and *being outside in weather*. In two other recent venues, we have characterized an additional 14 keystone interaction patterns (Kahn and Weiss, 2017; Kahn et al., 2018b). Thus here, in **Table 1**, we bring together all of the keystone interaction patterns to date, and describe them briefly, and note the ontogenetic and/or phylogenetic significance of each of them. For the reader interested in a fuller explication of any of the additional interaction patterns, we delineate which additional pattern is discussed in which venue. **Table 1** may be especially useful for practitioners insofar as it provides a condensed description of what children are actually doing at this nature preschool, and potentially other nature preschools with a similar landscape. For example, if a director of a nature preschool is trying to explain to parents what their children are actually doing each day outside, and why it is probably important for them, the director could draw directly on whatever parts of this table seem most relevant.

DISCUSSION

The qualitative research presented in this article seeks to make a compelling case – as a proof of concept – that child–nature interaction can be modeled in a nature preschool based on interaction patterns.

In support of our proof of concept, we provided a summary of the model's underlying theory which draws from constructivist psychology, ecological psychology, and evolutionary psychology. We also provided an account of interaction patterns, and discussed the phenomenological model we are developing, and the issue of validation. Then we moved to the substance of our research. We provided a description of seven keystone interaction patterns that have emerged from our observational data, along with an extended *nature language* to convey their ontogenetic and phylogenetic significance. Finally, we integrated these 7 interaction patterns with 13 other patterns published elsewhere. Thus, for the first time, we have in this article presented and synthesized 20 keystone interaction patterns for this nature preschool.

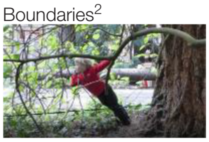
These 20 keystone interaction patterns do not complete the model for two reasons. First, additional qualitative analyses of more keystone interaction patterns is needed, along with a quantitative coding (with assessments of intercoder reliability) of all keystone interaction patterns so as to establish their relative frequency. We think we have most of the keystone interaction patterns identified, but not all of them. That work is currently ongoing, and will be reported at a later date. Second, our model is constructed to be open-ended, and thus is responsive to whomever wants to modify it based on their own sensibilities and goals. For example, it is possible to drill down with greater and greater specificity to name very specific interaction patterns, such as *sitting on log with left foot in the air; sitting on log with left foot extended on ground.* There are thousands of interaction patterns of this sort, if not more. Are they interesting? At this moment, not to us with the lenses that we bring forward, including that of developmental psychology, education, environmental education, and parenting. But if we were specialists in something like "child-sitting ergonomics," then such interaction patterns could be of particular interest, and be elevated to a keystone level. Assuming that the modeling of the

TABLE 1 | Toward modeling child–nature interaction in a nature preschool: 20 keystone interaction patterns.

Keystone interaction pattern (Image)	Description	Ontogenetic and phylogenetic significance
Using One's Body Vigorously in Nature[2] 	*Running on uneven ground* and *kicking at a wheelbarrow*, as shown in this image, represent only two of many instantiations of this keystone interaction pattern that can occur in a nature preschool.	As a species, we came of age using our bodies vigorously in nature. It was a requirement for survival. From this evolutionary perspective, our bodies and minds are optimally programmed to thrive through using our bodies in this way, which as modern people we often reduce to what we call "exercise." Nature preschools like Fiddleheads allow children the space and time to enact this keystone interaction pattern in many different ways.
Climbing High in Small Tree[2] 	This boy climbs the low-hanging branches of a small tree. He must take into account the differential load-bearing capacity of each limb as he makes his way up the tree.	This interaction pattern makes possible many other interactions that presumably have their origins in our evolutionary history. For example, *looking out from a natural vantage point* (tall tree, knoll, hillside) to be able to see what lay in a more distant landscape likely conferred an adaptive advantage.
Striking Wood on Wood 	The boy holding a stick strikes a woven-stick shelter surrounding the base of a tree, and at one point jumps from one of the logs to strike the wood. The girl observes the boy's behavior and explores her own ability to strike wood on wood.	Phylogenetically, this interaction likely came about with early tool use, and the discovery of how sticks could be used for human benefit. Developmentally, the enactment of this pattern can occur with a range of tools in hand (natural and artifactual), and provides a mechanism by which children learn the properties and affordances of the materials.
Leaning on and Hanging from Supple Tree Limbs[2] 	While speaking to a person on the outside edge of the classroom's boundary, this boy begins to lean his bodyweight on the small branches within his grasp. As he shifts his bodyweight forward and backward, the branches move and bend accordingly.	This form of interaction with nature illustrates a canonical principle of ecological psychology whereby interactions with the affordances of nature quickly create new affordances which lead to further and often more extensive interactions. One can almost see here the child's construction of knowledge, as he is learning how to balance himself amidst supple tree limbs. It includes proprioceptive knowledge, as he gains an understanding of his body in relation to a dynamic natural system.
Constructing Shelter 	This child is modifying the hollow of a tree by leaning branches up outside the hollow, thereby creating a little more protection and privacy.	The affordances of this nature classroom allow the boy to engage in place-making. Our Paleolithic ancestors enacted a similar pattern, often modifying natural areas, such as caves. Finding or constructing shelter represents a fundamental feature of ancestral life.
Digging in Ground[1] 	This boy uses a shovel in one of the nature classroom's mud pits. Initially, he was awkwardly scrapping the shovel across the surface of the ground. This photo captures the moment at which he discovers how to leverage his body over the shovel to yield the most efficient strategy for digging.	The use of tools by humans to mediate interaction with nature stands as one of the key evolutionary turning points for us as a species. Nature classrooms such as the one pictured here allow children to discover and construct for themselves the schema necessary for understanding and operating various tools most effectively with respect to their bodies and the environment.
Falling on Ground[1] 	This girl was running through the nature classroom when she put her right foot on a log that was slippery from the morning's rain. As she fell, she extended her right arm and rolled slightly onto her shoulder as she caught her fall.	*Falling on ground* safely is a developmental outcome requiring opportunity. As modern humans come of age in environments largely devoid of environments allowing for the learning of how to fall without seriously injuring oneself, there exists the possibility that children will mature into adults without the basic physical skills and body awareness necessary to avoid potential serious physical harm.
Not Falling on Ground[1] 	This boy was carrying a branch above his head and then tripped on a rock on the ground that he had not seen. He succeeds in *not falling on the ground* by dropping the branch as he regains his footing.	In development, a child learns to increasingly integrate schemas of action. In this case, it is the child dropping the branch to regain balance. More generally, this integration emerges whenever multiple interaction patterns are simultaneously enacted.

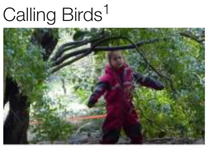
(Continued)

TABLE 1 | Continued

Keystone interaction pattern (Image)	Description	Ontogenetic and phylogenetic significance
Leaning Against Tree[1] 	The boy with the orange hood sits nestled within the roots of a cedar tree that he has designated previously to be his "magic spot," a place of comfort and self-regulation chosen in different areas in the nature classroom by each child. The girl standing offers him a flower as a symbol of their resolution following their heated quarrel.	In many cultures, trees are understood to have power. To lean against a tree is to engage in a relationship with it, and to feel its support physically and emotionally. In turn, the ability of children to regulate their feelings, especially when there is conflict with other children, is paramount in development. It is possible that direct contact with supportive parts of the natural world help children to self-regulate.
Lying on Earth 	After an altercation with her friends, this girl chooses to lie on the ground, in the few rays of sunlight that reach the floor of the nature classroom. In this particular example, she also chose to enact this pattern of lying on the earth in solitude, as a means of re-centering herself emotionally and physically.	Modern people are losing direct physical contact with the earth. That loss is likely due to ignorance and happenstance. Ignorance in that we have forgotten how good it feels to have one's body in contact with the earth. Happenstance in that the urban world is increasingly paved such that there is little ability to lie on earth; and even when there is opportunity, we often design nature areas to prevent this interaction pattern under the guise of comfort.
Being in Solitude in Nature 	Following an altercation with classmates, the child seeks solitude in an enclosed and private area surrounding the base of a tree at the edge of the nature classroom.	Children at Fiddleheads often take advantage of the privacy that more wild or secluded parts of the landscape affords. It sometimes appears to be an effective mechanism for self-regulating and regrouping: processing something difficult that had just occurred with other people.
Waiting Attentively in Nature[2] 	At an edge of the nature classroom replete with ferns and foliage, this boy waits patiently for the return of his friend. Minutes go by, as he stands attentive yet calm, amidst the chirping of birds and a light breeze ruffling the leaves of the surrounding plants.	Our urban technological world does not offer many natural affordances for attentively waiting. Rather, it seems that *peering into technological device while waiting* is becoming the norm. Attention Restoration Theory suggests that mental fatigue can be improved by time spent in nature. It is possible that *waiting attentively in nature* is one form of human–nature interaction that can restore mental and emotional capacities.
Making Social Boundaries on Earth[2] 	This boy dragged a long thick branch from another location into an open space and used it to make a boundary, which he then buttressed with wood rounds and rock that he also carried from elsewhere.	The Neolithic period brought forward a shift from nomadic to agricultural life, and thus the ability to store foods, and to thereby increase population. With such changes came an increasing focus on ownership of objects and land, and territorial boundaries to indicate property lines. Children enacted this form of interaction by drawing on the many "loose parts" of nature in the nature preschool, as well as the school's open space.
Pushing to the Edges of Social Boundaries[2] 	While swinging his body to and fro in the supple tree limbs of this tree bordering the edge of the classroom, the boy realizes he can nearly swing his head and torso across the boundary and beyond the classroom edge.	In healthy development, children need to test boundaries, physically and socially. The two are often intertwined at this nature preschool insofar as children know the rule (for safety) about staying inside the physical boundary of the classroom, but often enjoy going right to the edge (or just slightly over). This example also illustrates a fundamental component of the theory of ecological affordances, as one interaction with nature, *leaning on and hanging from supple tree limbs,* can engender the opportunity to engage in other related, but distinct, interactions, such as *pushing to the edges of social boundaries*.
Imagining Nature to be Something Other Than It Is[2] 	A girl who had been playing with another girl saw a long thin stick. She got on the stick and began to ride it, calling it a "train" and then a "horse" at different times. After initially claiming solitary ownership over the stick, the girl eventually decided to entice a friend of hers to join her for a "trip" around the center of the classroom.	The young child's mind undergoes a far-reaching transformation when it comes to understand that something can be represented as something other than what it is. Phylogenetically – tens of thousands of years ago, and perhaps much longer – this achievement of our species likely occurred though people interacting with nature, and then imagining nature to be something other than it is.
Looking at Wild Animals[2] 	This child was jumping over the log and exploring her ability to propel herself over it. She then notices a spider and invites a teacher to look at it with her. *Looking at animals* can be both an individual and social interaction.	Biophilia refers to the innate propensity for humans to affiliate with nature, and one of the most salient aspects of nature that humans affiliate with are animals. In our ancestral history, we hunted wild animals, and depended on them for our survival. We became interested and good at looking at them.

(Continued)

TABLE 1 | Continued

Keystone interaction pattern (Image)	Description	Ontogenetic and phylogenetic significance
Imitating Animals[2] 	The girl imitates the physical actions and vocalizations of a domestic housecat while making eye-contact with her classmate.	Imitation of domestic and wild animals can be considered as a form of reciprocity and communication, highlighting the vital position animals play in even modern lives.
Calling Birds[1] 	Standing in one of the most wild parts of the nature classroom, this girl raises and lowers her arms in a wing-like fashion, and imitates the sounds of the birds overhead.	It has been said that the human species cannot be fully itself without enacting, dreaming, and thinking about wild animals. In turn, birds are some of the wildest animals that people encounter in urban environments insofar as birds, especially those that migrate, are not hemmed in by human infrastructures and desires.
Cohabiting with a Wild Animal 	While digging in the ground in a pretend construction site, these children came across a worm wriggling in the earth. Along with the aid of a teacher, the children transitioned from a state of initial unease to fascination, and ultimately to respect for the worm's existence.	It has been said that one of the overarching problems of the world today is that we see ourselves as dominating over nature, rather than cohabitating, coexisting, and affiliating with it. In Paleolithic times, learning to live among the animals that shared our environment was a necessity for survival. For children, understanding the notion that one can live side-by-side with other organisms is an important lesson in developing a healthy relationship with nature and those around us.
Being outside in weather 	The child kneels near the mud pit of one of the nature classrooms and scoops up some of the rain-soaked earth with one of her hands.	Children in a nature preschool spend almost all of their time outside. *Being outside in weather* exists as an overarching keystone interaction pattern that can take on many forms for different environments – such as heavy rain for this Seattle-based nature preschool. Learning to adapt to the changing weather allows children the opportunity to develop skills of self-regulation, and immerses them in perhaps the wildest forms of nature accessible in an urban environment.

Interactions with superscript 1 have been described in detail in Kahn and Weiss (2017), and with superscript 2 in Kahn et al. (2018b). The others are described in detail in this article.

ergonomic child–nature interaction patterns are being done well, then it is not an issue of the modified model being right or wrong, but relevant or not relevant to a particular audience. That is an extreme example, of course. But it is possible that people even with a shared orientation may want to emphasize certain interaction patterns over others; and that is fine, and they would then provide the *nature language* to help others understand why that pattern is particularly significant. Thus in our view, our modeling is both product and process. Both are intellectual contributions.

Part of the strength of our approach to modeling is that it can account for forms of interaction that cut across many if not all nature preschools, while allowing for differences in the way that the interactions are instantiated, or in terms of the subsets of interaction patterns that are called forward to comprise the larger pattern. For example, *using one's body vigorously* may occur in all nature preschools, but in some schools that may involve *running up a hill* while also *running on flat land* while in other schools, like in the Fiddleheads main classrooms, there are no hills to speak of, so you would not see *running up a hill*. Or *climbing high in small tree* can occur in many different regions with many different species of small trees; though it will not occur in nature preschools where there are no trees. Thus future studies could employ our approach to modeling to compare nature preschools in different geographical locations (e.g., with more or less wild landscapes), or to compare nature preschools to traditional inside preschools in the same location. Along the same lines, our modeling, based on interaction patterns, can account for what is universal and particularistic based on culture and subgroups. Thus future studies could also employ our approach in comparative studies of nature preschools in different cultural settings.

With a working model in hand, one can also move beyond comparative studies and generate and test important hypotheses. For example, one hypothesis that we are currently exploring is whether more relational forms of interaction with nature (such as *calling birds, leaning against tree*, and *imitating animals*) occur in landscapes that have affordances that are more wild. If such a hypothesis bears out, it would speak to the importance, even in modern times, for children to connect to more wild forms of nature to develop relational ways of engagement.

DATA AVAILABILITY STATEMENT

The full video segments supporting each of the seven keystone interaction patterns will be made available by the authors, without undue reservation, to any qualified researcher.

AUTHOR CONTRIBUTIONS

PK: conceived study, co-responsible for leading intellectual work, did most of the actual writing. TW: responsible for data collection, co-responsible for leading intellectual work, assisted with writing. KH: involved with implementation, intellectual work, and writing.

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OPINION
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Contrasting Screen-Time and Green-Time: A Case for Using Smart Technology and Nature to Optimize Learning Processes

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INTRODUCTION

Tablets and smartphones (i.e., mobile technology) as learning tools for school use is on the rise worldwide (Norris and Soloway, 2015). The technology is reported to impact positively on learning outcomes (Major et al., 2017), by facilitating contextual and situated learning (Brown and Mbati, 2015). For instance, mobile devices are thought to stimulate personalized and informal learning by corroborating and adapting to the interests, preferences, and competencies of learners (Traxler and Wishart, 2011), while affording personal publishing and sharing (Mbati, 2017).

However, exposure to screens may also have more undesirable side-effects of concern to formal and informal learning. In so-called iPad schools where books are switched for iPads in class, play during break-time shifts from physical to more sedentary activities (Schilhab, 2017a). Crudely put, engagement with the external world of concrete phenomena and spontaneous events is switched for engagement with the mediated world of smart technology, where children watch and share YouTube videos, read Wikipedia, and are exposed to vast amounts of information from others (Holloway et al., 2013; Duarte Torres et al., 2014).

Hence, along with the increased use of mobile technology come attentional and cognitive shifts pertaining to the learning and development of the individual (e.g., Ward et al., 2017). Numerous studies have demonstrated that smart technology use influences attentional and cognitive processes in unexpected ways. For instance, it has been reported that devoting attention to mobile phones voluntarily or involuntarily changes the content and dynamics of conversations (Turkle, 2015), resulting in shallower content (Przybyliski and Weinstein, 2013) and lower levels of reported empathic concerns among interlocutors (Misra et al., 2016). It has also been argued that smart technology's capacity as information store has profound consequences on how we manipulate and memorize learned material (Sparrow et al., 2011; Barr et al., 2015; Dong and Potenza, 2017), although the actual effects on learning are also disputed (Aagaard, 2015; Heersmink, 2016). In meta-cognitive research, on-screen readers performed worse than print readers when tested in connection with self-regulated reading of expository texts (Ackerman and Goldsmith, 2011), suggesting that screen reading alters the recruitment of mental efforts (Lauterman and Ackerman, 2014).

In comparison, the natural world seems to engage attentional and cognitive processes differently. Following Attention Restoration Theory (ART, e.g., Kaplan, 1995) in opposition to screen watching (e.g., television), *unthreatening* greenish outdoor environments typically accessible to both urban and country dwellers stimulate by so-called soft fascination (Kaplan and Berman, 2010). Please note that *threatening* greenish outdoor environments may have more intrusive, yet desirable cognitive effects (e.g., Kahn et al., 2009). Accordingly, resting in green environments enhances so-called executive functioning (Bratman et al., 2012) in use when concentrating and thinking, and is therefore central for academic success (Diamond, 2013). Arguments for exposing students to nature are partly based on this effect (Matsuoka, 2010; Kuo et al., 2017). Although the restorative effect of soft nature on cognitive functioning, as proposed by ART, is persuasive with respect to promoting nature interventions in school, another much more profound effect of relevance to success in school and life not addressed by ART has gone largely unnoticed.

We advocate that the mental work occurring *during* restoration of executive functioning, so-called mind wandering, e.g., off-task thoughts that occur either with or without intention (Smallwood and Schooler, 2006), is crucially important in its own right. Given that screen watching and screen use is more likely to affect attentional and cognitive processes by hard fascination (Kaplan and Berman, 2010), to an extent that sometimes renders mobile technology use addictive (e.g. Rosen et al., 2013; Billieux et al., 2015), thus tapping into self-regulatory processes (Schilhab, 2017b), nature's facilitating effect on mind wandering becomes noteworthy.

In what follows, we (a) highlight how nature-induced soft fascination leaves room for spontaneous thoughts, which are under increased pressure from the mobile technology-induced hard fascination and more controlled thoughts and (b) emphasize the need for research relating green environments, open monitoring and divergent thinking.

ATTENTION

Forming part of executive functions (Engle, 2002; Posner et al., 2013), attentional control is closely related to success in school (Diamond, 2011). James (1892) famously distinguished between *involuntary* and *voluntary* attention, also known as stimulus-dependent and directed attention (e.g., Chun et al., 2011). The former refers to attention that requires no effort, such as when something dangerous, pleasurable or novel occurs (e.g., Sood and Jones, 2013) whereas the latter refers to the kind of attention employed when something is not particularly interesting and therefore requires a good deal of mental effort (Kaplan and Berman, 2010). Thus, stimulus-dependent attention often depends on external sense activity that drives learning automatically and *bottom-up*, whereas directed attention is independent of stimulus characteristics and works *top-down* (Wilson, 2002).

As noted by Kaplan and Berman (2010), James(1892, p. 88) pointed to "strange things, moving things, wild animals, bright things, pretty things, metallic things, words, blows, blood, etc. etc. etc." as engaging stimulus-dependent attention. In this understanding, mobile technology seems entirely unmatched in its ability to "call" up the attention of its user. Mobile technology affords immediate access to pleasure, and unexpected and novel stimuli and thus taps heavily into our attentional resources (Lee et al., 2014; Li et al., 2015) combatting e.g. social anxiety and boredom (Elhai et al., 2017) or feeding attentional impulsiveness (Roberts et al., 2015). Even long-term attentional effects, the so-called phantom vibration and phantom ringing hallucinations, seem to occupy the mind of heavy mobile technology users (Lee et al., 2014; Tanis et al., 2015).

NATURE-INDUCED SOFT FASCINATION

Conversely, natural stimuli seem to capture attentional processes in an opposing way, although it is worth noting that "untrammeled" and unmanaged wild nature is likely to have different attentional effects (Davis and Gatersleben, 2013). ART suggests that non-threatening natural environments are experienced with less cognitive effort, because they are "softly fascinating" with no elements that compete with each other for attentional focus (Kaplan, 1995). ART predicts that perceiving natural stimuli will allow finite cognitive capacities, such as focusing attention, to restore, alleviating the individual from cognitive fatigue that is experienced when these capacities are overused (Kaplan, 1995; Berman et al., 2008). Indeed, there is an existing research base that supports the notion that exposure to nature can be beneficial to cognitive processes (for review, see Ohly et al., 2016).

We suggest that non-threatening natural environments that softly fascinate have positive effects on cognition through the facilitation of spontaneous thought processes.

According to ART, nature-bound stimuli are less likely to signify a sense of immediate danger or otherwise pull attention along particular thought paths. Hence, engaging with nature-bound stimuli involves comparably fewer symbolic associations than engaging with smart technology. A pond full of carp signifies nothing or very little beyond itself. Carp swimming just "are"—the observation does not trigger a sense of danger, hard fascination difficult to disengage from or intentions to act, whereas a picture of carp as in advertisements normally signifies or stands for something different that instigates serial thought processes calling upon directed attention. It is likely that the "closed signification," which is the fact that nature's stimuli point to themselves and not away from themselves to something beyond, provides nature with the strength to decelerate or even obliterate thought processes (Schilhab, 2017c).

In a study that illustrated how the brain processes natural and non-natural stimuli differently, Berto et al. (2008) used eye-tacking technology to investigate how participants viewed two types of scenes. They found that viewing natural scenes was associated with greater exploration and fewer fixations; however, when viewing urban scenes, participants were more likely to fixate on certain stimuli. Greater scene exploration suggests greater fascination that is not cognitively demanding, whereas frequent and longer fixation suggests that attention is more readily captured by these stimuli that they are more cognitively demanding to process (Berto et al., 2008).

Being in a safe natural environment, where the surrounding stimuli have no intrinsic threat, goal, or task associated with them, may benefit non-perceptual cognitive processes important for learning. An environment with no goal-directed or task-positive stimuli may also be associated with activation of task-unrelated neural networks, such as the default mode network (DMN) (Andrews-Hanna et al., 2014). The DMN is associated with autobiographical memory and mind-wandering and has been shown to be separately involved in the maintenance phase of working memory alongside task-positive networks (Piccoli et al., 2015). Maintaining and remembering newly acquired information is one of the most commonly demonstrated cognitive benefits of exposure to natural stimuli (Ohly et al., 2016). Moreover, the cognitive load in working memory tasks can be predictive of the impact of natural stimuli, where the harder the task conditions, the greater the cognitive restoration associated with exposure to nature (e.g., Dadvand et al., 2015). This suggests that the harder the brain is working to shield memorized information from external and internal distraction, the greater the impact a natural environment will have on restoration of this and associated abilities.

DIVERGENT THINKING

The reduced pull on thought processes facilitates more self-generated thoughts where the mind "move[s] hither and thither without fixed course or certain aim" (Christoff et al., 2016, p. 719). Such episodes are considered adaptive since they allow individuals to, for instance, prepare for future events, to sustain a sense of self-identity and to re-interpret social encounters (Andrews-Hanna et al., 2014).

Spontaneous thought processes associated with the reduced external pull on thoughts also loosely resemble divergent thinking processes stimulating creative thinking and abilities to think "out of the box" (Colzato et al., 2012)[1].

This might suggest that in contrast to smart technology use, nature-bound stimuli are more likely to endorse so-called open monitoring mind states prevalent in certain meditative traditions (Tang and Posner, 2009; Howell et al., 2011; Lebuda et al., 2016). Following Hommel and Colzato (2017), focused-attention meditation (FAM) differs from open-monitoring meditation (OMM) and have different and sometimes even opposite impacts on cognitive processes. Whereas FAM traditionally trains directed attention capacities by sustained attention on a specific object, OMM "sustains attentive monitoring of anything that might occur in experience without focusing on any explicit object" (ibid. p. 115; see also Lutz et al., 2008).

[1] For a straightforward description of divergent and convergent thinking see Jones and Estees (2015, p. 474) who define divergent thinking tasks as generally focused on generating several possible "imaginative" answers, whereas convergent thinking tasks generally entail a narrowing of possible solutions to one optimal answer.

In the current context, we suggest that nature-bound stimuli are likely to induce open-monitoring mental states that typically promotes the divergent thinking style that allows many new ideas to be generated (Leong et al., 2014; Colzato and Hommel, 2017; Colzato et al., 2017). Studies examining the impact of acute moderate and intense physical exercise on convergent and divergent thinking in athletes and non-athletes (S Colzato et al., 2013) or the effect of walk (Keinänen, 2016; Zhou et al., 2017) could form the backdrop for a future research design to test the impact of nature-bound vs. mobile technology-bound stimulation (for the distinction between the effect of the outdoors and physical activity, see Oppezzo and Schwartz, 2014).

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Based on these ideas, we suggest that exposure to a natural environment or natural stimuli, may be seen as a useful and relevant intervention strategy to counteract the effect of exhausted cognitive capacities associated with overuse of smart technology. Coupling periods of smart technology use with periods of exposure to a natural environment may be optimal for learning.

Given the increasing use of mobile technology worldwide we also need to identify how technology can be used to encourage more children to get outside (Schilhab, 2018). The consequences of using smart technology within natural environments are not yet known although new research on the effect of Pokémon Go may provide some early indications (LeBlanc and Chaput, 2017; Ruiz-Ariza et al., 2018). Thus, future studies should investigate both how natural stimuli may counteract exhausted cognitive capacities and the effects of mixing nature-bound and technology-bound stimulations when mobile technologies are used in nature experiences.

AUTHOR CONTRIBUTIONS

TS, MS, and PB: conceived of the study; TS and MS: contributed conception of the study; TS: wrote the first draft of the manuscript; MS: wrote sections of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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PERSPECTIVE
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Implementing Green Walls in Schools

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Numerous studies in applied pedagogical design have shown that, at all educational levels, direct exposure to the natural environment can enhance learning by improving student attention and behaviors. Implementing green walls—a "vertical garden," or "living wall" interior wall that typically includes greenery, a growing medium (soil or substrate) and a water delivery system—provides environmental health benefits, but also provides a practical application within classrooms for minimizing directed attention fatigue in students by connecting them to "outdoor nature" within the indoor environment. Hands-on "project-based" learning is another pedagogical strategy that has proved to be effective across the spectrum of educational levels and across subject areas. Green walls have the potential to inspire critical thinking through a combination of project-based learning strategies and environmental education. The authors have outlined a curriculum involving the implementation of an indoor living wall system within a classroom-learning environment, incorporating project-based learning modules that interact with the wall. In conjunction with the passive health benefits of a green wall, project-based curriculum models can connect students interactively with indoor nature and have the potential to inspire real-world thinking related to science, technology, engineering, art, and mathematics fields within the indoor learning environment. Through a combination of these passive and interactive modes, students are connected to nature in the indoor environment regardless of weather conditions outdoors. Future research direction could include post-construction studies of the effectiveness of project-based curricula related to living walls, and the long-term impacts of implementing green walls in classrooms on school achievement and student behaviors.

Keywords: nature-based learning, green walls, project-based learning, nature in the classroom, environmental education, living walls art and STEM

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INTRODUCTION

In the United States, students spend an average of 6 to 7 hours per day in the classroom setting for approximately 180 days out of the year (Institute of Education Sciences, 2008). In an effort to improve standardized test scores, four out of ten schools nationwide have increased classroom instruction time in place of recess (Loucaides et al., 2009). Young learners are expected to maintain attention for prolonged hours during the school day and are more likely to suffer from directed attention fatigue, or decreased ability to stay focused on classroom activities. Attention restoration theory suggests that exposure to natural environments encourages involuntary attention, and these short breaks allow directed attention for the learning environment to reset (Kaplan, 1995).

A green wall, also known as a vertical garden or living wall, is defined as a vertical planting system that includes an integrated substrate, live plants, and in some cases an automated

Abbreviations: STEAM, Science, Technology, Engineering, Art, and Mathematics.

watering system. Implementing green walls in the classroom provides students with the opportunity to participate in passive, indirect attention, in order to have a restorative influence on focus and learning. There is limited evidence regarding the effect of incorporating nature into the classroom on student performance and behavior. One study of 170 Dutch students in grades five to seven found that children in classrooms with an indoor green wall had improved scores on a selective attention task and also rated their classroom more positively compared to children in classrooms without a green wall (Van den Berg et al., 2016). Another study in Taiwan found that junior high students in classrooms with plants had fewer sick days and misbehaviors, as well as higher reported measures of comfort and friendliness, compared to students in classrooms without plants (Han, 2009).

Stress recovery theory suggests that individuals have adapted over time to innately respond positively to natural environments, as opposed to built environments (Ulrich, 1983). In addition, plants have the potential to promote relaxation and recovery from stressful experiences. Visual access to nature from the classroom setting has been found to decrease attention deficit behaviors in children (Taylor et al., 2002). Views of nature from classroom windows have also been shown to improve directed attention skills compared to views of less natural scenes or of built environments (Tennessen and Cimprich, 1995). One randomized study of 94 public high school students in Illinois found that students assigned to classrooms with a "green" view scored higher on attention tasks and recovered from a stressful experience faster than students with no window or a window with a barren view (Li and Sullivan, 2016).

Academic achievement is positively influenced by exposure to nature in a variety of settings (McCormick, 2017). Vegetation surrounding schools is associated with improved standardized test scores on math and reading (Wu et al., 2014; Hodson and Sander, 2017). In addition, vegetation surrounding housing units in urban settings is associated with higher levels of cognitive functioning and attention scores among children (Wells, 2000; Taylor et al., 2002). Another study of 101 public high schools in Michigan found that views of greenery from classroom and cafeteria windows were associated with increased standardized test scores and graduation rates, in addition to decreased criminal behavior (Matsuoka, 2010).

Project-based, environmental education programs have been shown to increase student engagement, as well as improve academic performance in reading, writing, math, science, and social studies (Lieberman and Hoody, 1998; Chawla et al., 2014). To our knowledge, there is limited evidence regarding the implementation of green walls in schools as effective project-based learning curricula. The purpose of this article is to provide a practical application for implementing a nature-based learning curriculum into the classroom setting by utilizing green walls. By implementing green walls in classrooms, students can experience interactive learning through plant design, fabrication, and installation, and also gain passive exposure to nature. This can encourage environmental perspectives and minimize directed attention fatigue (Supplementary Figure 1).

USING NATURE AND PROJECT-BASED LEARNING AS A STRATEGY TO REDUCE EFFECTS OF DIRECTED ATTENTION FATIGUE

Through a series of pilot programs that utilize multiple project-based learning strategies in combination with a green wall program, we have developed a model curriculum that provides students with passive indoor exposure to nature. The curriculum also features an interactive learning workshop that engages students with nature and with science, technology, engineering, art, and math (STEAM) fields. The outlined curriculum for the green wall workshop utilizes the concept of a simple plant-growing lab to create an environmental education collaboration. A living wall can be built on or within a preexisting building wall, or can be freestanding; bringing nature indoors in this way creates an intimate, ongoing exposure to living plants regardless of outdoor conditions and does not significantly reduce usable floor space.

The curriculum teaches the students about "vertical" gardens, and teaches them how to design and install the green wall. Passive exposure to the living wall is defined as presenting students with visual access to the green wall throughout the day. If a green wall is placed within an atrium or a library, students may have intermittent passive exposure; incorporating green walls in classrooms (where students spend a majority of their time) will allow for longer durations of exposure and afford a greater degree of interactivity with the wall. Green walls can conceivably be placed anywhere within the learning spaces inside a school.

GREEN WALL MAKER WORKSHOP

The Green Wall Maker Workshop is a comprehensive approach for incorporating a green wall into a classroom, a project that allows students to participate in an interactive "design-build" experience that includes installation. As a broad-based project that incorporates both art and science, this workshop could be incorporated as a module within existing classes. The workshop is an example of "project-based learning," a pedagogical strategy in the "active learning" mode that has its roots in the work of psychologist and educational reformer John Dewey (McDermott, 1981).

Active learning contrasts with passive modes of learning such as listening to lectures or reading assigned texts. In the passive mode, students receive information; in an active mode, students must seek information. Project-based learning is a form of active learning that causes the student to "learn by doing" and to apply ideas in purposeful fashion in order to complete a directed project. For project-based learning within a science course, for example, students might "investigate questions, propose hypotheses and explanations, discuss their ideas, challenge the ideas of others, and try out new ideas" (Krajcik and Blumenfeld, 2006). However, educators in any discipline can incorporate this strategy as a pedagogical device; it has been an essential component of design education for decades (Erdman et al., 2002). The essence of project-based learning is that the student *constructs* meaning and knowledge based on direct experience, interacting with their environment.

Part 1: Study of Living Walls, Human Connection to Nature, and Plants

Part one of the workshop provides students with an opportunity to learn about how vegetation is brought indoors through methods related to STEAM. Students are given a 15-min presentation on how plants are used in architecture, and how creative process is the navigating tool for developing a green wall. This introductory presentation leads to hands-on learning through experimentation and one-on-one conversations with the green wall specialist (or other individual with an aptitude for the integration of plants within buildings). The objective of the specialist is to introduce plants as a component of interior environments, but also to inspire the students' interest in education or career possibilities within the STEAM disciplines that underlie the concept of green walls.

Once the presentation is completed, students are introduced to physical attributes of interior plants. They study plant characteristics including form, color, texture, and scale. Students interpret these characteristics by designing a small-scale multimedia collage utilizing construction paper (in colors similar to the plants), drawing utensils (to simulate foliage textures), and adhesive. The objective is for students to understand that each plant have different characteristics, and those elements are used to create a planting design for the living wall (Supplementary Figure 2). During this process, students are encouraged to discuss the following questions, in order to maintain a focus on the purposefulness of their exercise: *Why bring plants indoors? How is there a disconnection between inside a classroom and the outdoors? How do you feel when you are playing in a park? Do you feel that way while in the classroom? How do plants provide oxygen?* Following the specialist's presentation, studies of plants, and facilitated discussions, students will better understand how STEAM disciplines are used to bring plants into the built environment.

Part II: Development of a Planting Plan

After students complete their collages, they then break into groups and develop a planting plan. If there is more than one green wall to create, groups may be split based on the number of installations. If there is only one green wall, the students participate in a design competition. All learners are encouraged to consider the characteristics of plants, to employ pertinent mathematical/geometrical concepts for pattern-making, and to collaborate in a creative process throughout all stages of the project.

The initial step for teams is to establish a design concept or theme that they intend to abstract in the pattern of the planting plan (the theme could be, for example, a process such as the flow of water, or a form such as the shape of a leaf). After they have arrived at a concept, the next step is to reconcile that theme within the limitations of a grid pattern, utilizing colored sheets of paper on a white board grid that is a reduced-scale version of the entire green wall (Supplementary Figure 3). This scale-model "mock-up" of the wall is readily manipulable, allowing team members to rearrange the pattern until the team achieves a consensus pattern that successfully abstracts the theme. This exercise employs three essential design-engineering processes: the translation of abstract concept to physical pattern, collaborative decision-making, and iterative design, during which the students consider alternative solutions.

Once Part II is completed, students will have engaged in conceptual thinking, developed a basic understanding of plant biology and geometrical pattern-making, and worked in collaboration to create a unique planting plan. Students will further understand how this same design process can be utilized to accomplish projects in other real-world scenarios.

Part III: Fabrication of Living Walls and Plant Installation

Part three of the workshop, students may begin the formal fabrication the green wall(s) and subsequent plant installation. Some participating schools may not have the resources or requisite student skill sets to allow for the fabrication process to occur in the classroom. Alternatively, a carpenter, a skilled volunteer, or a living wall specialist could prefabricate the green wall(s), and the students begin their work with the installation of the plants that are represented in their respective planting plans. For schools that participate in the fabrication process, students engage in all construction stages and processes appropriate to their abilities, with guidance by the green wall specialist. Students may be engaged with all construction stages, from fastening the frame to the backing board to installing the unique planters specific to the respective workshop in preparation of plant installation (Supplementary Figure 4).

For the fabrication process, students are typically separated into teams that undertake particular tasks. During each step, students may discover construction challenges, such as ensuring the frame is square, securing and fastening the frame members, aligning the planters correctly, and physically attaching the green wall planters to the frame properly. These potential challenges often inspire discussion for collaborative problem-solving.

Once the frames of the green wall units are complete, the installation of plants begins, with the consensus pattern developed during the Part II exercise serving as the design template. The installation follows a pattern, but also includes crucial construction "detailing" that ensures the viability of the living system. Students must take care that the plants are installed with sufficient soil and that the plants are stabilized within the soil medium (Supplementary Figure 5). During the process, students are encouraged to occasionally break and review their progress to determine whether the green wall is being planted in accordance with their conceptual planting plan, or whether any modifications to the pattern might be desirable as the true-scale design comes into being. Once the students complete the plant installation, they assist with the clean up and preparation for the green wall(s) to be installed in their respective location(s).

Once Part III is completed, students will have learned about living wall fabrication processes, and will understand the relationship between the two-dimensional design plan (Part II) and the finished installation.

Part IV: Living Wall Maintenance Training and Recurring Activities

Because green walls feature living plants, all installations require on-going plant care, watering, and maintenance of aesthetic qualities. To ensure the living walls thrive, students are encouraged to attend to each wall on a weekly basis as part of their art or science class, along with oversight by a committed community volunteer or green wall specialist. Students may apply critical thinking skills to individualize the care of each plant and identify when a plant is stressed. Through instructional oversight, students are provided with an introduction to plant care. Learners have hands-on experience to determine when a plant requires pruning, has too little or too much water, is infested with a pest that needs to be eradicated, or if the plant needs to be replaced. These recurring maintenance activities affords students the opportunity to continue their collaborative interactions as well as take responsibility for something meaningful, beyond what is offered by traditional classroom work (Ruiz-Gallardo et al., 2013).

OTHER LEARNING OPPORTUNITIES WITH THE LIVING WALL PROGRAM

Throughout the entirety of the program, students are provided with an understanding of nature's role in STEAM fields through presentation and project-based learning opportunities. The students use concepts of science through methods of understanding plant biology, capillary action, and plant care. The engineered plant container for the green wall (created by computer-aided drafting technology and 3-D printing) highlights for students some of the key technologies that underlie the green wall system. Engineering principles are emphasized for the design process of the planters, as well as the project-based learning activities with which the students are engaged during the creative planning and fabrication of the living walls. Mathematical and geometrical concepts are critical for understanding the quantities of plants used during the design phase, the dimensional requirements of each panel, and the number of planters needed for each panel. Finally, beyond technical considerations, creative or artistic process itself is essential to the project; students are directly engaged in the conversion of abstract concepts to built, functioning artifacts.

ENSURING A SUCCESSFUL INSTALLATION

The long-term viability of the installation often depends on a volunteer supervisor who will ensure that students consistently maintain the green wall. The recurring plant care accomplished by the students under the trained supervision of a community volunteer, teacher, or a parent provides students with continued exposure to indoor nature, even during seasons when plants on the exterior may be dormant. Additionally, schools may experiment with growing certain varieties of edible plants (if sufficient lighting is available), which would enlarge the green wall concept to include potential for "vertical" indoor agriculture.

Most green walls in non-school institutional or commercial settings rely on maintenance by an outsourced Plantscape company, or by in-house trained horticultural technicians, which constitutes a significant ongoing expense. For schools, the authors propose that maintenance by students, staff or volunteers can obviate the involvement of outside agents, and that schools can seek funding for any ongoing or intermittent expenses through minor grants, artist-in-residency fees, or even through crowd-sourced funding. These strategies were essential to the implementation of the three pilot school projects mentioned in this paper.

CONCLUSION AND FUTURE DIRECTION

Using STEAM inspired project-based learning in this curriculum, students are provided with interactive and passive exposure to nature. This classroom model is a potential solution to reduce the effects of directed attention fatigue and improve student behavior by bringing nature indoors; at the same time, it affords students the opportunity to enhance their understanding of green technologies, build cooperative social skills, and develop design-process abilities by translating abstract concepts into built form—all of which is accomplished through directed, active-mode, project-based-learning. This active approach to learning has been associated with improved academic achievement within STEAM fields (Freeman et al., 2014). The students' initiation with these technologies and processes at the elementary school level could potentially lead to their involvement in more sophisticated applications of green technologies in subsequent education levels, or perhaps inspire their interest in educational specialization within STEAM programs beyond high school.

Ongoing research and development of green wall systems will provide additional opportunities for incorporation of these technologies within classrooms, as environmental enhancement and as opportunity for other project-based learning models. Future research is needed to better understand and measure the effectiveness project-based green wall programs on student learning and well-being, at various educational levels.

AUTHOR CONTRIBUTIONS

MBM was involved in curriculum design, education outreach, classroom pilot implementation, and manuscript writing. MS was involved in curriculum design and manuscript writing. MDM was involved with curriculum design and manuscript writing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.00619/full#supplementary-material

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Impacts of Outdoor Environmental Education on Teacher Reports of Attention, Behavior, and Learning Outcomes for Students With Emotional, Cognitive, and Behavioral Disabilities

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There are over 4 million students with reported emotional, cognitive, and behavioral disabilities (ECBD) in the United States. Teachers most frequently situate instruction inside, however, outdoor environmental education (EE) can improve academic and affective outcomes for many students, including students with ECBD. In North Carolina, U.S.A., an EE program utilizes outdoor science instruction for fifth-grade students. The program takes place over four to 10 full-school days across the year, and instruction occurs in both schoolyards and natural areas. The program aligns outdoor EE with state and national science education standards. Using a quasi-experimental design, the present study examined the impacts of the program on indicators of ECBD (e.g., student behavior, attention span), science efficacy, nature of science, and academic achievement for students with ECBD. We measured these factors using online surveys from both students identified with ECBD and their classroom teachers, as well as students with ECBD from matched control schools and their respective teachers. Students in both treatment (n = 99) and control (n = 62) classrooms took the survey two times over the school year. Quantitative data revealed teachers perceived students had significantly improved attention spans and decreased disruptive behaviors when learning outdoors. Students in the treatment group maintained measures of nature of science, science efficacy and science grades, keeping in line with their peers in the control group. We supplemented survey data with teacher interview data about their impressions of the outdoor program and the experiences of their students identified with ECBD. Teacher interview responses supported quantitative findings. These findings indicate that outdoor EE has the potential to be at least as effective a method for science instruction as classroom teaching, and in the case of addressing indicators of ECBD, outdoor EE may be a successful strategy for student learning.

Keywords: environmental education, attention, behavior, classroom, schoolyard, learning impairment, disability

INTRODUCTION

Throughout the United States, there are 4 million public school students (i.e., 18 and under) identified with emotional, cognitive, and behavioral disabilities (ECBD) (National Center for Education Statistics, 2017). The phrasing "emotional/behavioral/learning disability" under the Individuals with Disabilities Education Act (IDEA) (108th Congress, 2004) includes students with a variety of emotional, behavioral, and cognitive impairments-such as Attention Deficit Hyperactivity Disorder (ADHD), autism, and dyslexia. While the number of students identified as ECBD in the United States has been on the rise since the 1970s (National Center for Education Statistics, 2017), there have been variable efforts among states and school districts, both in terms of funding and training, to better assist these students (Baker et al., 2012, 2017; Alexander et al., 2015). However, these students consistently lag behind their non-ECBD peers academically (Cawley et al., 2002). This points to the need for creative ways to assist students who have been identified with emotional, behavioral, or cognitive disabilities, through reducing ECBD students' challenges and increasing learning outcomes.

One such creative way to reduce ECBD students' challenges to learning includes time in the outdoors. Benefits of outdoor experiences have been explored most deeply in research on students with ADHD. Kuo and Faber Taylor, in particular, have researched this topic and have found green space to be highly beneficial for students identified with ADHD (Kuo and Faber Taylor, 2004; Faber Taylor and Kuo, 2011). In a 2004 nationwide study that collected parent ratings of their children's experiences in green outdoor settings, researchers found that playing in green spaces significantly reduced symptoms of ADHD for youth of all income levels, locations, and community types (Kuo and Faber Taylor, 2004). In a similar study, Faber Taylor and Kuo (2011) also found that for children with Attention Deficit Disorder (ADD) and/or ADHD, their attention spans improved when they participated in routine play (i.e., majority of days in the week) in green spaces. Furthermore, playing in open green spaces (e.g., fields) was more successful in reducing hyperactivity for students with ADHD than playing indoors or in built outdoor environments. Other researchers have found similar effects: green space near homes and schools is associated with improved concentration, better attention, and less hyperactivity among children (Wells, 2000; Mårtensson et al., 2009; Van den Berg and van den Berg, 2011; Amoly et al., 2014; Flouri et al., 2014; Markevych et al., 2014; Kuo et al., 2018). Other research has revealed the benefits of the outdoors for individuals with other forms of EBCD. For instance, Farnham and Mutrie (2003) found that outdoor education significantly reduced anxiety and improved trust and group cohesion for a range of students with mild to moderate learning disabilities. Similarly, Melber and Brown (2008) reported on the benefits of informal education for students who receive special education services, ranging from learning disabilities to motor impairment. Melber (2004) emphasizes that science taught with hands-on, inquiry practices such as in the schoolyard, are especially accessible to students with disabilities.

Environmental education (EE) may be a particularly promising strategy for helping ECBD students, as it has potential to combine time outdoors with instructional practices shown to be effective with ECBD students. The United States' EPA (2018) defines environmental education (EE) as "a process that allows individuals to explore environmental issues, engage in problem solving, and take action to improve the environment" (para 1). EE is characterized by being inquiry-based, hands-on, experiential, and often, outdoors (Hanna, 1995; Crawford, 2000; Haney et al., 2007; Peterson, 2011; Ruiz-Gallardo et al., 2013; Zint et al., 2014)-which are all strategies that have been found to boost attitudes and learning among students with ECBD. In particular, the inquiry-based aspects of EE programming has been shown to improve learning outcomes for students with ECBD (Aydeniz et al., 2012; Kaldenberg et al., 2015). EE programs for children can range from a single lesson in school to residential-weeklong experiences; they can even span the entire school year (North American Association for Environmental Education, 2010). Because of this variety of both program type and length, EE is uniquely situated to be flexibly integrated into education to increase both outdoor time and hands-on, inquiry-based instruction for students in schools.

Outdoor EE that targets science instruction may be an especially effective approach for integrating EE into curriculum while decreasing indicators of ECBD. Outdoor EE can integrate well with science instruction through its authentic environment and direct interaction with the outdoors. Building on Brown et al.'s (1989) situated learning theory, students' learning can be enhanced by their engagement with topics such as ecosystems through direct interactions in the context of study (i.e., in the outdoors). Science instruction in US classrooms is rarely situated in the outdoors, despite the noted benefits in both cognitive and affective domains for students when they learn outside (Rickinson et al., 2004; Dyment, 2005; Carrier et al., 2013, 2014; Fägerstam and Blom, 2013; Rios and Brewer, 2014). Research on EE programming has found that science efficacy, science knowledge, and science achievement improve for all students after the experience (Tamir, 1991; Hiller and Kitsantas, 2014; Saribas et al., 2014; Dettweiler et al., 2015; Ardoin et al., 2017). Accordingly, outdoor EE may work to decrease indicators of ECBD (e.g., short attention spans and disruptive behaviors) as well as enhance learning, especially in science.

In our literature review, we located only two studies that have specifically examined how EE may be particularly helpful to students with ECBD. One such study focused on the effects of a garden-based learning program on students with disruptive behavior disorder in Spain. The year-long program had students working outside over half of their school hours and was purposefully hands-on and project-based. A 6-year analysis revealed that the intervention led to a significant decrease in dropout rates, a significant increase in classes passed, and an increase in overall behavior and attitude (Ruiz-Gallardo et al., 2013). In a study by Moore et al. (2016), experienced EE practitioners took a class of students on an experiential nature hike where they used technology to engage with the outdoors. Researchers conducted additional interviews and observations of two students with ADHD. The study revealed that the students with ADHD had positive, enriching learning experiences; teachers noted these students had greatly improved their participation when compared to their participation in the traditional classroom. Additionally, these students, who typically fell behind in academic achievement, scored as well as their peers on the environmental knowledge assessment after the program. While these studies reveal a possible connection between outdoor EE and improved learning and behavioral outcomes, neither involved a control group.

As few studies exist investigating the potential benefits of outdoor EE on students with ECBD and none include a control group, the purpose of this study was to examine the impacts of an outdoor environmental education program on students with ECBD, utilizing a quasi-experimental design. Specifically, we tested the impacts of an outdoor-and science-based EE program on both ECBD students' challenges to learning (behavior, attention span) and learning outcomes (science efficacy, nature of science, science academic achievement) during the 2016–2017 school year. We hypothesized that for students identified with ECBD, their participation in an EE program would: (1) result in teachers reporting longer attention spans and fewer disruptive behaviors in a classroom setting compared to a control group; (2) result in teachers reporting longer attention spans and fewer disruptive behaviors outdoors when compared to their attention and behavior in a classroom setting; and (3) increase learning outcomes (i.e., nature of science, science efficacy, and science academic achievement) for students in the treatment group as compared to a control group.

METHODS

Sampling

Our sample consisted of 161 fifth-grade students with ECBD in North Carolina, U.S.A. Students ages ranged from 9 to 12 years old, with a median age of 10 years old. We focused on fifth-grade students, since they are in the late stages of middle childhood (ages 6–12) and approaching adolescence (ages 12–18)-a critical period for developing ethical and ecological knowledge necessary for influencing environmental education outcomes, such as environmental engagement (Kellert, 1985). We sampled in two stages: teachers, then, students. Treatment group teachers were recruited through an environmental education program in the southeastern U.S. (28 teachers, 99 students). Control group teachers were randomly selected from a list of matched control schools in the same geographic area. Schools were matched by percent of free-reduced lunch, percent of students that were white, location (e.g., in the same district or an adjacent district), and by charter or traditional distinction. We then created a sample frame of schools associated with those matched schools and invited a random subset of teachers from those schools to participate. We contacted 263 teachers, and 63 teachers agreed to participate as control, representing a 24% response rate. As we contacted these teachers a few months in advance of the study, a subset dropped out of the study prior to the pretest due to switching grade levels, moving schools, retiring, or other reasons. Forty-two teachers participated in the pretest as a control. Teachers in both treatment and control groups were asked about students whose Individual Education Plans identify them as ECBD, and we included those students in this study. As we only included classes with teachers that that had identified students with ECBD, we had usable data from 14 teachers (associated with 62 students) in the control group and 28 teachers (associated with 99 students) in the treatment group. Although self-selection bias may exist among teachers, students should not be affected as students are assigned to teachers regardless of their environmental interests or attention and behavior. In order to establish that our sample was representative of the general student population in North Carolina, we compared our final sample of students ($n = 112$) with the North Carolina population of students with Individual Education Plans as a whole using z-tests for proportions of gender (i.e., male vs. female) and a binary indicator of ethnicity (i.e., white vs. non-white). We found no significant differences ($p = 0.55$ and $p = 0.54$, respectively) (Russell, 2016). Of our sample, 33% students were female, 50% identified as non-Hispanic white, 11% as black, 4% as Hispanic/Latino, 2% as Asian/Pacific Islander, 13% as Native American, 16% as other, and 5% identified with two or more races. There were no differences in distributions of gender, race, or socioeconomic status across treatment and control groups (**Table 1**). All students whose parents provided consent were included in the study.

Treatment

This study was part of a larger program evaluation for an environmental education program in the southeastern U.S.A. The EE program that took place over the course of the 2016–2017 school year focuses on experiential, outdoor science learning, environmental literacy, and connection to the natural world. Schools participate in the program 4 to 10 full school days throughout the school year with an average of six lessons spread across the school year (e.g., one per month). The program took place both in the schoolyard and nearby natural areas, like state parks. Assuming teachers followed state guidelines, students also received indoor instructional time on each of the related state standard topics for approximately four, 1-h weekly sessions, which last 4–6 weeks for each of the science standard's unit of study.

TABLE 1 | Demographic comparison of treatment and control groups.

	Treatment	Control	*p*-value
GENDER			
Male	71.2% (57)	56.3% (18)	0.935
Female	28.8% (23)	43.7% (14)	
RACE			
White	51.3% (41)	46.9% (15)	0.400
Non-white	48.8% (39)	53.1% (17)	
ATTEND TITLE I			
Yes	85.0% (68)	93.7% (30)	0.895
No	15.0% (12)	6.3% (2)	

Percentage of total students reported with actual number of students in parentheses. Two-sample t-test results reported.

The EE program targets fifth-grade students and centers on essential state science standards for this grade level. The first lesson in the EE program is an introduction to outdoor learning. This introductory day highlights skills and safety procedures for outdoor learning, scientific tools and uses (e.g., compass, hand lens), and science practices. Subsequent lessons highlight North Carolina's science standards that address the following topics: terrestrial and aquatic ecosystems; weather; ecosystem interactions; forces and motion; inheritances and adaptation; living systems; and matter and energy (Department of Public Instruction, 2015). Teachers choose from these topics to correspond with their scheduled science program to best supplement classroom instruction. The lessons last 4–6 h and typically involve a hike, a hands-on science experiment, science journaling, nature exploration, and group reflection. Students are split into small groups (maximum 12 students) for each lesson, which are supervised by a chaperone (e.g., parent/guardian, teacher, principal) and taught by the EE program instructor. The EE program instructors are all trained in hands-on, inquiry-based techniques and standards-based science content. Classroom teachers typically rotate between small groups within or between lessons.

Data Collection

Teachers administered online surveys in school during fall 2016 and the winter and spring of 2017. We provided each teacher with a survey protocol that they were asked to follow. This protocol had a script for providing instructions to students, information on helping students, and details on accessing and taking their own survey. In addition to surveys, we interviewed teachers to provide a rich picture of the students' EE experiences during the program. We measured students' science efficacy and the nature of science through a 14-item student survey (**Table 2**), which drew on the S-STEM (Unfried et al., 2015) and NOSI-E (Peoples et al., 2013) instruments, respectively. Scales were edited to facilitate a shorter instrument and to better align with the EE program goals. We pilot tested the full evaluation in spring 2016 with 609 students and 31 teachers. Both scales were valid and reliable (**Table 2**).

Teachers reported on student behavior, attention span, and academic achievement in science through teacher surveys administered before and after the EE program. To compare data over time while maintaining anonymity, all students were given teacher-generated, anonymous ID numbers. Teachers then utilized these ID numbers when filling out their surveys. We asked all teachers to rate each student's attention span and disruptive behavior in their classroom at the beginning and end of the study period (before and after enrollment in the outdoor EE program for treatment teachers, respectively). In addition, we asked treatment teachers to rate each student's attention and disruptive behavior for the outdoor EE program, including their expectations of student attention and behavior in the program (pre-test) and observed attention and behavior in the program by the end of the year (post-test). Teachers characterized students' attention spans on each survey in a range from short (1) to long (5); and disruptive behaviors from frequent problems (1) to none (5). This method of rating student attention and behavior is common practice in elementary school classrooms—especially for required documentation for ECBD student records (Finn, 1993; Friend and Bursuck, 2002)—and has been used in numerous similar studies (Doucette, 2004; Kam et al., 2004; Kuo and Faber Taylor, 2004; McFarland et al., 2013; Amoly et al., 2014). We also asked teachers to report science achievement as traditional grades (e.g., A to F). Although rating this method likely allowed for variance among teachers (i.e., different teachers may assess the same student differently), our analysis focused on changes over time, which relied on the same teachers assessing the same students over the course of the year. Teacher data were checked for errors (e.g., reverse coding, non-numerical) by two independent researchers and cross-referenced with the teacher, if necessary.

To gain further information on teachers' impressions of the EE outdoor program and experiences for students in the program, we interviewed eight teachers who agreed to follow-up interviews in summer 2017. We recorded, transcribed, and coded teacher interviews to document their impressions of the outdoor EE program and its impact on their students, including students with ECBD, to enhance our understanding of the program experience for these students. Aliases were given to all teachers for the analysis and interpretation.

Data Analysis

We analyzed our data using Stata software, version 14.2. We relied on paired *t*-tests to compare changes over time within the treatment group and ANCOVA (analysis of covariance) between the treatment and control group, respectively. We used these tests because they allowed for a direct comparison of individual students between their pre- and post-tests. As each student was compared against him-or herself, students not taking either the pre- or post-test due to school absences on the day teachers administered the surveys were not included in the analysis. Because of this, our final sample comprised 112 students, 80 treatment students and 32 control students. We compared students taking only the pre- or post-test to the rest of the sample and found no differences in terms of outcome variables.

We originally included a covariate for both taking students outside and amount of time spent outside during the school year (apart from the treatment associated with this study). Fifty percent of control and 71% of treatment teachers reported that they took students outside during the school year. Both control and treatment teachers had similar rates of taking students outside (14 days per year and 12 days per year, respectively). As there was no relationship between these indicators of time spent outside during the school year and learning outcomes (attention, science achievement, etc.), we omitted this in the final analysis of our results.

RESULTS

Quantitative Data

Prior to attending the outdoor EE program, teachers reported moderate attention spans ($M = 3.65$, SD $= 1.19$) and low levels of disruptive behavior ($M = 4.25$, SD 1.10) for their

TABLE 2 | Item-level statistics for science efficacy and nature of science scales among students identified as ECBD ($n = 112$).

Item Wording	Mean	SD	Cronbach's alpha	Factor loadings
Science efficacy			0.83	
I feel good about myself when I do science	3.99	0.84	0.80	0.77
I might choose a career in science	3.04	1.18	0.81	0.68
I like learning about science	4.07	0.92	0.80	0.73
I think about science when I'm not at school	3.23	1.27	0.81	0.68
Science is one of my favorite subjects	3.73	1.24	0.81	0.71
In the future, I will be able to do more advanced science work	3.52	1.22	0.81	0.70
I talk to my family or friends outside of school about what I've learned about science	3.30	1.22	0.80	0.69
Nature of science			0.76	
A good way to know if something is true is to do an experiment	3.88	1.01	0.75	0.50
Experiments are used to see what happens in nature	3.88	0.84	0.72	0.64
Science helps answer questions about how something works	4.13	0.84	0.71	0.72
Scientists use what they found in the past to help explain their new findings	3.94	0.93	0.72	0.70
Conclusions can change when new evidence is found	3.85	0.92	0.70	0.75
Scientists create different types of experiments to answer their questions	4.16	0.79	0.71	0.71
If we do the same experiment many times, we may get different results	3.74	0.95	0.76	0.45

All items were coded from 1 (strongly disagree) to 5 (strongly agree). Scale-level Cronbach's alpha displayed in first row, and item-level alpha measures represent the resulting alpha, if the item were removed. Factor loadings calculated through principle component analysis and verimax rotation.

students in the classroom, as well as moderately high science grades ($M = 76.5\%$, $SD = 12.70$). Among the treatment group, teachers expected shorter attention spans ($M = 1.94$, $SD = 2.29$) and more disruptive behaviors ($M = 1.81$, $SD = 2.13$) when students were learning outside. Student responses on the pre-test indicated relatively high levels of science efficacy ($M = 24.90$ out of 35, SD 5.98) and understanding of the nature of science ($M = 27.57$, $SD = 4.02$). We found acceptable levels of reliability and validity for both the science efficacy and nature of science scales (**Table 2**). We also note that there were no significant differences in pre-test scores for all student-reported variables (science efficacy and nature of science) between treatment and control groups. However, teachers reported higher levels on every measure for the treatment group vs. the control group on the pre-test scores (attention: mean difference = 0.78, $t = 3.08$, $p = 0.003$; behavior: mean difference = 0.62, $t = 2.56$, $p = 0.01$; science grades: mean difference = 7.53, $t = 2.88$, $p = 0.005$). This may reflect a difference among teachers in appraisal of their students. However, our analysis related to hypothesis testing compared within group changes, with the same teachers assessing the same students at the time of the pre- and post-test, which should mitigate any challenges comparing treatment and control groups.

We found support for hypotheses two, but not hypothesis one, as there were no differences in changes in teacher reports of classroom attention and behavior when comparing treatment and control groups [attention: $F_{(1, 94)} = 0.20, p = 0.653$; behavior: $F_{(1, 94)} = 0.04$, $p = 0.845$]; however, teacher reports of students' attention and behavior levels when in the outdoor EE program improved over the course of the EE program to exceed classroom levels. Teacher reports of classroom attention and behavior remained stable for both the treatment and control groups, as there were no significant differences in pre- and post-scores for either measure in either group. However, among the treatment group, we found that teacher reports for both attention and behavior significantly improved for the outdoor EE program (**Figure 1**). Although prior to seeing students in the EE program teachers expected relatively short attention spans ($M = 1.81$ out of 5, $SD = 2.13$) and frequent disruptive behaviors ($M = 1.94$ out of 5, $SD = 2.29$) outdoors, their appraisal of these measures was significantly higher (i.e., longer attention spans, improved behavior) at the end of the study period (attention: pre/post mean difference = 2.48, $t = 5.70$, $p = 0.000$; behavior: pre/post mean difference = 2.55, $t = 5.50$, $p = 0.000$). Further, both of these measures exceeded similar classroom levels at the time of the post-test in the treatment group (attention: outdoor/indoor mean difference = 0.54, $t = 5.23$, $p = 0.000$; behavior: outdoor/indoor mean difference = 0.25, $t = 2.95$, $p = 0.002$).

We found partial support for hypothesis three that the outdoor EE program significantly increased learning outcomes for students. Science efficacy and science grades remained the same over the study period for students in both the treatment and control groups (**Figure 2**). The nature of science significantly increased for students in the treatment group, while the understanding of nature of science for students in the control group stayed the same (treatment: pre/post mean difference = 0.90, $t = 1.85$, $p = 0.034$; control = pre/post mean difference = −0.22, $t = -0.27$, $p = 0.605$). However, ANCOVA results detected no differences between treatment and control groups across any measure. Students with IEPs did not make significant gains in nature of science scores [$F_{(1, 111)} = 0.14$, $p = 0.710$] nor in teacher-reported academic achievement in science [$F_{(1, 96)} = 1.58$, $p = 0.214$].

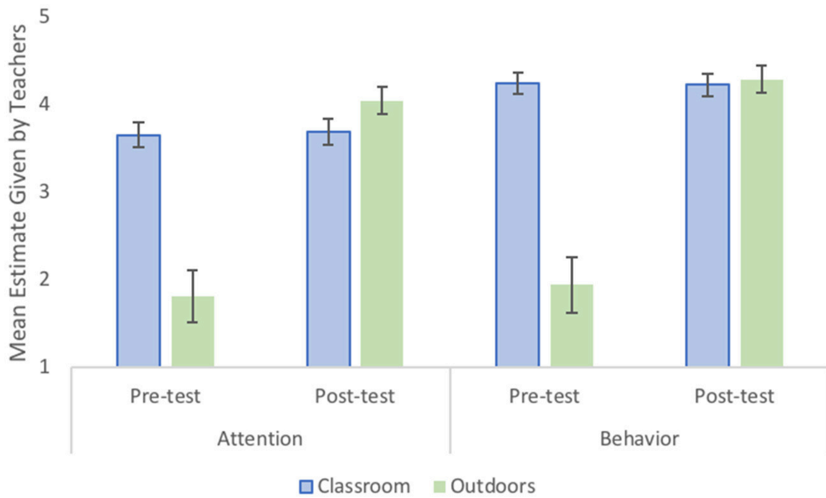

FIGURE 1 | Classroom and outdoor attention behavior among the treatment group. Teachers provided estimates of attention span and behavior levels from short (1) to long (5) and poor (1) to excellent (5), respectively. Error bars represent standard error. Paired *t*-tests indicate that differences between the teacher-reported pre- and post-test scores for attention and behavior while outdoors were significant (attention: $t = -5.70$, $p = 0.000$; behavior: $t = -5.50$, $p = 0.000$) as well as differences between the post-test scores in the classroom vs. outdoor settings (attention: $t = -5.23$, $p = 0.000$; behavior: $t = -295$, $p = 0.003$).

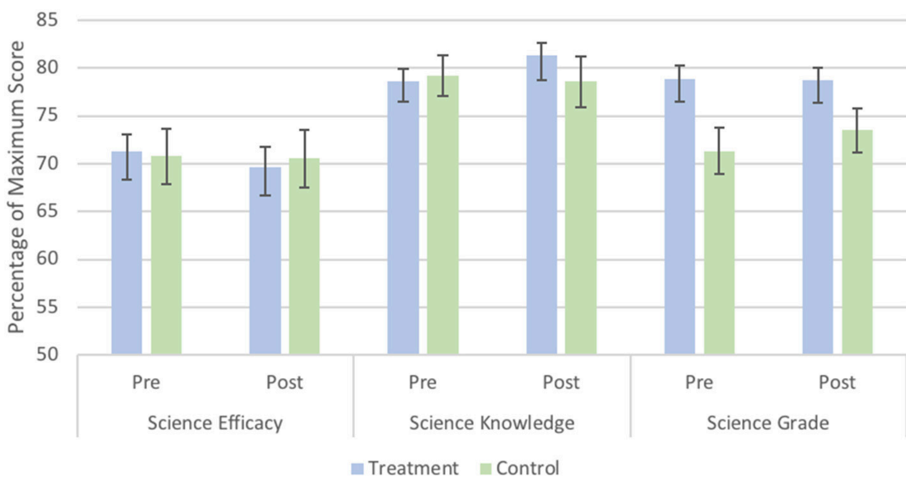

FIGURE 2 | Change in science efficacy, nature of science, and science grades among treatment and control groups. All measures are represented by percentages of the maximum score. Error bars represent standard errors.

Qualitative Data

Interview data about teachers' impressions of the outdoor EE program and experiences of their students with ECBD during the program are shown in **Table 3**. An overall theme that emerged from one teacher interview (Bailey) was the "value of getting kids outside more." Another teacher (Davis) elaborated saying, "Children just don't go outside anymore. My personal favorite thing is getting them outside and exposing them to doing something outside." In line with hypothesis two—participation in the outdoor EE program significantly decreases challenges to learning (i.e., disruptive behaviors and short attention span)—teachers saw students with ECBD become more engaged when learning outside: "They (students with ECBD) were attentive and fully interacted with the activities. They felt they were successful which does not happen much in the regular classroom." Negative cases emerged as well. Some teachers reported obstacles to outdoor learning with the weather such as when was rainy or cold. Taylor described students' distress when they were asked to spend outdoor time writing in their journals rather than moving and exploring. When asked what part of the environmental education program students disliked, Taylor described students' initial complaints about physical activity that they clearly overcame. "The first couple of times when we were having to do all that walking...not being able to sit in front of something with a screen. They're used to passive learning but by the fourth time they were sad and crying that it's

TABLE 3 | Emergent themes from interviews with teachers.

Teacher	Theme-Outdoors	Theme-ECBD students
Jessie	You don't have to go really far away, just use what you have. Use what's in our backyard…using the plants around you.	Even (Students who) are really rough and tough, you would find them out there playing with leaves and you know, just enjoying it. (In describing reluctant student) She's not an outdoorsy type person, but she just embraced it and enjoyed it when she gave it a trial.
Bailey	(in the outdoors) you can intertwine living systems, genetics, and body systems…weather, terrestrial ecosystems, and then we always do aquatic ecosystems.	(ECBD students) so unique, full of energy and unique. They have their own way of looking at the world, and when they got in that creek, it was just one of the happiest moments. I mean they're all picking up rocks and looking at them and so excited. They were just loving it…you never know what lessons that they connect to …definitely activities that connect well to different identities and groups. (Instructors) work really hard to connect with each group. Seems to be the easiest curriculum to teach. There's no science anxiety like you hear about reading or math anxiety.
Casey	Just to appreciate and understand what's going on outside…I mean I love that part of it.	They make it a little not so scary for (ECBD students) who really don't like (classroom) science. I think they make it at least more fun and more interesting and engaging, and not so frightening.
Davis	(Strongest features) integration of the science curriculum with the forest.	They (ECBD) were attentive and fully interacted with the activities. They felt they were successful which does not happen much in the regular classroom

over," thus emphasizing the impact of repeated, science-aligned experiences.

DISCUSSION

The present study adds to the literature on the impact of outdoor environmental education on students with ECBD utilizing a quasi-experimental, mixed methods design. Although past literature has supported a possible connection between outdoor EE and improved outcomes, in this study, we employed control groups to determine the potential of repeated, science-aligned, outdoor EE programming for improving student outcomes.

Our results related to students' attention and behavior suggest that teachers of ECBD students should consider the outdoors as a useful setting to increase attention and diminish disruptive behaviors. Although teachers expected students to have difficulty paying attention and avoiding disruptive behaviors outdoors, they reported longer attention spans and less disruptive behaviors outdoors for these students by the end of the year. We offer three possible explanations. First, teachers may have expected short attention spans and disruptive behaviors outdoors prior to the program and were pleasantly surprised from the first day outside onward. Secondly, teachers' perceptions of the behaviors themselves could have changed so that behaviors they previously considered disruptive (i.e., interrupting an instructor with a question) were considered as acceptable or indicative of high engagement. These two explanations are plausible in the context of prior research reporting that few teachers perceive the outdoors as an acceptable location for formal instruction beyond the preschool years (Ernst and Tornabene, 2012) and teachers in both United States and in the United Kingdom have concerns about student behavior and classroom management when teaching outdoors (Fox and Avramidis, 2003; Ernst, 2009). However, it is possible that teachers' expectations at the beginning of the study period aligned with actual student attention and behavior, and both measures did actually improve over the course of the outdoor sessions with more exposure to outdoor EE. This third explanation aligns with past research on the effects of green space on students with ECBD, which suggests that time outdoors can improve attention and reduce hyperactivity (Ruiz-Gallardo et al., 2013; Amoly et al., 2014; Flouri et al., 2014; Moore et al., 2016; Kuo et al., 2018). Our qualitative results show some evidence of each of these explanations, as some teachers expressed surprise at how engaged ECBD students were outdoors; others seemed to transform how they viewed behavior as appropriate or not; and others reported changes in the students themselves. Although teacher perceptions may have shifted rather than actual student attention and behavior, this perception shift is beneficial. Teacher perceptions can influence academic achievement well-into a student's future (Alvidrez and Weinstein, 1999; Sorhagen, 2013; Baker et al., 2015), and a shift in perceptions around student attention and behavior outdoors may reduce any apprehensions around outdoor instruction. We did not find treatment effects associated with classroom attention and behavior, but future research should continue to examine the possibility that our findings may transfer to impacts in the classroom. As recent research finds increased classroom engagement after lessons in nature (Kuo et al., 2018), future research may find similar trends among with ECBD, particularly with a larger sample size than our study. We suggest further research that replicates this study include more objective measures of student attention and behavior to further identify ways in which outdoor instruction may relate to ECBD student attention and behavior in the outdoors and in the classroom.

In addition to addressing indicators of ECBD, teachers should consider outdoor EE a viable instructional strategy for science teaching, as it appears as least as effective in supporting science learning for students with ECBD than traditional science instruction. Elementary school teachers often feel challenged to differentiate their instruction in classrooms that include students with a range of academic and behavioral strengths, and these challenges are often exacerbated when teaching science (Southerland and Gess-Newsome, 1999; Tobin and Tippet, 2014). Opportunely, other studies have demonstrated that outdoor EE has led to gains in science knowledge for all students (Jon Schneller et al., 2015; Wells et al., 2015). In our study, those findings seem to hold true for ECBD students specifically, suggesting outdoor EE can help teachers supplement science instruction for all students using a single approach. Additionally, outdoor EE has been shown to positively impact science interest and efficacy (Mohr-schroeder et al., 2012; Hiller and Kitsantas, 2014; Dettweiler et al., 2015). As nature of science, science efficacy and science grades appeared to remain stable in both treatment and control groups, outdoor EE instruction appears just as effective for students with ECBDs as classroom instruction in maintaining these measures. Since educators may cite concerns that outdoor EE may take away from instructional time (Carrier et al., 2014), these results are particularly encouraging. Instead of taking away from instructional time, outdoor EE seems to contribute to sustaining science efficacy and performance, even at an age when interest in science tends to wane (Cheung, 2009). Although some teachers are not aware that outdoor EE is effective (Ernst, 2007), it can be as rigorous and effective as indoor instruction and has potential to improve test scores (Volk and Cheak, 2003; Danforth, 2005; State Education and Environment Roundtable (SEER), 2005; McFarland et al., 2013). Future research is needed that focuses on students with ECBD to compare their progress with that of their peers when students experience more frequent outdoor EE. Additionally, as all data were self-reported, there are potential biases both from teachers and students. The researchers attempted to lessen this bias by not disclosing the specific details of this research apart from the larger program evaluation. However, teachers' perceptions of factors beyond our control, such as the outdoors as a learning environment, could have influenced ratings of attention and behavior (Pas and Bradshaw, 2014).

We suggest future research continue to explore outdoor EE as a teaching opportunity to engage students with ECBD. There are a host of benefits for students learning in nature, from improved classroom engagement (Kuo et al., 2018) to decreasing hyperactivity and inattention (Faber Taylor and Kuo, 2011; Moore et al., 2016). The bulk of this research centers on indicators of ECBD (e.g., attention and behavior), and our results align with findings suggesting that time outdoors can mitigate these indicators. In this study, repeated outdoor, science-based EE not only appears to decrease indicators of ECBD, but it also facilitates science learning on par with classroom techniques. Previous literature suggests outdoor EE can have similar impacts on all students, and our study indicates that these findings could extend specifically to those with ECBD. As the number of students with ECBDs continues to increase, teachers need creative solutions to instruct these students. We suggest outdoor EE that is repeated throughout the school year and aligned with standards may prove an invaluable tool to enhance science instruction for all students and, specifically, to reach those identified as ECBD.

ETHICS STATEMENT

The protocol was approved as exempt from the ethics review process by the Institutional Review Board for the Protection of Human Subjects in Research of North Carolina State University (IRB Protocol #6533). We provided teachers with a choice of using an active or passive informed consent form for students and parents, in accordance with the requirements of the school districts. Active consent required parent consent and student assent signatures, while passive consent required similar signatures if students and/or parents wanted to opt out of the study. Consent was obtained from all research participants and from the parents/legal guardians by the method chosen by the teachers/schools.

AUTHOR CONTRIBUTIONS

RS was involved in study design, quantitative data acquisition, data analysis, and manuscript writing. SC was involved in qualitative data acquisition, data analysis, and manuscript writing. KS was involved in study design, quantitative data analysis, and manuscript writing.

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Might School Performance Grow on Trees? Examining the Link Between "Greenness" and Academic Achievement in Urban, High-Poverty Schools

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In the United States, schools serving urban, low-income students are among the lowest-performing academically. Previous research in relatively well-off populations has linked vegetation in schoolyards and surrounding neighborhoods to better school performance even after controlling for important confounding factors, raising the tantalizing possibility that greening might boost academic achievement. This study extended previous cross-sectional research on the "greenness"-academic achievement link to a public school district in which nine out of ten children were eligible for free lunch. In generalized linear mixed models, Light Detection and Ranging (LiDAR)-based measurements of green cover for 318 Chicago public schools predicted statistically significantly better school performance on standardized tests of math, with marginally statistically significant results for reading—even after controlling for disadvantage, an index combining poverty and minority status. Pupil/teacher ratio %bilingual, school size, and %female could not account for the greenness-performance link. Interactions between greenness and Disadvantage suggest that the greenness-academic achievement link is different for student bodies with different levels of disadvantage. To determine what forms of green cover were most strongly tied to academic achievement, tree cover was examined separately from grass and shrub cover; only tree cover predicted school performance. Further analyses examined the unique contributions of "school tree cover" (tree cover for the schoolyard and a 25 m buffer) and "neighborhood tree cover" (tree cover for the remainder of a school's attendance catchment area). School greenness predicted math achievement when neighborhood greenness was controlled for, but neighborhood greenness did not significantly predict either reading or math achievement when school greenness was taken into account. Future research should assess whether greening schoolyards boost school performance.

Keywords: geographic information systems, academic performance, greening, schoolyards, socioeconomic status, income, race, urban tree canopy assessment

INTRODUCTION

In the United States, schools serving predominantly urban, low-income populations are struggling. Sixth graders in the richest school districts are four grade levels ahead of children in the poorest districts; there are large gaps between white children and their black and Hispanic classmates; and the gaps are largest in places with large economic disparities (Reardon et al., 2017). Children who attend urban schools in low-income areas have shown the lowest academic achievement in the country for decades (Bernstein, 1992). In the absence of large-scale, structural solutions to poverty and discrimination, low-cost interventions that help disadvantaged urban children reach their potential are urgently needed.

Recent evidence points to the tantalizing possibility that planting in and around schoolyards could actually boost academic achievement. Three key preconditions for learning—ability to concentrate, manageable levels of stress, and intrinsic motivation to learn—have each been tied to green settings and views. Recent experimental work in a school setting echoes a large body of research on the restorative effects of contact with nature on both attention and stress (for reviews, see Kuo, 2015; Becker et al., 2017); views of greenery from classroom windows improve concentration and reduce both self-reported stress and heart rate, whereas classrooms without green views do not (Li and Sullivan, 2016). Along the same lines, learning in relatively green classrooms, in school gardens, and in natural contexts has been associated with high levels of student interest in numerous studies (e.g., Skinner and Chi, 2012; Alon and Tal, 2015; Lekies et al., 2015; for reviews, see Blair, 2009; Chawla, 2015). And at least one quasi-experimental study has shown teaching course material outdoors boosts students' intrinsic motivation (Bølling et al., 2018).

Given that concentration and intrinsic motivation to learn are each strong contributors to learning (Rowe and Rowe, 1992; Mantzicopoulos and Morris, 1995; Taylor et al., 2014), and given that stress appears to be an important barrier to learning (Grannis, 1992; Leppink et al., 2016), it seems possible that combining these effects simultaneously within a given student might powerfully aid that student's ability to learn. These effects might be further compounded in a context in which each student is not only more prepared to learn themselves, but is also surrounded by other students more prepared to learn. If so, we might see systematically better academic performance in children attending greener schools and living in greener surroundings.

Indeed, at least four studies have now tied measures of school and neighborhood greenness to academic performance—even after controlling for important potential confounds (Browning et al., 2018). Matsuoka (2010) found that cafeteria views of trees and shrubs correlated with graduation rates and academic merit awards in high schools across southeastern Michigan. Wu et al. (2014) reported that greenness in 250 m to 2,000 m buffers around Massachusetts public schools predicted standardized test scores. More recently, two studies have tied tree cover to test scores—Kweon et al. (2017) examined the greenness-academic achievement (G-AA) link in public elementary, middle, and high schools in Washington, D.C.; and Hodson and Sander (2017) found the G-AA link in third graders' reading scores (although not math scores) in St. Paul, MN, United States.

Does the greenness-academic achievement link extend to schools serving predominantly urban, low-income populations? Because previous G-AA research has been conducted in school districts serving relatively few disadvantaged students, it is difficult to say. Minnesota, Michigan, and Massachusetts are each well below the average percentage of students eligible for free and reduced lunch nationwide (48%, U.S. Department of Education, 2017a). The Washington D.C. study did include a substantial proportion of low-income students, with an average of 65% of students eligible for free or reduced lunch. However, nearly one-quarter of public schools serve poorer populations than does the Washington D.C. school district (Rich et al., 2016)—and academic performance drops exponentially with decreases in parental income (U.S. Department of Education, 2017b). Thus it is unclear whether the G-AA link holds in the schools where it may be most needed.

This study examined the G-AA relationship in a predominantly urban, low-income, minority school district in which 90% of students are free lunch eligible and 10% are white. Recent work in this district found no G-AA link, but employed coarse "greenness" measures, did not distinguish between different types of vegetation, and failed to consider potential interactions between green cover and student disadvantage (Browning et al., 2018). The current study addresses each of those limitations and has four aims: to examine the relationship between greenness and academic achievement in the context of disadvantage; to determine the extent to which this relationship is driven by greenness immediately around schools versus in surrounding neighborhoods; to examine the contributions of different kinds of green cover to academic achievement; and to examine the relationship between school greenness and disadvantage.

Our first aim was to examine the relationship between greenness and academic achievement in the context of disadvantage. There are reasons to expect this relationship to hold or even strengthen in low-income urban populations. Previous work in inner-city populations has shown striking benefits of residential greenery on residents, including lower levels of mental fatigue (Faber Taylor et al., 2002), more effective life functioning (Kuo and Sullivan, 2001a), better self-discipline (Faber Taylor et al., 2002), and lower levels of aggression (Kuo and Sullivan, 2001b). Further, the effects of green cover on academic achievement could be stronger in disadvantaged populations—to the extent that violence, crowding, and noise in low-income neighborhoods are likely to result in chronic mental fatigue (Kuo, 1992), the rejuvenating effects of green views and elements might be more needed and larger in children from such neighborhoods.

At the same time, there are reasons to think the greenness–academic performance relationship might be weaker in more disadvantaged schools. The more disadvantaged a school, the more likely it is to restrict or eliminate recess: high-poverty schools are over four times more likely than other schools to forego recess entirely, and schools with predominantly African American student bodies are over 2.5 times more likely to forego recess than predominantly White schools (National Center for Education Statistics [NCES], 2006). Without recess outdoors, students' experience of any greenery present is limited. As a result, even if a disadvantaged school has an adequate level of green cover, its students might not benefit. Further, there is some indication that disadvantaged schools are less likely to have adequate levels of green cover (Kweon et al., 2017).

In sum, disadvantaged schools might benefit more or less from greening than their relatively well-off counterparts. The current study asks whether the relationship between greenness and academic achievement holds in a predominantly disadvantaged population of schools—and within this population, whether the G-AA relationship is strengthened, weakened, or unaffected in the most disadvantaged schools.

The second aim of this study was to examine the unique contributions of greenness immediately around schools versus in surrounding neighborhoods to academic achievement. In two of the previous G-AA studies, the focus was on large areas extending far beyond the schoolyard: Wu et al. (2014) examined the area around a school within a radius of as much as 1.25 miles, and Hodson and Sander (2017) studied school catchment areas—the area within a school's attendance boundaries, in which its student body lives. Greenness in these large geographic units can be conceptualized as consisting of two parts—an inner, school zone which corresponds to students' experience of greenness during the school day, and an outer, neighborhood zone within which students might experience greenness outside of the school day. If students' experience of greenness during the school day plays a substantial role in academic achievement, that would be good news for school administrators, as that experience seems relatively amenable to intervention. School districts can choose to plant and maintain (or not) trees in their schoolyards with relative autonomy. In an urban landscape, a school's viewshed is not only a relatively small area but typically consists chiefly of school property and the public rights of way immediately surrounding a school—relatively little private property is involved.

The available evidence suggests that school greenness matters. Two studies have examined the impacts of school greenness on cognitive and academic outcomes. Dadvand et al. (2015) examined cognitive development among 2,600 students in 36 schools and found that children in greener schools showed more rapid cognitive development. School greenness in that study included greenness on school property and within a 50 m buffer around school boundaries; cognitive development was operationalized as children's gains in working memory and attention over the course of a year. A second study, by Kweon et al. (2017), examined greenness on school property and found that schools with more tree cover performed better on standardized tests even after multiple confounding factors were taken into account.

At a smaller scale than the schoolyard, studies on classroom views of nature suggest the importance of nature in the schoolyard. Matsuoka (2010), Benfield et al. (2015), and Li and Sullivan (2016) studied the effects of classroom views on cognitive and academic outcomes; each showed positive effects. Of these, the Li and Sullivan (2016) findings are of particular note as their use of a randomized controlled experimental design helps build the case for a cause-and-effect relationship between green views and cognitive outcomes in an educational setting. Thus, it is at least plausible that students' experience of greenness at school—the inner zone in our conceptualization—plays a substantial role in the greenness-academic achievement relationship.

To what extent does students' experience of greenness in the larger environment (the outer, neighborhood zone in our conceptualization) matter? For neighborhood schools (schools that serve the students in the surrounding neighborhood—as opposed to magnet or charter schools, which serve students district-wide), this larger landscape comprises the bulk of their students' experience of nature outside of school—at home, through the neighborhood during their commute to and from school, and in the neighborhood after school and on weekends. No studies of which we are aware have directly examined this question. Wu et al. (2014) and Hodson and Sander (2017) found that greenness in the larger landscape *including* the school environment (inner plus outer zone) predicted academic performance, but their studies do not tell us how much of this relationship is driven by school greenness (the inner zone alone), nor how much of it is driven by neighborhood greenness (the outer zone alone), nor how much neighborhood greenness might boost academic performance over and above the effects of school greenness. Dadvand et al. (2015) examined a small part of the larger landscape—the greenness around an individual student's home and on their commute to school—and found that student home greenness does not predict outcomes and commute greenness only weakly predicts outcomes. Although they did not study the impacts of the neighborhood landscape as a whole, their findings regarding these smaller pieces of the larger landscape suggest that neighborhood greenness plays a relatively unimportant role in cognitive outcomes.

To what extent do neighborhood greenness and school greenness contribute to the relationship between overall greenness and academic achievement? In this study, to determine the relative importance of neighborhood greenness and school greenness, we broke overall greenness into its constituent parts (inner and outer zones) and examined the unique contributions of each, in hopes that the results might help guide future efforts to boost academic achievement through greening. While the findings would necessarily be cross-sectional and not causal, they might suggest where greening-for-academic-achievement efforts offer the highest potential return on investment.

The third aim of this study was to examine the contributions of different kinds of green cover to academic achievement. Previously, Normalized Difference Vegetation Index (NDVI)-based work examined only "greenness" or total vegetative cover over relatively large areas and did not distinguish between different kinds of green cover. However, three studies have used measures other than NDVI. Matsuoka (2010) found that a measure of school cafeteria views of nature in which views incorporating trees and shrubs were designated as more natural than views incorporating only views of grass, positively predicted standardized test scores, graduation rates, and 4-year college plans. Further, in that same study, the percentage of lawn per landscaped area negatively predicted test scores and college plans and did not predict graduation rates. Kweon et al. (2017) found tree cover positively related to school performance in both math and reading test scores; grass/shrub cover was negatively related to achievement in some analyses and not related in others. In Hodson and Sander's (2017) study, tree canopy was positively tied to reading performance, and grass/shrub cover was not; neither tree nor grass/shrub cover was tied to math performance. Thus the previous literature would seem to suggest that grass and shrub cover do not contribute to academic achievement whereas tree cover does. In this study, the relationship of tree cover and grass/shrub cover to academic achievement were examined separately in hopes of suggesting what greening-for-academic-achievement efforts might focus on planting for the highest potential return on investment.

This study's fourth and final aim was to examine the relationship between greenness and disadvantage. Existing research on the relationships between income, race, and access to nature often reflect the general view of trees and parks as pleasant but non-essential amenities. Wealthier areas are, on average, substantially greener than their less well-off counterparts (Zhu and Zhang, 2008), and this difference is so stark that it can be seen from space[1]. In urban settings, both low-income and minority residents have been found to have less access to green cover and green spaces (e.g., Byrne and Wolch, 2009; Landry and Chakraborty, 2009; Wen et al., 2013; Rigolon et al., 2018). And to the extent that the greenness of a neighborhood is likely to be reflected in the greenness of a school situated within it, it is perhaps unsurprising that the racial/ethnic composition of schools is tied to levels of schoolyard green cover, where the percentage of white students predicts a higher level of schoolyard green cover (Kweon et al., 2017).

As green cover is increasingly tied to such important aspects of a healthy, functioning city as residents' health (Kuo, 2015; South et al., 2015; Browning and Rigolon, 2018), neighborhood crime (Kuo and Sullivan, 2001b; Troy et al., 2012; Kondo et al., 2016) and violence (Kuo and Sullivan, 2001a; Branas et al., 2011; Troy et al., 2012; Wolfe and Mennis, 2012; Kondo et al., 2015), and as green cover has been increasingly tied to academic achievement, the relationship between green cover and disadvantage is of increasing importance. In this study, we examined school and neighborhood green cover in relation to levels of disadvantage in the student bodies served.

In a school district in which nine of ten students, on average, are eligible for free lunch, we examined the relationship between greenness and school-level measures of academic achievement in 318 Chicago public schools. Six potential confounding factors were considered—students' family income, pupil/teacher ratio, total number of students, students' race/ethnicity, %bilingual, and %female—and our analyses addressed multicollinearity and spatial autocorrelation.

[1] http://billmoyers.com/2012/06/10/how-to-spot-income-inequality-from-space-count-the-trees/

MATERIALS AND METHODS

Setting and Population

This study examined public elementary schools in Chicago. Chicago Public Schools is the third largest school district in the United States and serves a predominantly low-income minority population. In the 2009–2010 time frame of this study, 87% of third graders were eligible for free lunch, and only 8.7% were White; 45% were African-American, 43% Hispanic, and 3% Asian/Pacific Islander. Twenty-six percent of third graders spoke a language other than English at home and scored "below proficient" on an English language test administered by the Illinois State Board of Education[2]. The Chicago Public Schools are a context in which academic underachievement is of pressing concern: at the time window of this study, almost 60% of its students were not meeting grade standards in reading or math on the Illinois State Board of Education's Illinois Standardized Assessment Test (ISAT)[3].

Complete data were available for 395 schools. As a central focus of this study was to compare the contributions of school greenness and neighborhood greenness, we excluded 27 schools without a schoolyard and 10 schools serving students outside their immediate neighborhood. Twenty-three catchment areas were assigned to more than one Chicago Public School; in these cases, we selected the school identified by as primary and excluded the others. An additional 15 schools were removed because they failed multivariate normality criteria in chi-square tests of squared Mahalanobis Distances and visual inspection of Quantile–Quantile plots (Tabachnick and Fidell, 2007). The final sample size was 318 schools.

Greenness Measures

Greenness was assessed for each school for two kinds of green cover and three geographic zones. Tree canopy cover and grass/shrub cover were assessed separately; because grass/shrub cover was predominantly composed of grass, we refer to it as grass cover[4]. Greenness for three different geographic zones—catchment, school, and neighborhood—was assessed separately (**Figure 1**). *Catchment* refers to the area a neighborhood school serves, defined by its attendance boundaries; thus catchment greenness refers to the percentage of green cover within the area in which a school's students live (**Figure 1A**). *Catchment* differs from the radial buffers used in Wu et al. (2014) in that it precisely captures the boundaries of the residential areas of students who attend a given school.

School refers to the zone corresponding to students' experience of nature at school. It encompasses not only any green cover on school property but also in its viewshed as captured in a 25 m buffer around the schoolyard consisting primarily of public rights of way (**Figure 1B**).

[2] Please see http://cps.edu/SchoolData/Pages/SchoolData.aspx, specifically in the Demographics section see reports on "Limited English Proficiency, Special Ed, Low Income, IEP" and "Racial/Ethnic" for school year 2009–2010.

[3] Please see http://cps.edu/SchoolData/Pages/SchoolData.aspx, especially the Assessment Reports, ISAT reports and Overall reports.

[4] http://maps.fieldmuseum.org/CRTI/MuniCanopy/Chicago/Chicago.PDF

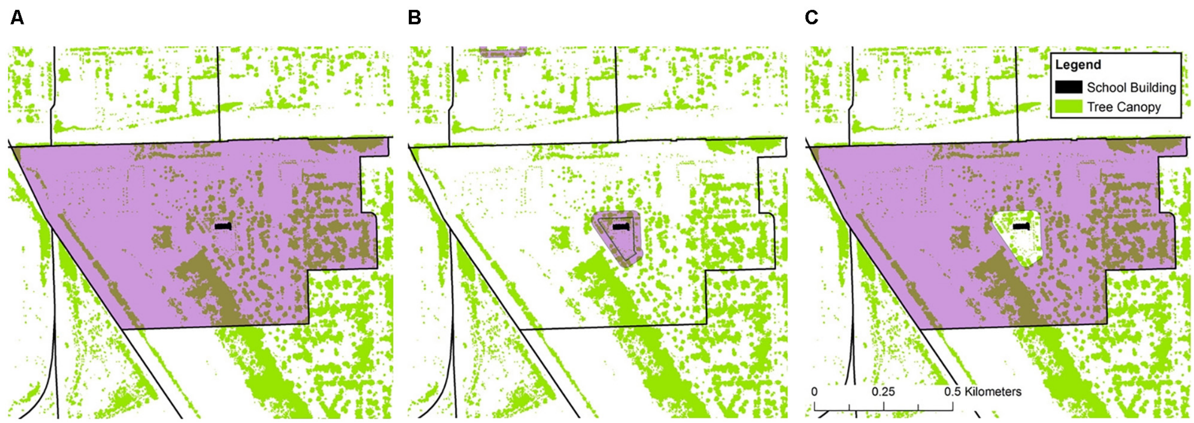

FIGURE 1 | This figure depicts the three geographic areas examined in this study: Catchment **(A)**, School **(B)**, and Neighborhood **(C)**. Catchment comprises all the area within a school's attendance boundaries and is made up of two non-overlapping components: School, which includes school property and a 25 m buffer around school property, and Neighborhood, which comprises the area inside the attendance areas but outside the school property and 25 m buffer.

Neighborhood comprises the area left over when the school area is subtracted from the catchment area—the area inside a school catchment but outside the school zone (**Figure 1C**). This area captures students' experience of nature on their way to and from school, at home, and in the neighborhood after school and on weekends, other than in the schoolyard or 25 m buffer. It should be noted that *Neighborhood* greenness does not fully represent each student's out-of-school contact with nature, in that students living near the attendance boundary are especially likely to experience nature outside of the catchment. But it does reasonably approximate the everyday contact with nature that students from a given school are likely to have in common, particularly to the extent that students living near the attendance boundary will experience neighborhood greenness on their way to and from school.

For each of these three geographic zones, each of the two types of greenness was assessed; thus greenness for each school was captured in six variables: *Catchment Trees*, *School Trees*, *Neighborhood Trees*, *Catchment Grass*, *School Grass*, and *Neighborhood Grass*.

Greenness variables were assessed by combining green cover data from the Chicago Urban Tree Canopy Assessment with information about school attendance areas and property boundaries provided by the City of Chicago. The Chicago Urban Tree Canopy Assessment (C-UTC)[5], produced by the United States Forest Service and the University of Vermont Spatial Analysis Laboratory, classifies each square meter of land across the City of Chicago into one of seven land cover classifications for the period 2009–2010, including the two used here—tree canopy and grass/shrub—as well as bare earth, water, buildings, roads, and other paved surfaces. These land cover classifications are based on remote sensing data from two sources: Light Detection and Ranging (LiDAR) data and National Agriculture Imagery Program (NAIP) data. LiDAR imagery, collected with a scanning laser instrument mounted onto a low-flying airplane, provided a snapshot of tree and grass/shrub cover (among other kinds of cover) over a 4-day period in April 2009. NAIP, administered by the United States Department of Agriculture, applies object-based image analysis techniques on aerial imagery acquired during the agricultural growing seasons in the United States to extract land cover information (for more information, see MacFaden et al., 2012).

School attendance areas and school property boundaries (based on schools' tax parcel polygons) were obtained from the City of Chicago. The City of Chicago Data Portal makes this information available for download for free[6].

By combining C-UTC's classifications of each square meter of land around schools in our sample with information on school attendance area boundaries and school property boundaries, we calculated the percentage of tree and grass/shrub 1 m^2 pixels falling within each of our three zones for each of the schools in our sample. All geospatial data processes and buffer creations were performed in ArcMap 10.4.1 (Environmental Systems Research Institute (ESRI), 2016). We calculated the percent canopy cover and percent grass/shrub cover for each polygon by isolating the pixels from the Urban Tree Canopy dataset that fell within, or overlapped with, the polygon of interest using the Tabulate Area tool.

Catchment Trees

Catchment trees was the percentage of 1 m^2 pixels falling in or on a school's attendance boundaries that were classified as tree cover in the Chicago Urban Tree Canopy dataset for 2009–2010. This variable and other greenness variables were centered (recoded, subtracting the average percent tree cover across all schools in our sample) to avoid multicollinearity (see the section "Data Analysis").

[5] http://gis.w3.uvm.edu/utc/

[6] https://data.cityofchicago.org/

School Trees

School trees was the percentage of 1 m^2 pixels falling in or on a school's property or its viewshed, operationalized as a 25 m buffer around the property classified as tree cover in the same dataset.

Neighborhood Trees

Neighborhood trees was the percentage of 1 m^2 pixels falling in or on a school's attendance boundaries and outside the school property and 25 m buffer classified as tree cover.

Catchment Grass

Catchment grass was the percentage of 1 m^2 pixels falling in or on a school's attendance boundaries classified as grass or shrub cover.

School Grass

School grass was the percentage of 1 m^2 pixels falling in or on a school's property and 25 m buffer classified as grass or shrub cover.

Neighborhood Grass

Neighborhood grass was operationalized as the percentage of 1 m^2 pixels falling in or on a school's attendance boundaries and outside the school property and 25 m buffer classified as grass or shrub cover.

School Performance and School Characteristics

Information about each school's performance and characteristics were drawn from the Chicago Public Schools open-source data portal[7]: Reading and math performance on the ISAT, percentage of students eligible for free lunch, percentage of students in different racial/ethnic groups, percentage of female students, total number of students, and pupil/teacher ratio. To align with our geospatial data, data were drawn for academic year 2009–2010.

School Performance (Academic Achievement)

School-level academic achievement was operationalized as the percentage of third graders at a school meeting or exceeding expectations in reading and math on the ISAT given in March 2010. While standardized tests have their limitations, they provide a consistent metric for comparing academic achievement across schools, unlike grades, which reflect variation in grading practices from school to school. The ISAT is an assessment developed by the Illinois State Board of Education in coordination with its test development partners. At the time these data were collected, ISAT performance was an important metric at both the student-level and the school-level, playing an important role in decisions of whether a student would be held back a grade, on the one hand (Chicago Public Schools Policy Manual, 2009), and decisions of how much Title I federal funding a school might receive, on the other (van der Klaauw, 2008). Third-grade standardized test performance predicts future outcomes such as high school graduation and college enrollment (Lesnick et al., 2010) and has been used in previous G-AA studies (Wu et al., 2014; Hodson and Sander, 2017).

[7] http://cps.edu/SchoolData/Pages/SchoolData.aspx

Reading performance

Reading performance refers to a school's performance on the ISAT reading test for school year 2009–2010—specifically, the percentage of third-grade students who met or exceeded the third-grade standard on that test.

Math performance

Math performance refers to a school's performance on the ISAT mathematics test for school year 2009–2010—specifically, the percentage of third-grade students who met or exceeded the third-grade standard on that test.

Covariates

A number of school characteristics previously found to predict academic achievement were included.

Disadvantage

Socioeconomic status and race/ethnicity are each strong predictors of academic achievement. Although neither poverty nor race is destiny, sixth graders in the richest school districts are four grade levels ahead of children in the poorest districts; the average test scores of black students are, on average, roughly two grade levels lower than those of white students in the same district; and the Hispanic-white difference is roughly one-and-a-half grade levels (Reardon et al., 2017). At the school level, income and race/ethnicity are often so strongly associated that including both factors independently and simultaneously in models will risk violating the assumptions of regression due to multicollinearity.

The high correlations between income and race/ethnicity have posed a methodological conundrum for G-AA research which different studies have approached in different ways. Studies by Hodson and Sander's (2017) and Kweon et al. (2017) avoided multicollinearity by including only socio-economic status and not race/ethnicity in their regression models. Unfortunately, although income disparities contribute substantially to race differences in academic achievement, race remains a significant source of disadvantage even after income has been taken into account (Bohrnstedt et al., 2015; Reardon et al., 2017). Because race/ethnicity is tied to greenness (Landry and Chakraborty, 2009; Wen et al., 2013; Rigolon et al., 2018) as well as academic achievement (Bohrnstedt et al., 2015; Reardon et al., 2017), leaving race out of greenness-achievement models may entail failing to address a major confounding factor.

Two studies—Matsuoka (2010) and Wu et al. (2014)—included both income and race/ethnicity in their models, thereby addressing both of these potentially important confounds. However, Wu et al. (2014) did not report tests of multicollinearity and subsequent application of their model to a different dataset yielded extremely high levels of multicollinearity, with Variance Inflation Factors in the thousands (Browning et al., 2018)—much higher than even the most liberal suggested threshold of 10.0 (Field, 2014). Matsuoka (2010) reported that multicollinearity was not an issue but did not report Variance Inflation Factor values which would allow readers to assess the extent to which multicollinearity was present.

In this study, we operationalized income as the percentage of students at a school eligible for free lunch and race/ethnicity as the percentage of students identifying as other than white. Income and race/ethnicity were highly correlated (r = 0.90, p < 0.001), and preliminary analyses showed that including both variables as separate predictors in a model resulted in multicollinearity. To take both income and race/ethnicity into account while avoiding multicollinearity, we combined income and race/ethnicity into a single variable: *Disadvantage*. Combining related but different predictors into a summary index is a statistically robust and theoretically appropriate way to resolve multicollinearity while maintaining the effects of related, but different, concepts (Ahmad et al., 2006). Substituting a combined *Disadvantage* index in place of separate income and race/ethnicity variables reduced all Variance Inflation Factor values to below 3.0, which is the maximum threshold recommended by Zuur et al. (2009) (see **Supplementary Table 1.1**).

Disadvantage was the average of two variables: the percentage of students at a school who were eligible for free lunch and the percentage of students at a school not identified as White. *Disadvantage* was centered (recoded, subtracting the mean Disadvantage score) to avoid multicollinearity with the interaction term capturing the interaction between greenness measures and *Disadvantage*.

%Bilingual

%Bilingual was the percentage of all students in a school whose family spoke a language other than English at home and who scored "below proficient" on an English proficiency language test administered by the Illinois State Board of Education. On average, students who lack English proficiency perform more poorly in school than students who are monolingual (in English) or bilingual but proficient in English (Collier and Thomas, 2004; Han, 2011). Bilingual status has been used as a covariate in two previous G-AA studies: Wu and colleagues (2014) did not report whether it was significantly related to academic achievement; Hodson and Sander (2017) found a significant negative relationship with three of four achievement measures.

%Female

%Female is the percentage of third graders in a school who were female. These data were not available on the portal and were obtained through a Chicago Public School Office of Accountability Research Review Board External Data Request. Research suggests a gender gap in academic achievement. Historically, most studies demonstrate that boys perform better than girls in mathematics achievement tests (Hyde et al., 1990) – although this gender gap may be subsiding over time (Lindberg et al., 2010). Studies continue to demonstrate girls perform better than boys on reading comprehension tests (Lynn and Mikk, 2009). Only one G-AA study to date, to our knowledge, has included this variable (Wu et al., 2014); although the authors did not report whether %female was related to achievement, they did make two plots of the G-AA relationship, one for schools with more females than average and one for schools with less; because these graphs visually suggested that the G-AA link was stronger for schools with fewer females, we included %female in the covariates examined here.

Number of students

Number of students is the total number of students at each school. We considered this variable as a potential predictor of academic achievement since the total number of students may influence pupil–teacher ratios (see below) and ultimately the attention and resources given to each student (Mosteller, 1997). While Matsouka (2010) found number of students was non-significant in multivariate models examining greenness and achievement-related outcomes, Kweon et al. (2017) found it was an important covariate in models with greenness and math performance.

Pupil/teacher ratio

Pupil/teacher ratio is the total number of students divided by the total number of teachers in a school. It is an important indicator of the resources at a school and has been shown to have moderately large effects on test scores and other measures of academic achievement, including in randomized control trials where test scores improve as a direct result of decreasing classroom size (Mosteller, 1997). This variable has been used in two recent G-AA studies, but neither reported a significant relationship with achievement. Wu et al. (2014) provided no results related to pupil/teacher ratio, and Kweon et al. (2017) found no significant relationship with math or reading performance in multivariate analyses; because pupil/teacher ratio was available in our source data and was important to address as a potential confounding variable, we examined it here.

Data Analysis

Bivariate correlations were used to give an initial picture of which types of greenness (tree cover and grass cover), which components of greenness (school, neighborhood, and catchment) and which potential confounding variables were related to academic achievement.

After conducting bivariate correlations, we tested for spatial autocorrelation. Previous G-AA studies conducted across multiple counties have found spatial autocorrelation (Wu et al., 2014; Hodson and Sander, 2017). The data here were drawn from a single county. To check for within-county spatial autocorrelation, we constructed generalized linear models (GLMs) predicting school performance using *School Trees, Neighborhood Trees,* and *Disadvantage* as predictors and analyzed the residuals from these models for spatial autocorrelation in GeoDa (Anselin et al., 2006). The results showed within-county spatial autocorrelation was present for reading (Global Moran's I = 0.074, Z = 2.3, p = 0.014). To ensure neither academic achievement model suffered from spatial autocorrelation, we concluded GLM would not suffice for this study.

Chicago was delineated into distinct, stable "Community Areas" in the 1930s by the University of Chicago's Social Science Research Committee using information from local agencies and the United States Census (Local Community Fact Book Chicago Metropolitan Area, 1990, p. xvii); although the 77 Community Areas were too fine-grained for our purposes (containing in many cases only a single school per area), they are aggregated into nine groups or "sides" which proved to be at an appropriate scale to capture spatial autocorrelation. Generalized linear mixed models

(GLMMs) with a random effect for these sides showed no spatial autocorrelation in the residuals ($p > 0.05$).

Accordingly, we used GLMMs with sides modeled as a random effect to examine relationships among green cover, disadvantage, and academic achievement. In this model, we examined the unique contributions of neighborhood and school greenness, respectively, controlled for *Disadvantage*, and included interactions between neighborhood and disadvantage as well as school greenness and disadvantage. For these models, the greenness and disadvantage variables were centered to avoid structural multicollinearity as a consequence of including interactions between greenness and disadvantage.

RESULTS

Table 1 provides descriptive statistics. As would be expected from the statistics for the school district as a whole (in which 87% of third graders were eligible for free lunch, and only 8.7% were White), this was, overall, a high-disadvantage sample, with 88% of third graders free lunch eligible and 9.6% White. Given the level of disadvantage, it is perhaps not surprising that school performance was low, with roughly two out every three children not meeting grade-level expectations for reading (63%) and math (66%).

Table 2 shows the bivariate correlations for the variables in this study. As would be expected, schools' reading and math performance were highly correlated.

Tree cover was significantly related to academic achievement. Each of the three tree cover measures (catchment, school, and neighborhood) predicted better reading performance (each with a p-value of <0.001), as well as better math performance ($p < 0.01$, $p < 0.001$, $p < 0.01$ respectively), and the Pearson correlation coefficients were of a magnitude that suggested a meaningfully large relationship between tree cover and achievement. Of the three tree cover measures, school trees were more strongly correlated with both reading and math than either neighborhood trees or trees in the catchment as a whole, suggesting that school tree cover might be a more important factor in achievement than neighborhood tree cover.

TABLE 1 | Descriptive statistics.

Variable (possible range)	Range	Mean ± SD
Reading performance (0–100)	6.5–91.1	36.64 ± 17.5
Math performance (0–100)	3.4–89.7	34.17 ± 18.42
*Catchment trees** (0–100)	0–37.07	12.20 ± 6.99
*School trees** (0–100)	2.09–44.70	20.01 ± 7.93
*Neighborhood trees** (0–100)	4.33–54.03	19.36 ± 7.43
*Catchment grass/shrub** (0–100)	0–56.30	17.17 ± 13.07
*School grass/shrub** (0–100)	2.36–52.39	18.25 ± 8.49
*Neighborhood grass/shrub** (0–100)	5.26–62.74	22.19 ± 6.67
%Disadvantaged (0–100)	19.16–100	89.30 ± 17.97
%Free lunch eligible (0–100)	10.04–100	88.15 ± 18.95
%Non-White (0–100)	20–100	90.44 ± 17.97
%African–American (0–100)	0.1–100	50.41 ± 44.28
%Hispanic (0–100)	0–99.5	37.33 ± 38.27
%Asian (0–100)	0–42	2.48 ± 6.3
%Native American (0–100)	0–2	0.08 ± 0.29
%Bilingual (0–100)	0–53	13.34 ± 14.73
%Female (0–100)	26–69	49 ± 6
Number of students (0–100)	164–2081	643.19 ± 328.51
Pupil/teacher ratio	11.73–24.6	18.4 ± 2.16

*N = 318 for all variables. *Denotes variables which were centered in subsequent GLM analyses to avoid multicollinearity; to calculate their means, minimum values, and maximum values after centering, subtract each by the mean value given in the table.*

While all measures of tree cover were significantly tied to academic achievement, the measure including both grass and shrub cover was not related to academic achievement. Neither *Catchment Grass*, nor *School Grass*, nor *Neighborhood Grass* was related to either reading or math performance, indicating that grass (and shrub) cover did not contribute to academic achievement in this study (Aim 3). In subsequent analyses, we focus on the contributions of tree cover to academic achievement and do not examine the contributions of grass or shrub cover further.

Of the various possible confounding variables examined, *Disadvantage* was strongly related to both *Reading Performance* and *Math Performance*. *%Female* and *Pupil/Teacher Ratio* were not related to academic achievement and are not examined further. Also, *Number of Students* was only marginally related to math performance and *%Bilingual* was only marginally related to reading performance. Subsequently, neither of these were considered in subsequent analyses. In summary, we only considered *Disadvantage* in future analyses since other predictors were not statistically significantly related to academic performance.

The bivariate correlations between measures of greenness and disadvantage help address our fourth Aim. Schools serving relatively disadvantaged students were systematically less green in and immediately around their schoolyards: disadvantage was significantly negatively correlated with school tree cover (Pearson correlation coefficient, $r = -0.40$, $p < 0.001$) and marginally significantly negatively correlated with school grass cover ($r = -0.10$, $p < 0.10$). *Disadvantage* was also significantly negatively related to *Neighborhood Trees* and *Catchment Trees* ($r = -0.33$, $p < 0.001$, and $r = -0.34$, $p < 0.001$, respectively), but was not related to neighborhood or catchment grass.

When we examine the means and ranges of tree cover for schools at different levels of disadvantage, the pattern is clear: schools serving more white, well-off students have more tree cover (**Table 3**). In the most disadvantaged quartile, *School Trees* (the percentage of the schoolyard and surrounding 25 m buffer covered by tree canopy) ranged from 0 to 26%, with a mean of 9%; in our least disadvantaged quartile (mean 64% free lunch eligible and 65% non-White), *School Trees* ranged from 0 to 37%, with a mean of l6%). Thus, school tree cover in the extremely disadvantaged schools was roughly half that in less disadvantaged schools (54%).

Table 4 shows results of a GLMM examining the relationships between greenness, disadvantage, and academic achievement while accounting for the part of the county a school belongs to. Accounting for school location was performed by including a

TABLE 2 | Bivariate correlations among standardized test scores, greenness, and potentially confounding variables, $N = 318$.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Reading performance		0.87	0.25	0.37	0.24	0.05	0.07	0.04	−0.74	−0.11	−0.03	−0.02	0.03
2 Math performance	0.87		0.18	0.35	0.18	−0.02	0.05	−0.03	−0.72	0.08	0.13	−0.03	0.09
3 Catchment trees	0.25	0.18		0.41	1.0	0.28	0.14	0.29	−0.34	−0.27	−0.10	−0.01	0.00
4 School trees	0.37	0.35	0.41		0.37	0.02	0.02	0.02	−0.40	0.00	0.10	0.01	0.11
5 Neighborhood trees	0.24	0.18	1.0	0.37		0.29	0.15	0.30	−0.33	−0.28	−0.10	−0.01	0.00
6 Catchment grass	0.05	−0.02	0.28	0.02	0.29		0.35	1.0	−0.05	−0.33	−0.12	−0.08	−0.08
7 School grass	0.07	0.05	0.14	0.02	0.15	0.35		0.31	−0.10	−0.13	−0.04	−0.07	0.00
8 Neighborhood grass	0.04	−0.03	0.29	0.02	0.30	1.0	0.31		−0.04	−0.33	−0.12	−0.07	−0.08
9 %Disadvantaged	−0.74	−0.72	−0.34	−0.40	−0.33	−0.05	−0.10	−0.04		0.06	−0.02	0.02	−0.05
10 %Bilingual	−0.11	0.08	−0.27	0.00	−0.28	−0.33	−0.13	−0.33	0.06		0.58	−0.02	0.23
11 Number of students	−0.03	0.13	−0.10	0.10	−0.10	−0.12	−0.04	−0.12	−0.02	0.58		0.03	0.51
12 %Female	−0.02	−0.03	−0.01	0.01	−0.01	−0.08	−0.07	−0.07	0.02	−0.02	0.03		0.06
13 Pupil/teacher ratio	0.03	0.09	0.00	0.11	0.00	−0.08	0.00	−0.08	−0.05	0.23	0.51	0.06	

$0.095 < |x| \leq 0.113$ corresponds to $p < 0.1$, two-tailed. $0.113 < |x| \leq 0.149$ corresponds to $p < 0.05$, two-tailed. $0.149 < |x| \leq 0.189$ corresponds to $p < 0.01$, two-tailed. $0.189 < |x|$ corresponds to $p < 0.001$, two-tailed.

TABLE 3 | The relationship between disadvantage and school tree cover.

Disadvantage quartiles	Range of %school tree cover	Mean of %school tree cover
Least (64% free lunch eligible, 65% non-White)	0–37%	16%
Second (93%, 97%)	0–31%	12%
Third (97%, 99%)	0–26%	11%
Most Disadvantaged (99%, 100%)	0–26%	9%

random effect variable that identified each school as belonging to one of nine community area groups for the City of Chicago (Local Community Fact Book Chicago Metropolitan Area, 1990). We include the two greenness measures (*School Trees* and *Neighborhood Trees*) but not the third measure linked to academic performance (*Catchment Trees*), because we intended to compare greenness immediately around schools versus greenness in surrounding neighborhoods (Aim 2). Our focus is on greenness due to tree cover but not grass cover, since grass cover did not predict achievement in bivariate correlations. Last, we include the single covariate linked to academic achievement in bivariate correlations (*Disadvantage*) as well as its interaction terms with the two measures of greenness to address Aim 4.

As **Table 4** shows, there was a significant main effect for *School Trees* on math and marginally significant main effect on reading performance, indicating that *School Trees* contribute uniquely to the prediction of academic achievement even after *Neighborhood Trees* are statistically controlled for. *Neighborhood Trees*, however, showed only a marginally significant relationship with math achievement and no relationship to reading achievement once *School Trees* were statistically controlled for. These findings suggest *School Trees* are stronger drivers of academic performance than other types of greenness, including grass cover and trees in surrounding neighborhoods. **Table 4** also shows statistically significant interaction terms between *Disadvantage* and *School Trees* – but not *Neighborhood Trees* – indicating the effects of trees around schools on academic performance vary by levels of disadvantage at the school.

DISCUSSION

Summary of Findings

The first aim of this study was to determine whether the G-AA link found in previous studies also held for a highly disadvantaged school district. Previous work in Washington D.C., Minneapolis-St. Paul, and Massachusetts had samples that were composed of 65%, 39%, 35%, and 21% low-income students, respectively (Matsuoka, 2008; Wu et al., 2014; Hodson and Sander, 2017; Kweon et al., 2017). We found that the greenness academic achievement (G-AA) link holds even in a school district where 90% of students were free lunch eligible and fewer than 10% were White. We found a main effect of greenness—more specifically, school tree cover—for school performance in math with a marginally significant main effect for school performance in reading. The advantage of greener schools in math could not be accounted for by levels of disadvantage in their student bodies, nor the percentage of bilingual students, the number of students, the percentage female, nor the pupil/teacher ratio. It appears that the G-AA link holds in schools with high levels of disadvantage.

Interestingly, a significant interaction between school greenness and disadvantage in their relationship to math achievement suggest that the G-AA link is moderated by levels of disadvantage in a student body. Although there was no clear pattern in the relationship, at least three factors may contribute to this moderation. Particularly disadvantaged student bodies may experience chronic mental fatigue, making them more responsive to a greener, more cognitively restorative school environment. On the other hand, among the most disadvantaged schools, the green cover present may not provide a large enough "dose" of green to make a difference in achievement. And finally, a tendency for more disadvantaged schools to forego outdoor recess (National Center for Education Statistics [NCES], 2006)

TABLE 4 | Using school trees, neighborhood trees, and school disadvantage levels to predict academic achievement in Chicago public schools while accounting for the community area group in which a school is located.

	Math scores		Reading scores	
Predictors	β	*SE*	β	*SE*
School trees	0.22*	0.10	0.18+	0.09
Neighborhood trees	−1.59+	0.82	−0.45	0.76
%Disadvantaged	−0.78***	0.05	−0.75***	0.05
School trees*%Disadvantaged	0.01**	0.01	0.01+	0.00
Neighborhood trees*%Disadvantaged	−0.02	0.03	0.02	0.03
Marginal R-squared[1]	0.52		0.55	
Conditional R-squared[2]	0.53		0.57	
Moran's I index	0.030 (Z = 0.9), p = 0.15		0.029 (Z = 1.0), p = 0.098	

*+ <0.10, * <0.05, ** <0.01, *** <0.001. [1] R-squared for fixed effects; [2] R-squared for both fixed and random effects.*

may limit students' exposure to any green cover present attenuating any G-AA link in these schools.

The second aim of this study was to examine the unique contributions of the greenness immediately around schools and the greenness farther away. In this study, school greenness predicted math achievement and marginally predicted reading achievement even when greenness of the surrounds was taken into account. Neighborhood greenness only marginally predicted math performance when school greenness was considered. This suggests that in previous studies focusing on greenness in the larger landscapes around schools (Wu et al., 2014; Hodson and Sander, 2017), the links between greenness and achievement may have primarily reflected the greenness immediately around the schoolyard and a tendency for greener neighborhoods to also have greener schoolyards. Re-analyses of the data used in those studies (Wu et al., 2014; Hodson and Sander, 2017) in which both near-school and more distant greenness are entered as separate predictors in the same model can tell us whether the previous, positive findings for neighborhood greenness on school performance stand on their own.

The third aim of this study was to examine the contribution of different kinds of green cover. In Chicago Public Schools, we found tree cover to be an important predictor of academic performance, but not grass and shrub cover. This echoes findings in both the Washington D.C. and Minneapolis-St Paul studies, in which trees show significant positive relationships with achievement but grass and shrubs show null or even negative relationships. The current study represents the third city/region in which grass and shrubs have not statistically contributed to academic achievement in public schools. At this time it appears that the link between green cover and achievement is driven primarily by tree cover. Future research should continue to distinguish between tree cover and grass/shrub cover. It is important to note that because measures based on the NDVI do not distinguish between different forms of cover, NDVI-based studies may show no or even negative associations between greenness and academic achievement even if an underlying positive tie between tree cover and achievement exists (Browning et al., 2018).

The fourth and final aim of this study was to examine the relationship between greenness and disadvantage. We found disadvantage was significantly negatively related to greenness, such that the more disadvantaged the student body residing in a neighborhood, the less tree cover existed in the neighborhood and around the school. In schools serving an extremely disadvantaged student body (e.g., 99% free lunch eligible, 100% non-White), tree cover was roughly half (54%) that in schools serving a largely disadvantaged student body (64% free lunch eligible, 65% non-White), and it seems likely that the tree cover in this high-poverty school district falls far short of well-off school districts. Given the research pointing to disease-fighting impacts of contact with nature (Kuo, 2015; South et al., 2015), impacts on crime (Kuo and Sullivan, 2001b; Troy et al., 2012; Kondo et al., 2016) and violence (Kuo and Sullivan, 2001a; Branas et al., 2011; Troy et al., 2012; Wolfe and Mennis, 2012; Kondo et al., 2015) – all of which are critical issues in low-income urban neighborhoods – as well as the possibility that school trees might boost academic achievement, the paucity of tree cover in low-income areas is not merely an aesthetic issue but an important environmental justice issue.

Methodological Contributions

Three small innovations in this study may be useful in future research. First, in this study, we conceptualized greenness in terms of non-overlapping zones. This separation of zones enabled us to examine the unique contribution of each region to the prediction of academic performance over and above that of other regions. Previous G-AA work has examined entire attendance areas (Hodson and Sander, 2017), schoolyards (Kweon et al., 2017), or increasingly large (overlapping) buffers around schools (Wu et al., 2014), but not mutually exclusive zones; consequently they do not allow the localization of the effects of greenness within larger zones. Second, in our models, we included an interaction term for the moderating effect of disadvantage on the G-AA relationship and centered our disadvantage and greenness variables to prevent multicollinearity. In these data, at least, the interaction was a robust effect and, indeed, without it the relationship between greenness and achievement was consistently significantly *negative* (Browning et al., 2018). And finally, while we are far from the first to combine two conceptually related, highly correlated, uniquely predictive factors into a single index to minimize multicollinearity, the introduction of this practice in to the study of G-AA seems useful and important. Without it, researchers are caught between accepting either extreme instability in estimating effects due to multicollinearity on the one hand and omitting a major confounding variable on the other.

Limitations

Four characteristics of this study limit the conclusions that can be drawn from its findings. First, because this study was correlational, no conclusions can be drawn regarding whether school greenness is, in fact, affecting school achievement; it is possible that our controls for socioeconomic status and other factors that drive achievement were inadequate. True experiments involving landscape change are typically impossible. However, a new project underway in Louisville, KY, United States may more rigorously address the question of cause-and-effect. Led by The Nature Conservancy and numerous partners including researchers at the University of Louisville, the Green Heart study will rapidly green neighborhoods while other neighborhoods serve as controls, to assess the impacts of greening on a wide range of human health and well-being measures[8]. Second, because we wished to examine the effects of greenery immediately around schools and in the surrounding neighborhood on students living in that neighborhood, we limited our study to neighborhood-based schools. As our sample excludes schools that draw from multiple neighborhoods or even the entire city of Chicago, it is impossible to say whether the G-AA relationship found here extends to magnet, charter, and other multi-neighborhood schools in this city or elsewhere. As these types of schools are growing in number across the United States, assessing the potential contributions of school and residential green on academic achievement for these school types is increasingly important. Third, because we were unable to obtain test scores for individual students, we were able only to study test performance at the level of schools. A study examining test scores and controlling for confounding variables at the individual student level would be stronger. Lastly, like most studies in this line of investigation, this study was cross-sectional, examining only the G-AA relationship in a single school year (2009–2010). However, schools, students, and landscapes change with time. One recent study found that while Chicago Public School test scores were below grade, over time, many Chicago Public School students show significantly more *growth* in test scores than students in other public school systems (Reardon and Hinze-Pifer, 2017). And landscapes can change for the better (i.e., trees planted and maintained, or school yard pavement removed and planted with trees and gardens) or for the worse (i.e., trees lost due to an invasive species like the Emerald Ash borer). A study able to examine test scores *and* changes in greenness over time would complement the existing body of cross-sectional work. A study allowing longitudinal, individual, and school-level modeling of the G-AA relationship would be stronger still.

Implications for Research and Practice

Given the pressing need to identify feasible ways to boost academic achievement in urban low-income schools, the low cost of greening and its many important ancillary benefits, and the consistent findings in this and previous correlational studies, it is time to conduct field experiments examining standardized test performance in urban, low-income schools randomly assigned to tree planting and control conditions.

Our findings that near-school trees predict performance better than neighborhood trees is good news for school administrators. Schools have jurisdiction over planting and maintenance decisions on their properties; further, much of the 25 m buffers fall on city-owned rights-of-way. Nor would the cost of planting and maintenance necessarily have to fall on the school district. In many cities, there are tree planting programs that purchase and help plant trees on public rights-of-way including school grounds and medians. In Chicago, the non-profit Openlands runs several urban forest-related programs, including "Space to Grow" and "Building School Gardens" that specifically target school landscapes and "TreeKeepers," which trains volunteers in tree planting and care. Similarly, Philadelphia's Tree Tenders focuses on schools, and Los Angeles hosts one of the first urban forestry non-profits, TreePeople. Each of these organizations reaches out to schools to assist with landscape transformations and subsequent maintenance, thereby placing meaningful changes in tree cover in reach of even financially strapped school districts.

Greening immediately around schools would cost considerably less than greening the broader neighborhood. Consider the costs entailed in a 10% increase in tree cover in the near-school area versus a school's attendance area. The average dimension of the schoolyard and its 25 m buffer in our sample was approximately 165 m by 165 m, an area of 27,149 m^2. The average dimension of the attendance area was approximately 1,228 m by 1,288 m, an area of 1,509,594 m^2. Assuming that the average installation cost is \$100 and the mean crown radius after 10 years of growth is 5 m, each tree would cover 78 m^2 at the price of \$1.28 per square meter. It would take 35 trees to increase tree cover by 10% in the schoolyard + 25 m buffer, but it would take 1,936 trees to increase tree cover by 10% in the surrounding neighborhood. The difference in cost of these two greening efforts is substantial: school greening would cost \$3,500, and attendance area greening would cost sixteen times that amount (\$193,600) in this scenario.

Another encouraging outcome from our study is that our data further reinforces the importance of trees over grass and shrubs for academic achievement. Increasing tree cover is easier to incorporate into pre-existing landscapes than grasses or shrubs because tree plantings require smaller footprints and create large canopies of "greenness" above. Planting a few trees thus exponentially increases the green cover around schools compared to planting grasses or shrubs, and maintaining growing trees further expands their canopy.

CONCLUSION

The study here suggests that greening has the potential to mitigate academic underachievement in high-poverty urban schools. This study also helps guide the *where* and *what* of such efforts. Green cover predicted academic performance even in a highly

[8]https://www.nature.org/newsfeatures/pressreleases/green-heart-project-launches-in-louisville.xml

disadvantaged population of schools. The G-AA link was driven primarily by near-school trees and not by residential tree cover, suggesting that experimental greening efforts might focus on school grounds and the areas within view of the school. Further, tree cover was tied to academic performance, but grass and shrub cover was not, suggesting that experimental greening efforts might focus on planting trees. Finally, even within this high-poverty school district, there was substantial inequity in levels of school tree cover across different levels of disadvantage; we urge researchers and practitioners to conduct field experiments simultaneously addressing this inequity and determining whether its relationship to school performance is causal.

AUTHOR CONTRIBUTIONS

MK secured funding, conceptualized the study, guided data analysis, participated in interpretation of data, and lead the write-up. MB prepared data for analysis, guided and conducted data analysis, participated in interpretation of data, wrote substantial portions of the manuscript, and reviewed the manuscript. SS prepared data for analysis, guided and conducted data analysis, prepared tables and figures, and reviewed the manuscript. KL guided selection of GIS and analytic methods, calculated greenness variables, prepared data for analysis, participated in interpretation of data, prepared tables and figures, and reviewed the manuscript. LW provided funding, participated in interpretation of data, and reviewed the manuscript.

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SUPPLEMENTARY MATERIAL

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Green Breaks: The Restorative Effect of the School Environment's Green Areas on Children's Cognitive Performance

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Restoration involves individuals' physical, psychological, and social resources, which have diminished over the years in the process of meeting the demands of everyday life. Psychological restoration can be provided by specific environments, in particular by natural environments. Studies report a restorative effect of nature on human beings, specifically in terms of the psychological recovery from attention fatigue and restored mental resources that were previously spent in activities that require attention. Two field studies in two Italian primary schools tested the hypothesized positive effect of recess time spent in a natural (vs. built) environment on pupils' cognitive performance and their perceived restorativeness, using standardized tests. In Study 1, children's psychological restoration was assessed by measuring sustained and selective attention, working memory, and impulse control, before and after the morning recess time. Team standardized playtime was conducted in a natural (vs. built) environment, and the perceived restorativeness was measured after each recess time. Results showed a greater increase in sustained and selective attention, concentration, and perceived restorativeness from pretest to posttest after the natural environment condition. In Study 2, the positive effect of free play recess time in a natural (vs. built) environment was assessed during the afternoon school time on sustained and selective attention and perceived restorativeness. Results showed an increase in sustained and selective attention after the natural environment condition (vs. built) and a decrease after the built environment break. Higher scores in perceived restorativeness were registered after the natural (vs. built) environment condition. Team standardized playtime and individual free play recess in a natural environment (vs. built) support pupils' attention restoration during both morning and afternoon school times, as well as their perceived restorativeness of the recess environment. Theoretical and practical implications are discussed in terms of nature's role both for the school ground design or redesign and for the organization of the school's activities.

Keywords: attention, restoration, nature, school, children, green areas

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INTRODUCTION

Restorative environments can be defined as environments that both permit and promote restoration (Hartig, 2004). Restoration refers to the psychological and physiological recovery processes elicited by specific environments and environmental configurations (Joye and Van den Berg, 2011); this recovery process consists of the renewal or recovery of adaptive resources that were depleted in the process of meeting the demands of everyday life (Hartig, 2004). Two main theories—the Attention Restoration Theory (ART) (Kaplan and Kaplan, 1989; Kaplan, 1995) and the Stress Reduction Theory (Ulrich, 1983)—describe the processes underlying the renewal of psychological resources (e.g., the capacity of directing and sustaining attention, inhibiting impulses, and maintaining concentration) through environmental characteristics. Within the scope of the present research, we intend to address psychological restoration elicited by children during break times that are experienced either in a natural or built environment at their school. In particular, we intend to address how children restore their cognitive performance and perceive psychological restoration based on where they spent their recess time—that is, having the break in a natural or a built environment.

This research is grounded in the ART, which is likely to be the most influential theory that investigates the restorative effect of nature on human beings. Specifically, the theory focuses on psychological recovery from attention fatigue and restored mental resources that were previously spent in activities that require directed attention (Kaplan and Talbot, 1983). In fact, directed attention is involved in most daily-life activities; it is voluntary and requires mental effort to ignore distractions and inhibit impulses to maintain focus. Particularly, directed attention is prone to attentional fatigue, which may cause lowered ability to concentrate and solve problems, increased irritability, and increased tendency to make mistakes and incur accidents. Situations that do not require directed attention, allow people to rest the inhibitory mechanism, which eventually leads to attention restoration (Staats, 2012). Within this realm, natural environments help in reducing the constant demands of directed attention; interesting and aesthetically pleasing aspects of natural environments capture attention without an overly high demand for cognitive processing, allowing the mental process known as psychological restoration to occur (Russell, 2012).

In the present research, we aim at two different goals. First, we intend to address children's cognitive restoration after taking a break (i.e., recess time) in the natural environment or in the built environment of their school. Therefore, we focused on certain attention components subject to depletion during school time. Specifically, we measured working memory, sustained and selective attention, and impulse control, which are the attention components involved in school activities. Second, we intend to address children's perceived restoration after recess time in the natural or built environment, specifically in terms of the four characteristics that, according to the ART, define a restorative environment (Staats, 2012): people should experience the feeling of *being away*, distant from distractions and demanding stimuli; they should also experience *fascination*, which refers to the person's effortless attraction for certain environmental elements and engagement in environment-related activities; furthermore, people should sense the environment's *extent*, which describes its richness and coherence in terms of being perceived as a whole other world; finally, they should feel the *compatibility* between the environment and personal interests, purposes and inclinations, allowing the person to do whatever he/she wants to do. Being away, extent, and compatibility support fascination, which plays a key role in restoration (Kaplan and Kaplan, 1989; Kaplan, 1995). In this study, in addition to the abovementioned three components of attention, we also measured children's perceived restoration with a self-report scale based on these main characteristics given by the ART. However, in the second experiment, we only measured the most relevant components, *fascination* and *being away* (Gonzalez et al., 2010).

In the literature, several studies have used the ART to understand the restoration processes occurring in everyday life contexts, such as in individuals' home, school, or workplace. Workplaces, for example, are demanding contexts, and a restorative effect on cognitive capabilities may play an important role on individuals' well-being and the quality of the work done (Staats, 2012). For example, restorative experiences at the workplace can compensate for job resource demands (Bellini et al., 2015a,b). Some studies, in fact, corroborate the hypothesis of a positive restorative effect of the presence of nature in workplaces: views of nature (compared with other views) reduced stress and increased workers' job satisfaction (Shin, 2007). Furthermore, workers seem to actively look for contact with nature in their work environment. In offices without windows, people brought indoor plants and pictures of nature (Bringslimark et al., 2011); what followed was an improvement in performance on attention-demanding tasks only from participants in the office with plants (Raanaas et al., 2011) when compared with those in the office without plants. Therefore, for adults, contact with nature seems to be crucial in demanding contexts like workplaces, where they spend most of the day.

Similarly, in everyday life contexts like at home and school, children may experience the same need for restoration provided by nature. Generally speaking, the capacity to direct attention is crucial for children's everyday activities (Kuo, 2001; Kuo and Sullivan, 2001). Home, for example, is identified as a restorative environment (Hartig, 2012; Wells and Rollings, 2012), and some studies report a positive effect of nature on children's cognitive functioning (considering children of different ages, up to 18 years). Living in a place with more natural elements can foster children's improved attentional capacity (Trancik and Evans, 1995; Faber-Taylor and Kuo, 2006), as well as increase their capability to inhibit impulses (Faber-Taylor et al., 2002). Wells (2000) found that, in children between 7–12 years of age, staying at home with an exposure to the natural environment outside is associated with more concentration, attentional capacity, self-discipline, and impulse control. Moreover, specifically for girls the same study reports an association between green view and higher focusing capacity, increased inhibition of impulses, and increased delay of gratification. Flouri et al. (2014) found a connection between near-home nature and less hyperactivity in children, also related to a better emotional resilience and behavioral regulation. In line with this, Wells and Evans (2003) reported an association between the daily at-home contact with nature and stress resilience in children. Moreover, a study conducted amongst children with attention deficit hyperactivity disorder (ADHD) (Faber-Taylor et al., 2001) revealed that exposure to nature through activities carried out in green environments was related to better attentional functioning. In addition, children reported better ratings for activities conducted within natural settings than for activities conducted within built outdoor or indoor settings. In line with these results, self-report measures of parents and caregivers of children suffering from ADHD showed a reduction of symptoms after activities conducted in natural (vs. built) areas (Faber-Taylor et al., 2001; Kuo and Faber-Taylor, 2004; Faber-Taylor and Kuo, 2011). Similarly, a 20 min walk in nature helped ADHD children's attention capacity (Faber-Taylor and Kuo, 2009), while playing in a natural area helped them to perform better on a concentration task (van den Berg and van den Berg, 2011).

Yet, taking into consideration the environments relevant to children, school is their second main everyday life context. In fact, excluding home, school is where children spend more time than in any other indoor environment (Mendell and Heath, 2005); it certainly is also a cognitively demanding context for them. Therefore, children at school may be in need of restoration and may experience this effect on attention restoration provided by nature. In fact, past research has shown that natural environment in schools helps children to concentrate. Studies have usually compared indoor and outdoor environments (Bagot, 2004; Bagot et al., 2015), focusing either on indoor nature (such as green walls, van den Berg et al., 2016) or on natural views from windows (Liu and Sullivan, 2016). Other studies, on the other hand, have focused on the enhanced working memory and sustained attention of primary school pupils in schools with green and natural surroundings (Dadvand et al., 2015). Moreover, studies on preschoolers have shown that nature may boost children's concentration (Grahn et al., 1997; Carrus et al., 2015). For example, they are more attentive in areas with trees and shrubbery (Mårtensson et al., 2009); they also express greater attentive abilities and motor coordination in day cares with natural elements (Grahn et al., 1997). Furthermore, natural environments are rated as being more restorative than indoor or built environments when addressing children's perceived restoration; in particular, comparing more vs. less natural school playgrounds within a given environment was associated to significantly higher perceived restoration (Kelz et al., 2013).

Thus, although research about children's relationship with nature and with regard to the psychological restoration provided by nature in school environments is indeed increasing (Berto et al., 2015; Dadvand et al., 2015; van den Berg et al., 2016), there is still a research gap regarding some specific aspects. For example, in some instances, a measurement of baseline attention is missing (Berto et al., 2015), or a proper comparison between different outdoor environments belonging to the same school (Bagot, 2004; Bagot et al., 2015; Berto et al., 2015) is yet to be done. However, since school may generate cognitive fatigue, deplete pupils' resources, and decrease their attention capability (Pellegrini and Davis, 1993), it seems crucial to conduct an assessment of attention restoration on cognitive performance during actual school time. Thus, systematic field studies regarding benefits of nature-at-school on children's cognitive functioning are still needed. This research aims to fill this gap by addressing these issues with two field experiments conducted within school contexts. Specifically, the present research intends to address whether recess time in a natural (vs. built) environment within the school can provide psychological restoration to a sample of primary school children. Two experimental studies are presented here, which were conducted in the morning and in afternoon school times. An assessment of attention restoration before and after recess in the natural (vs. built) environment and children's perceived restorativeness of the environments have been provided, and the theoretical and practical implications have been discussed.

The Research

The current research intends to provide an assessment of children's psychological restoration after recess time in a natural (vs. built) environment within the school context. In particular, two main general issues are addressed via two field experiments: (a) whether natural (vs. built) environments in schools elicit post break attention restoration in primary scholars and (b) whether pupils perceived the natural environment as more restorative than the built one.

Study 1 investigated whether or not recess time spent in a natural environment at school exerts attention restoration on pupils. The sample was composed of 4th and 5th grade students, in order to compromise between keeping the age as uniform as possible and keeping the procedure manageable with standard tools. Standardized measures of the three attention components, working memory, sustained and selective attention, and impulse control were used. A mixed-model crossover design was used, where the test/retest experiment was conducted in two different outdoor environments of the same school (natural vs. built). By this procedure, it was possible to rule out possible confounds linked to the indoor vs. outdoor distinction. We also used controls for the activity carried out by the pupils during their recess time in order to prevent other confounding effects related to the children's play; thus, the same team play competitive activity was administered during recess time in both environments. Also, perceived restorativeness was measured with an Italian version of the perceived restorativeness scale (PRS) adapted for children (Hartig et al., 1997; Pasini et al., 2009). This first study focused on the morning school session.

In line with Study 1, Study 2 was developed to address the positive effect of natural (vs. built) environment on attention restoration and perceived restorativeness on primary school children. We made some changes in the procedure and research design in order to address the generalizability of the results produced by Study 1. Specifically, in this between-subjects experiment, we avoided a possible learning effect that could have occurred in the attention scores given that we repeated the same test multiple times. In terms of attention measurement, only one of the three attention tests used in Study 1 was maintained. Children were tested with two measurements of sustained and selective attention (i.e., the main attention dimension involved during school time). Also, we conducted the study during the afternoon-lunch time, assuming that children could be more in need of restoration because they would have accumulated attention fatigue during the morning. Furthermore, during recess time, children were not allowed to engage in any team play activity, but they could play freely in the environment (natural vs. built). The free play was chosen in order to give them the opportunity to truly explore and experience the environment, which, on the contrary, in the previous study was left as the surrounding for a structured team game. Finally, sampled children were from the 5th grade only, since they were easier to manage when compared with the 4th graders, based on the experience from Study 1, within a standard procedure.

FIGURE 1 | Natural environment of Study 1.

FIGURE 2 | Built environment of Study 1.

STUDY 1: MORNING RECESS TIME AND ATTENTION RESTORATION

Study 1 aimed to test the attention restoration provided by a natural environment within the school context when compared with a built one. Thus, a quasi-experimental design assessed the three different attention components involved during school time. Specifically, with a pretest (time 1, T1) and a posttest (time 2, T2) measurement, we tested the positive effect of recess time in natural (vs. built) environment on sustained and selective attention, working memory, and impulse control. Moreover, we addressed children's perceived restorativeness after recess time in the natural (vs. built) environment, counterbalancing the manipulation order to avoid confounding effects [(a) natural environment condition/built environment condition; (b) built environment condition/natural environment condition]. Then, according to the ART (Kaplan and Kaplan, 1989; Kaplan, 1995), we hypothesized the following.

- H1: Children's sustained and selective attention will be greater in T2 (vs. T1) after recess time in the natural (vs. built) environment.
- H2: Children's working memory will be greater in T2 (vs. T1) after recess time in the natural (vs. built) environment.
- H3: Children's impulse control will be greater in T2 (vs. T1) after recess time in the natural (vs. built) environment.
- H4: An interactive effect between condition and manipulation orders on children's perceived restorativeness can be observed. Specifically, children's perceived restorativeness will be greater in the natural (vs. built) environment in both the orders' presentations of manipulation.

Method

Participants and Context

The sample was formed by primary school children who attended a public school located in a middle class urban area in Rome, Italy. Eighty-two children (average 10.1 years of age; 39 girls, 43 boys) attending two 4th grade and two 5th grade classes, participated in the study. The school was selected by expert researchers because it offered different outdoor areas, one in a natural environment (**Figure 1**) and one in a built environment (**Figure 2**). The natural area is the school garden (1,303 m^2), while the built one is the courtyard in front of the school entrance (139 m^2). We conducted the recess activity either in the whole area of the built environment or in a portion of the school garden resembling the width of the built one, to avoid possible differences that could be derived from playing in a bigger area. Ordinarily, children spend their morning recess time inside their classrooms and the after-lunch break time outdoors (teachers can freely make a decision about bringing them in the natural area or in the built area, which are both known to the children). In this experiment, during the morning recess time, the selected class of children was the only group to play outside during recess time (all other children in the school had the break inside their classrooms as usual).

Measures

Sustained and selective attention

The Bells test (Biancardi and Stoppa, 1997) is a standardized measure of selective and sustained attention. The test composed of a sheet (21.5 cm × 28 cm) with small black drawings of different symbols (house, tree, bird, bell, etc.). In total, in each sheet there are 35 bells embedded within 280 different distracting stimuli. The attention task involved marking all the bells with a pencil with a time-cap of 120 s. The attention score, ranging from 0 to 35, is calculated based on the total number of bells detected.

Wrongly marked symbols are not computed in the final score. The complete test has four different sheets plus a small trial sheet.

Working memory

The digit span test (in WISC-IV, Wechsler intelligence scale for children, Fourth edition; Wechsler et al., 2003) is a standardized measure of attention and concentration, which is connected with information maintenance in the working memory. In the original task, administered individually, the person is asked to repeat aloud a progressive series of numbers in the same order as they are given first (digit span forward, DSF) and then in the reverse order (digit span backward, DSB). For the present research, the task was adapted for a collective administration in class; children were asked to listen to the progressive series of numbers and then write down (instead of repeating it aloud) the digit sequence after the "stop" signal displayed by the experimenter. Another experimenter checked if the children did not follow instructions, for example, by writing the sequence before the "stop" signal. Digit span forward is composed of six series of digits (from 2 to 7 digits) and DSB is composed of five series of digits (from 2 to 6 digits). As in the original task, the total score is computed as the sum of the precisely written series (DSF and DSB).

Impulse control

The go-no-go test (in BIA, battery for the assessment of children with ADHD, Marzocchi et al., 2010) measures the capacity to inhibit a dominant response. Children receive a marker pen and a sheet (21.5 cm × 28 cm) with 20 items, each item composed a drawing of a "path" made up of 14 squares. The test involved listening and executing the instructions given by a tape. For each item, the tape plays a series of two types of sounds, the "go" tone and the "no-go" tone. The "go" and "no-go" sounds are identical for the first 208 ms, while the no-go tone is marked by a concluding exclamation sound. When the tape begins, children start from the first item (path 1). When they hear the "go" tone, they have to dot the first available square of the path with a marker pen; on the contrary, when they hear the "no-go" tone, they have to inhibit the dominant response of dotting the square and not make the move on the path. The score is calculated based on the number of correct items (paths with the correct number of dotted squares according to the tape) out of 20.

Perceived restorativeness

The original self-report scale for measuring perceived restorativeness (PRS) was developed by Hartig et al. (1997). In this study, the Italian short version (Pasini et al., 2009) was used. The scale, comprising of eight items with an 11-point scale (from 0 = "not at all" to 10 = "completely") was adapted for children by rephrasing few items. Most of the items had verbs in the conditional form, which had been replaced with the indicative form to make them more easily comprehensible. Item number 3 ("*Things and activities that I see there seem to complement in quite a natural way*") was replaced with item number 23, taken from the Italian complete version of the scale (Pasini et al., 2009) ("*There you can easily see how things are arranged*"). Reliability of the final 8-item scale used in Study 1 was either good or sufficient, especially considering that it is based on a sample administration in primary school children (αNaturalEnvironment = 0.78; αBuiltEnvironment = 0.65).

Procedure

A brief description of the study was provided through the informed consent sheet, which was then signed by the school and the parents of each child involved. Three couples of parents did not sign the consent form for their children; thus, these three students participated in the activities of the research but were not included in the sample. Participants with parental consent were excluded if children were absent on the testing day.

Before starting with the experimental procedure, children were enrolled in usual school activities starting at 8:30 a.m. Teachers were told to manage usual class activities as if nothing new would occur. Then, children completed the three paper-and-pencil measures of attention immediately pre (i.e., T1) and post (i.e., T2) their break time, in either one of the two different conditions: play in the natural environment (garden) or in the built (courtyard) environment of their school. Right after the break, they also completed a self-report measure of perceived restorativeness—which referred to the place (natural vs. built area) in which they played during the break time. All tests were collectively administered by giving the relevant instructions and a trial task, to assure a complete understanding from the participants. Children were tested with the same procedure in two different weekdays. For each class, the same weekday was chosen within 1 week for administering the procedure, taking care, as much as possible, of keeping the atmospheric conditions and schooling schedule constant. Data were gathered during the spring in order to have nice weather conditions, in March–April 2014.

A within-subjects design was used (**Figure 3**). All children were tested in both the built and natural environment condition during the morning school time. Treatment order was crossed, so that half of the sample (one class from the 4th and one from the 5th grade) was exposed to the natural environment condition first and then to the built environment condition; similarly, the other half of sample was then exposed to experimental conditions in the opposite order.

Children were told to listen carefully to all the instructions and not to cheat. Children's right to stop the experiment, if they were not comfortable with it, was also clarified. To protect confidentiality, the results of each attention test have been anonymized through a personal identification number assigned to each participant. The procedure followed a given daily timetable and was performed in the morning. Children were asked to play a competitive team-game, after being divided into two teams, with an equal number of girls and boys placed on each team. The activity was a competitive game similar to basketball. Each team consisted of players and a goalkeeper, who held a small wooden stick. The goal of the game was to score points by throwing a rubber ring into the goalkeeper's stick. Each team had to score on its own goalkeeper and had to prevent the opponent team from scoring as well. The rubber ring could be advanced only with the hands, either by dribbling or by passing to the teammates, moving forward with three or fewer steps. It was forbidden to pass the rubber ring directly to a teammate

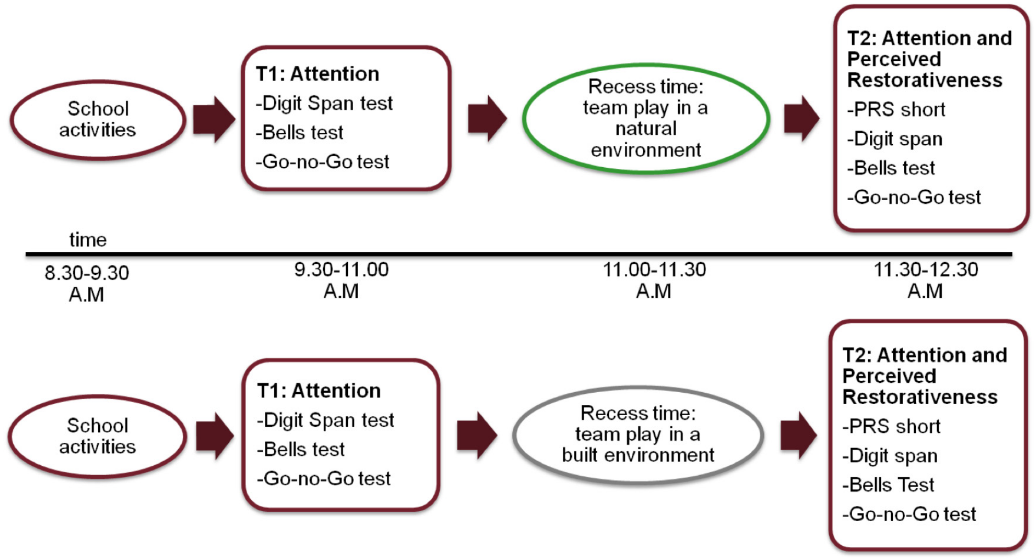

FIGURE 3 | Within-subjects procedure for Study 1.

without throwing it and to take it directly from the opponent's hands.

In order to test our hypotheses, the presentation order of the two conditions was taken into account as a covariate. In fact, we added the order variable in the procedure to counterbalance the experimental design and to exclude potential confounding effects given by the manipulation of the independent variable. A series of 2 × 2 repeated-measures analyses of covariance (ANCOVAs) were conducted to test the hypothesized significant effect of condition (natural vs. built environment) and time (T1 vs. T2) on sustained and selective attention (H1), working memory (H2), and impulse control (H3), while controlling for the presentation order of conditions. These analyses were followed by a series of protected *t*-tests (Howell, 2012) and by a *z*-test, to allow for the specific hypotheses to be tested. Finally, for PRS, a repeated measures ANCOVA was conducted to test the effect of condition (recess time in the natural vs. built environment) on perceived restorativeness, controlling for the presentation order of conditions (natural-built/built-natural); specifically, we expected a significant main effect of the natural environment condition on perceived restorativeness.

Results

H1: Sustained and Selective Attention

Results (marginal means and standard deviations) for sustained and selective attention are reported in **Table 1**. The repeated-measures ANCOVA showed a significant main effect of condition on the DV controlling for the presentation order, $F(1,73) = 85.61$; $p < 0.001$; $\eta_p^2 = 0.54$; also, results showed the non-significant effect of time on the dependent variable, $F(1,73) = 0.13$; $p = 0.72$; $\eta_p^2 = 0.002$. Results showed a non-significant two-way interaction effect of condition and time on sustained and selective attention, $F(1,73) = 0.18$; $p = 0.67$; $\eta_p^2 = 0.003$. However, we proceeded to the subsequent follow up comparisons through two protected *t*-tests (in line with the recommendations provided by Howell, 2012) in order to test for our specific H1. Results showed that, only in the natural environment, participants significantly restored their sustained and selective attention from T1 to T2. Specifically, when experiencing their recess time in the natural environment, pupils reported a significant improvement in Bells test's scores from T1 ($M = 31.85$, $SE = 0.31$) to T2 ($M = 32.61$, $SE = 0.30$), $t(75) = 2.45$; $p = 0.016$; $d = 0.40$. Yet, when the recess time occurred in the built environment, participants did not report a significant difference between T1 ($M = 31.55$, $SE = 0.34$) and T2 ($M = 31.77$, $SE = 0.34$) in their sustained and selective attention scores, $t(75) = 0.73$; $p = 0.47$; $d = 0.12$.

H2: Working Memory

Results (marginal means and standard deviations) for working memory are reported in **Table 1**. The repeated-measures ANCOVA showed a significant main effect of condition on the DV controlling for the presentation order, $F(1,71) = 21.97$; $p < 0.001$; $\eta_p^2 = 0.24$; also, results showed a non-significant effect of time on the DV, $F(1,71) = 1.72$; $p = 0.19$; $\eta_p^2 = 0.02$. Importantly, results showed a significant three-way interaction effect of condition and time on working memory, controlling for the presentation order [$F(1,71) = 43.04$; $p < 0.001$; $\eta_p^2 = 0.38$], which, therefore, was a significant covariate. The subsequent follow up comparisons were conducted through two protected *t*-tests (Howell, 2012), fully confirming H2 (**Figure 4**). In fact, only in the natural environment, participants significantly restored their working memory from T1 to T2. Specifically, when experiencing their recess time in the natural environment, pupils reported a significant improvement in digit span test scores from T1 ($M = 15.22$, $SE = 0.34$) to T2 ($M = 16.38$, $SE = 0.38$), $t(73) = 4.12$; $p < 0.001$; $d = 0.68$. Yet, when the recess time occurred in the built environment, participants did not report a significant difference

TABLE 1 | Marginal means, standard deviations and '*t*' of sustained and selective attention, working memory, and impulse control scores in Study 1.

Condition	Sustained and selective attention			Working memory			Impulses' control		
	T1	T2		T1	T2		T1	T2	
	M (SD; N)	*M (SD; N)*	*t*; sig.	*M (SD; N)*	*M (SD; N)*	*t*; sig.	*M (SD; N)*	*M (SD; N)*	*t*; sig.
Natural environment	31.85 (2.74; 75)	32.61 (2.70; 75)	t = 2.45; p = 0.016	15.22 (3.02; 73)	16.38 (3.31; 73)	t = 4.12; p < (<0.001	16.85 (3.77; 75)	16.79 (3.66; 75)	t = 0.19; p = 0.85
Built environment	31.55 (3.59; 75)	31.77 (3.45; 75)	t = 0.73; p = 0.47	15.42 (3.94; 73)	15.86 (3.27; 73)	t = 1.55; p = 0.12	16.59 (3.46; 75)	16.97 (2.72; 75)	t (1.04; p (=0.30

between T1 (M = 15.42, SE = 0.41) and T2 (M = 15.86, SE = 0.38) in their working memory score, $t(73) = 1.55$; $p = 0.12$; $d = 0.26$.

H3: Impulse Control

Results (marginal means and standard deviations) for impulse control are reported in **Table 1**. The repeated-measures ANCOVA showed a significant main effect of condition on the DV controlling for the presentation order, $F(1,73) = 4.33$; $p = 0.04$; $\eta_p^2 = 0.06$; results showed a non-significant effect of time on the DV, $F(1,73) = 0.60$; $p = 0.44$; $\eta_p^2 = 0.008$. Also, results showed a marginally significant three-way interaction effect of condition and time on impulse control, controlling for the presentation order, $F(1,73) = 3.73$; $p = 0.06$; $\eta_p^2 = 0.05$. Thus, we proceeded with the subsequent follow up comparisons, conducted through two protected t-tests (Howell, 2012), to test H3. Results showed that in the natural environment, participants did not increase their impulse control from T1 (M = 16.85, SE = 0.43) to T2 (M = 16.79, SE = 0.42), $t(75) = 0.19$; $p = 0.85$; $d = 0.03$. Neither they did in the built environment, where no difference emerged between T1 (M = 16.59, SE = 0.40) and T2 (M = 16.97, SE = 0.31) in their impulse control score, $t(75) = 1.04$; $p = 0.30$; $d = 0.17$.

H4: Perceived Restorativeness

Results (marginal means and standard deviations) are reported in **Table 2**. A repeated measures ANCOVA showed a significant main effect of condition on the DV controlling for the presentation order, $F(1,74) = 30.53$: $p = 0.000$; $\eta_p^2 = 0.292$. Results showed that children rated the natural environment as significantly more restorative than the built one (**Figure 5**).

Discussion

The results of Study 1 mostly confirmed our hypotheses and provided a series of insights related to the effect of natural

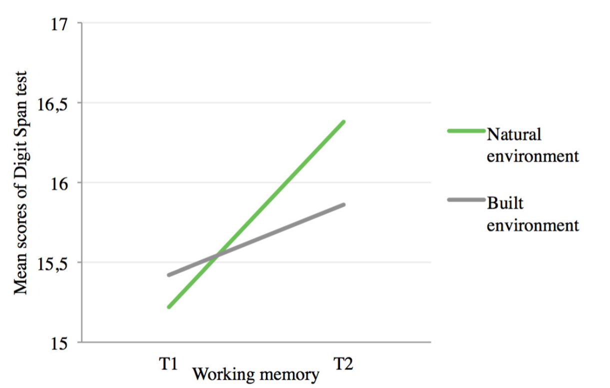

FIGURE 4 | Results of Study 1 for H2. Repeated measures ANCOVA for the three-way interaction effect of condition and time on working memory, controlling for the presentation order [$F(1,71) = 43.04$; $p < 0.001$; $\eta_p^2 = 0.38$]. Natural environment condition T1 (M = 15.22, SE = 0.34); natural environment condition T2 (M = 16.38, SE = 0.38), $t(73) = 4.12$; $p < 0.001$; $d = 0.68$. Built environment condition T1 (M = 15.42, SE = 0.41); built environment condition T2 (M = 15.86, SE = 0.38) in their sustained and selective attention scores, $t(73) = 1.55$; $p = 0.12$; $d = 0.26$.

TABLE 2 | Marginal means and standard deviations of perceived restorativeness in Study 1.

Condition	*M* (*SD*; *N*)
Natural environment	5.64 (1.59; 76)
Built environment	4.14 (2.06; 76)

environments on the restoration of pupils' attentive components. After spending their recess time in the natural environment, students performed better both in the sustained and selective attention test and in the working memory test: H1, related to the restorative effect of natural environments on students' sustained and selective attention, was confirmed at the pairwise comparison level; H2, related to the restorative effect of natural environments on students' working memory, was fully confirmed; H3, on the other hand, was not confirmed, because no restoration effect was found for impulse control irrespective of the environment in which the students spent their recess time. About this first group of results, it should be noted that our participants performed quite well in all experimental conditions; thus, it is possible that a ceiling effect occurred, buffering the omnibus effect. Accordingly, in Study 2, we slightly modified the test in order to avoid possible learning effects given by the repetition of the exact same test. Finally, H4 was fully confirmed; students reported greater perceived restoration in the natural environment condition (vs. built), controlling for the presentation order. Based on these findings, we proceeded to Study 2, which was conducted following the results and insights that emerged from Study 1. In Study 2, we further explored the effect of the natural environment on students' attention restoration.

STUDY 2: AFTERNOON RECESS TIME AND ATTENTION RESTORATION

Study 2 aimed to replicate the significant main effects of Study 1, testing attention restoration provided by a natural (vs. built) environment within the school context while introducing some changes. First, to generalize the attention restoration and perceived restorativeness results with a different procedure, we replaced the crossover design of Study 1 with a between-subjects quasi-experimental design. Furthermore, we conducted Study 2 in the afternoon instead of in the morning because children would have accumulated the full morning load; they would be more tired during the afternoon and perhaps more in need of recovery. Thus, we carried out a pretest (T1) and a posttest (T2) measurement during an afternoon (rather than a morning) school session. Also, during recess time, children were left free to play (contrary to the competitive team play activity rule in Study 1), to test attention restoration effect when children could explore and interact with the environment. These changes were made to allow the broader generalizability of the results. Furthermore, in Study 2, contrary to Study 1, only 5th grade pupils were sampled. Thus, we minimized potential problems related to the management of instructions to be given to two different age-groups of children.

Hypotheses of Study 2 were planned accordingly to the ART (Kaplan and Kaplan, 1989; Kaplan, 1995) and according to the insights provided by Study 1. Here we focused on the measurement of sustained and selective attention only (rather than working memory), as it is more involved in all school activities. Following the results of Study 1 and according to the theoretical basis of the ART, we also hypothesized a higher perceived restorativeness after recess time in the natural environment (vs. built) condition. Therefore, in Study 2 we hypothesized the following.

H5: A significant interaction effect between time (T1/T2) and condition (natural/built) on children's sustained and selective attention. Specifically, we expect that children's sustained and selective attention will be higher in the natural (vs. built) environment at T2, whereas no differences are expected at T1 between the natural and built environments.

H6: A greater perceived restorativeness after recess time in children in the natural environment condition (vs. built environment).

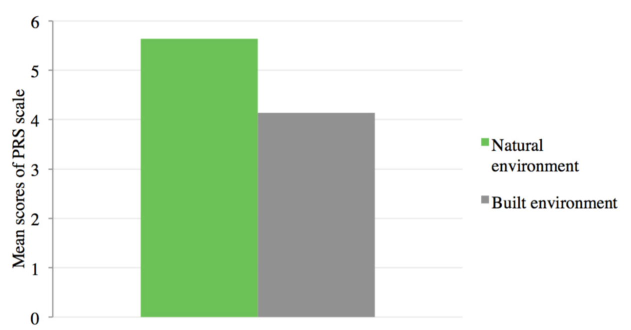

FIGURE 5 | Results of Study 1 for H4. Repeated measures ANCOVA for the effect of condition on perceived restorativeness, controlling for manipulation order, $F(1,74) = 30.53$: $p = 0.000$; $\eta_p^2 = 0.292$. Natural environment condition ($M = 5.64$, $SD = 1.59$, $N = 76$); built environment condition ($M = 4.14$, $SD = 2.06$, $N = 76$).

Method

Participants and Context

The sample was formed by primary school children from a public school located in a middle class urban area in Rome, Italy. Expert researchers selected the school as it offered both a natural area (**Figure 6**) and a built area (**Figure 7**). The two areas used for the experiment have almost equal dimensions (around 460 m^2) and are close to each other (natural elements are visible from the built area and *vice versa*). Usually, both during ordinary morning and afternoon recess time, children play outdoors, moving freely around both the natural environment and the built environment. Thirty-six children (average 10.8 years of age; 17 girls, 18 boys) participated in the study. Children were recruited from two different 5th grade classes; out of them 18 students, all enrolled in one randomly selected class, were assigned to the natural environment condition; the other 18, enrolled in the other class, were assigned to the built environment condition. During recess time, other children from other classes (not involved in the experiment) were playing outside in the built and natural environments. Similar to Study 1, informed consent was obtained from both the school and the parents; only one student participated in the study activities but was not included in the sample, because her/his parents did not sign the consent form.

Measures

Sustained and selective attention

As in Study 1, the Bells test (Biancardi and Stoppa, 1997) was used to measure selective and sustained attention. Unlike Study 1, in this study the stimulus to be detected was changed between T1 and T2, in order to diminish any learning effect risk. To keep the tests as comparable as possible to its original version, we selected new target stimuli as they were present in a number similar to the original stimulus; also, the time to detect the new target stimuli was proportioned according to their amount. At T1, the target stimulus was the "bird": there were 20 birds to be detected in 68 s; alternatively, at T2 the target stimulus was the "house": there were 21 houses to be detected in 72 s. However, as with the original version of the test, the total number of stimuli in the picture (target stimuli plus distractors) was the same for both the new versions. Wrongly marked symbols were not added to the total score, which ranges from 0 to 20 for T1 and from 0 to 21 for T2. This procedure of using new stimuli in each repetition of the test allowed us to reduce potential confounding effects (e.g., learning effect, boredom, etc.).

Perceived restorativeness

The PRS was adapted by the 8-item version used in Study 1 (Pasini et al., 2009). In this study, only the 4 items corresponding to the "fascination" and "being away" constructs were selected, they have been reported as the most relevant ones in terms of perceived restoration (Gonzalez et al., 2010). Reliability of the final 4-item scale was optimal (=0.80).

Procedure

In Study 2, a between-subject procedure was conducted (**Figure 8**). The sample, which only composed of 5th grade children, was assigned to the two quasi-experimental conditions. The procedure followed a timetable; from 8:30 a.m. to 1:00 p.m., children were enrolled in usual school activities and then had their lunchtime at the school canteen. Students were instructed as described earlier in Study 1; confidentiality and anonymity were assured with the same procedure from Study 1. At T1, from 1:00 p.m. to 2:00 p.m., children performed the attention test (Bells test), other measures have not been considered in this paper. Each one of the tests was administered collectively after a trial administration. After T1, children had their recess time from 2:00 p.m. to 2:30 p.m. (free play in a natural environment vs. built environment); during the 30 min break time, children were told to stay only in the natural (vs. built) environment and that they were free to play whatever they liked. After the break, at T2, from 2:30 p.m. to 4:30 p.m., a drawing task about their break time place was administered (this was not considered in this paper). After the drawing task, the self-report measure of the PRS—which referred to the environment (natural vs. built) they played in—was administered. Then, following the same order administered at T1, the attention test (Bells test) and the other measures were administered. Data were gathered during the end of May 2016; springtime was chosen in order to have a sufficiently milder temperature to comfortably allow outdoor play.

A 2 × 2 mixed model analysis of variance (ANOVA) was conducted to test the interaction effect of condition (natural/built) and time (T1/T2) on selective and sustained attention (H5), measured by the Bells test. Then, a one-way ANOVA was conducted to test the main effect of natural environment (vs. built environment) on perceived restorativeness (H6), measured by the PRS.

FIGURE 6 | Natural environment for Study 2.

FIGURE 7 | Built environment for Study 2.

TABLE 3 | Standardized means and standard deviations and *z*-values of sustained and selective attention scores in Study 2.

	Sustained and selective attention		
	Natural environment	Built environment	
	M (SD; N)	M (SD; N)	z; sig.
T1	−0.08 (1.21; 18)	0.102 (0.78; 17)	$z = 0.54; p = 0.59$
T2	0.37 (1.10; 18)	−0.40 (0.72; 17)	$z = 2.47; p = 0.007$

Results

H5: Sustained and Selective Attention

Before testing our hypothesis, we standardized the main variables owing to the difference in the two versions of the test used at T1 and T2; by this procedure, the omnibus effect resulting from our main analysis will not be flawed. Results (means and standard deviations) are reported in **Table 3**. A mixed model ANOVA showed non-significant main effects of time[1] $F(1,33) = 0.017$; $p = 0.897$; $\eta_p^2 = 0.001$ and condition, $F(1,33) = 0.983$; $p = 0.329$; $\eta_p^2 = 0.029$. Most importantly, results showed a significant interaction effect of time and condition on the attention score: $F(1,33) = 10.00$; $p = 0.003$; $\eta_p^2 = 0.233$ (**Figure 9**). Since the main effects were not significant, we proceeded with further analysis given the significant interaction effect and the performed standardization, the specific hypothesized effect was tested with a series of mean difference z-tests. Results of the first z-test showed, at T1, no significant difference in attention between natural ($M = -0.08$; $SD = 1.21$; $N = 18$) and built environments ($M = 0.102$; $SD = 0.78$; $N = 17$): $z(33) = 0.54$; $p = 0.59$, indicating that pupils sustained and that the selective attention was at the same level before the manipulation occurred. Then, the second z-test showed a significant difference at T2; in the natural environment condition, the attention score was significantly higher ($M = 0.37$; $SD = 1.10$; $N = 18$) than in the built environment condition ($M = -0.40$; $SD = 0.72$; $N = 17$), $z(33) = 2.47$; $p = 0.007$, indicating that sustained and selective attention was higher for pupils who spent recess time in the natural environment. On the whole, results confirmed H5 indicating that pupils' attention was higher after recess time spent in the natural environment than after recess time spent in the built environment. In other words, given the comparable baseline, our results show that sustained and selective attention is better when recess time is spent in the natural environment than when recess time is spent in the built environment.

[1] Given that after the standardization the overall mean z-score before and after is zero, no main effect of time can be expected.

H6: Perceived Restorativeness

Results (means and standard deviations) are reported in **Table 4**. The one-way ANOVA showed a significant main effect of natural environment (vs. built environment) on perceived restorativeness. Participants reported significantly higher scores in the PRS after recess in the natural area than in the built playground, $F(1,33) = 10.76$; $p = 0.031$, $\eta_p^2 = 0.246$.

Discussion

On the whole, results that emerged from Study 2 further confirmed the attention restoration effect of a natural environment on students' cognitive performance. The refined measure of sustained and selective attention used here allowed us to overcome the possible limitations that occurred in Study 1; as expected, certain components of attention are better restored if students are allowed to interact with a natural setting than with a built setting. Accordingly, and in line with Study 1, results showed a significant effect of the natural environment (vs. built environment) on perceived restorativeness, confirming that students were reported to feel more restored after spending time in the natural setting of their school.

GENERAL DISCUSSION

The general aim of this research was to investigate the restorative benefits of nature on different cognitive components in children in a school setting, a crucial context of their daily-life. Study 1 produced important new results regarding the attention restoration of different attention components that are typically depleted during school time. In fact, after spending recess time in a natural environment (i.e., at T2), students' attention scores were significantly higher than the attention scores measured at T1 (before recess time), specifically in terms of sustained and selective attention (H1) and working memory and concentration

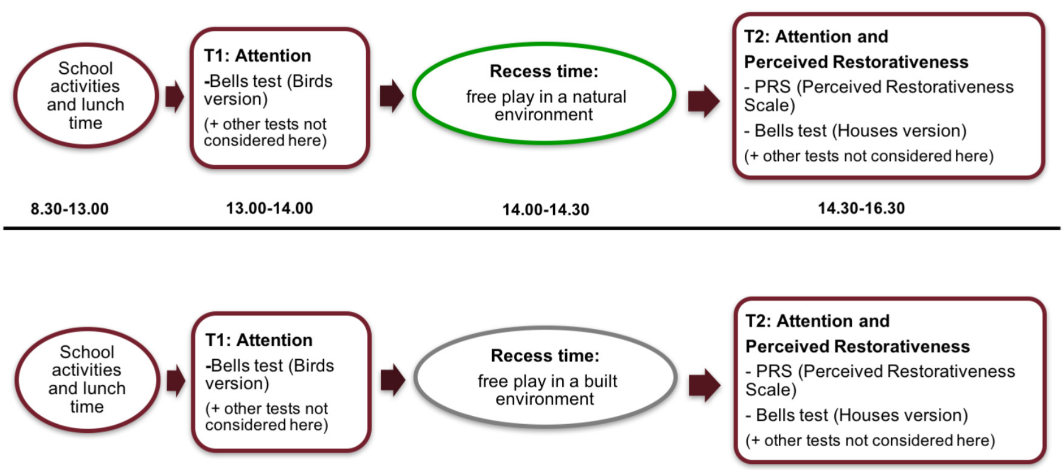

FIGURE 8 | Between-subjects procedure for Study 2.

(H2). Importantly, these effects were not found if students spent their recess time in a built environment. Furthermore, perceived restorativeness (H4) was higher after the natural environment condition (vs. built). Findings from previous studies are in line with our results, both for attention (Wells, 2000; Faber-Taylor and Kuo, 2009, 2011) and perceived restorativeness (Wells, 2000; Bagot, 2004; van den Berg and van den Berg, 2011; Chawla et al., 2014; Bagot et al., 2015; Berto et al., 2015). However, no effects were found on impulse control irrespective of the environmental setting (Schutte et al., 2015), disconfirming H3.

In Study 1, we used a quasi-experimental procedure via a crossover design. This design and the crossed order of the conditions represent controlling factors, which strengthen the interpretation of the results by ruling out some alternative explanation or confounding factors. Other important features of Study 1 consist of the pretest and posttest measurements comparing two school environments that already coexist in a school context; we could keep both the outdoor feature and the activity carried out constant in this study. Therefore, we only manipulated the location of the activity, that is, the crucial environmental feature (natural vs. built) of our study. In this respect, compared to the standard relevant literature, results from our comparisons are noteworthy. Also, it should be noted that these results emerged after the usual study activities conducted in the morning, meaning that our study was realistically embedded in the school routine.

Findings of Study 1 were crucial in designing Study 2 (based on a mixed-model experimental design), in which an interaction effect of time (T1/T2) and condition (natural/built) was hypothesized; specifically, higher attention scores were expected in the natural environment condition at T2. In Study 2, we introduced some changes in the method, in order to rule out potential errors or confounding effects related to the within-subjects procedure used in Study 1: firstly, the experiment was conducted in the afternoon school time, when children may need more restoration; secondly, we used a revised measurement of sustained and selective attention in order to rule out the potential learning effect of repeating the same test more than once (as it was in Study 1); finally, we chose a sample composed of older children (5th grade only) in order to capitalize on their higher ability in instruction comprehension, avoiding other potential confounding factors.

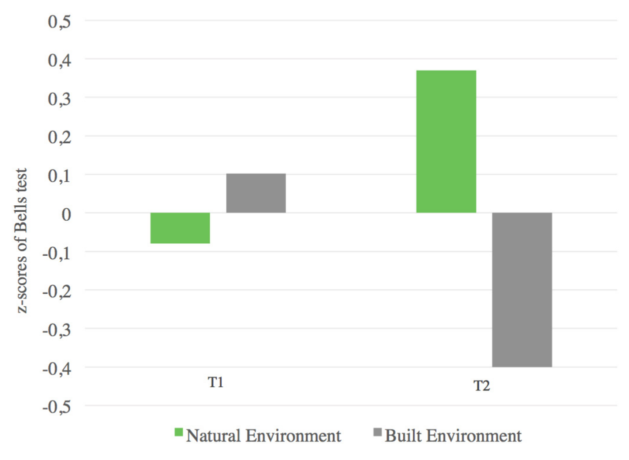

FIGURE 9 | Results of Study 2 for H5. *z*-test for sustained and selective attention scores at T1; natural environment condition (M = –0.08; SD = 1.21; N = 18) and built environment condition (M = 0.102; SD = 0.78; N = 17): $z(33) = 0.54$; $p = 0.59$; *z*-test for sustained and selective attention scores at T2; natural environment condition (M = 0.37; SD = 1.10; N = 18) and built environment condition (M = –0.40; SD = 0.72; N = 17), $z(33) = 2.47$; $p = 0.007$.

TABLE 4 | Means and standard deviations of perceived restorativeness in Study 2.

	Perceived restorativeness
	***M* (*SD*; *N*)**
Natural environment	5.33 (2.63; 18)
Built environment	2.85 (1.71; 17)

Thus, as expected, Study 2 gave a clearer picture in terms of the anticipated results, by confirming the hypothesized effects. In fact, an interaction effect of condition (natural vs. built) and time (T1 vs. T2) was reported on sustained and selective attention (H5), and a main effect of the natural (vs. built) environment condition was reported on perceived restorativeness (H6); pupils recovered their attention from T1 to T2 after an afternoon break only in the natural setting, and they perceived more restoration after a break in the natural setting (rather than after a break in an equally outdoor but built place). An interesting result was also shown in the built environment condition; in fact, unlike Study 1, attention scores decrease from T1 to T2 in the built environment. As a field study, this result can be better understood if both the characteristics of the environment and the children's habits during school time are considered. As described earlier, the natural and built environments were close to each other, and during normal recess time children could freely move around both the environments. The instruction to play only in the built environment could have sounded like a limitation for children: they were repeatedly asking the researchers to let them also play in the natural environment. So, playing only in the built environment could have put them in a negative mood, and recess time could not have been restorative for them. This may be identified as a constrained restoration (Hartig et al., 2007), which occurs when the renewal of depleted resource is obstructed by some circumstances (in this case not being allowed to play in the natural environment). One possibility, in further research, should be to investigate the relation between decreased attention in the built environment condition and children's recess time habits. Moreover, the between-subject design was, in this case, a limitation, providing only one recess time measurement for each condition; in further studies, a crossover design could help to control this effect.

Considering the natural environment condition, results are in line with the findings from Study 1 but also from other studies (Wells, 2000; Faber-Taylor et al., 2001; Bagot, 2004; van den Berg and van den Berg, 2011; Corraliza et al., 2012; Bagot et al., 2015; Berto et al., 2015). Furthermore, the present research showed the positive effect of nature on psychological restoration: (a) in a field study, providing both a crossover and a between-subject design; (b) in a real life situation (our study was embedded in school activities); (c) using preexistent standardized tools for measuring attention involved in school time activities; (d) comparing two different outdoor environments; (e) testing attention restoration in the morning and in the afternoon; (f) assessing attention restoration that occurred after recess time spent in a team play activity and with free play. Specifically, as previous findings have suggested (Bagot et al., 2015), children's perceived restorativeness experiences during playtime are considered as more important than physical characteristics of the school playgrounds. In literature, the positive effects of nature on attention are reported both when children play in a competitive activity and when they are left free to play (Grahn et al., 1997; Fjørtoft and Sagaie, 2000). In our research, we showed that two equally important activity formats (standardized team play activity in Study 1 and free play in Study 2) are capable of activating the restorative process, provided that a natural (vs. built) outdoor setting is the actual setting for such activities. Moreover, in Study 2 the new 4-item PRS scale (composed of fascination and being away items only) showed optimal reliability (see section "Perceived Restorativeness"). This shorter scale seems more suitable for children, who can be more fatigued by long procedures. Thus, it becomes a useful tool for measuring perceived restorativeness, which is now available for further studies, considering that fascination has been identified as the most important factor in restorative experiences (Staats, 2012).

Limitations and Future Directions

Although the results that emerged showed a quite clear pattern of effects, some caution should be called in when interpreting such results. First, it should be noted that in Study 1 we might have incurred a ceiling or learning effect due to the repetition of the test materials, which might have buffered the omnibus effect that was found; beyond the significant increase that emerged in the natural environment condition, a slight (yet, non-significant) increase in the attention scores was also registered in the built environment condition. As a *post hoc* speculation, if indeed a ceiling or learning effect occurred in Study 1, this could be related to the version of the go-no-go test. This test, in fact, is normally used to account for attention deficits, and it could not properly detect the small attention fluctuations within the normal population; therefore, it is possible that this specific test, within these conditions and procedure, was simply too easy for the sampled children. Potentially, a between-subjects procedure or a modified test material could solve this issue, as demonstrated in Study 2 where sustained and selective attention was measured by selecting the different sets of target stimuli to be administrated at T1 or T2.

Second, the hypothesized significant increase in impulse control scores (H3) from T1 to T2 in the natural environment condition was unexpectedly unconfirmed (Faber-Taylor et al., 2002; Mårtensson et al., 2009). Although a specific explanation for this unexpected result cannot be drawn from the present research (given the lack of other potential explanation variables), this finding is consistent with recent results showing a similar absence of effect on a similar topic (Schutte et al., 2015). Therefore, further research should deeply focus on the effects of natural environments on impulse control, yet, possibly including mediator or moderator variables, which could eventually explain such specific processes.

Finally, another important point to be discussed is how the children spent their recess time. As highlighted from the present research, nature provides benefits on attention when children are engaged in competitive and fatiguing team play activity (Study 1) and in free play as well (Study 2). In Study 1, children were involved in a team play activity, which were physically and mentally demanding and competitive. On the one hand, by standardizing the break time we controlled for various possible confounding factors, and the activity provided was similar to the usual games children play during recess (e.g., football). On the other hand, though, this team play activity might have reduced the possible restorative effects of nature, because the environment was simply a surrounding background. This arrangement did not match the common relaxing activities usually carried out to elicit attention restoration from natural environments. That is, it did not properly correspond to the prototypical people-environment interaction theorized in the ART for triggering the restorative experience (Hartig et al., 2003). However, results on the perceived restorativeness scores show that children still perceived the differences between the natural and built environments. In fact, even if they did not directly interact with their surroundings with a proper exploration or free play, they rated the experience in the natural surrounding as more restorative than in the built one (keeping constant the time slot, duration, and activity carried out, before and during the break). Potentially, any team activity possessing a proper interaction with the natural environment should, therefore, only increase the restorative effects showed here. Accordingly, in Study 2 recess time was organized to allow children to directly interact with the environment (coherent with the classical restorativeness literature, Hartig et al., 2003). Children were left free to play and explore the environment, engaging in different types of activities and games. This solution overcomes the limits of Study 1 in terms of activity operationalization, thus, avoiding the need to put the environment as just a surrounding background. This, in fact, confirms, and even strengthens, the role of the natural environment in influencing children's ratings of perceived restorativeness, which were significantly higher after a break in the natural (vs. built) environment condition. However, this can further present a factor that differently impacts the activation of the restorative process; in fact, when children played freely, they could do various activities, and this consequently could elicit multiple variables which are harder to control (e.g., the type of play, the choice of peers to play with, the possibility to have a conflict with a peer, etc.). These variables could have affected the children's performances measured at T2. Future research could better address these issues, for example by monitoring playtime via videotaping and measuring children's activity.

On the whole, the decision to assess attention restoration and perceived restorativeness in a quasi-experiment conducted in a field produced both pros and cons. On the one hand, the benefits of nature on children are assessed in their real-life contexts and, so, our results are related to ecologically relevant processes, relations, and activities. On the other hand, various variables are harder to control in a field study than in a laboratory study (e.g., different features of both environments, children's habits for recess time, normal school activities, etc.). In fact, even if we tried to control for various external factors (e.g., teachers were told to work on the same subject and with a comparable cognitive demand across the various days of administration), certainly there are uncontrollable variables that can interfere with the experiment.

Consequently, taking into account the limitations and findings of the present research program, further studies should assess whether experiences with nature in school settings can affect not only perceived restorativeness and cognitive performance such as attention (as demonstrated in the present study) but also other psychological variables related to children's experiences at school, such as emotional and affective reactions or social attitudes and behaviors. Furthermore, in the present research (specifically, in Study 1), we ruled out any possible effect related to the order of presentation of our experimental conditions. Yet, we acknowledge that having pupils take their recess time in the built environment first and in the natural environment afterwards (or *vice versa*) could have eventually exerted an effect on their attention restoration and on other related psychological processes; future research should, therefore, investigate such issues. Finally, starting from the proposed experimental procedure, research should develop (quasi-) experiments along new lines, such as integrating psychological measurements with physiological parameters, as some studies already have done (Berto et al., 2015); offering a more precise evaluation of characteristics and dimensions of the tested natural environments (e.g., in terms of presence of natural elements and type of greenery, as described in Bagot et al., 2015); and carefully assessing children's play and activity features. As Chawla (2015) argued, an optimal option in this field should be the development of an integrated method, using both correlational and experimental designs and ethnographic methods.

CONCLUSION

The fundamental importance of providing pupils with school environments that can foster positive learning as well as promoting psychological and physiological well-being is, of course, critical. The ideal school environments seem to be those with an attractive outdoor area, where children can be active both inside and outside of the classroom (Gifford, 2007). Evidence-based design guidelines from research in environmental and architectural psychology should lead to interventions, taking into account children's needs and contributions in this process (Sanoff and Walden, 2012).

Concrete implications and practical applications should be used for both existing and new school environments, in order to better organize the school's management and activities by incorporating children's outdoor natural environments as a crucial feature. In the present manuscript, we provide evidence that natural environments in schools can help students with better recovery of their attention resources, as well as in feeling more restored and less stressed and fatigued. In light of these results, and drawing on the more general literature, we present a set of positive outcomes related to students' interaction with nature; these outcomes can lead policy makers, schools managers, teachers, and practitioners in general, to promote psychological and physiological well-being of the students in a broader sense.

1. As it has emerged from the present research, after recess time in nature, children in schools show better recovery of their attention abilities and perceive time spent in a natural environment as more restorative than in a built one. This recovery process happens both in the morning and in the afternoon recess time. Literature shows that greener schools help children to concentrate (Bagot, 2004; Bagot et al., 2015; van den Berg et al., 2016) and enhance their attentive abilities (Grahn et al., 1997; Mårtensson et al., 2009).
2. Nature provides benefits for improving attention when children are engaged both in a competitive team play activity and in a free play (Grahn et al., 1997; Fjørtoft and Sagaie, 2000).

Thus, in our view, based on the results that emerged here and in the broader literature on the present topic, green spaces and natural areas should be present in every school; furthermore, they should be used both for leisure and educational activities. Yet, if this is not possible, pupils should have the possibility to get in touch with nature and to engage in activities and learning experiences within natural environments as much as possible, in order to boost their psychological and physiological well-being.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Ethic Committee Guidelines of Sapienza Università di Roma, with written informed consent from all subjects. All participants' parents gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Ethic Committee Guidelines of Sapienza Università di Roma.

AUTHOR CONTRIBUTIONS

GA, SD, PP, and MB jointly planned the research design and built the procedure. GA, AG, and VC collected data and prepared the data for the analyses. GA and SD carried out data analyses, with the help of feedback from MB. GA drafted the manuscript together with MB, with feedbacks from SD, IP, AG, VC, and PP.

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Outdoor Education in Italian Kindergartens: How Teachers Perceive Child Developmental Trajectories

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Outdoor Education (OE) refers to organized experiential education that takes place in the outdoor, characterized by action-centered and thematic learning processes. Literature shows how OE may have beneficial effects on different areas of child development, including cognitive abilities, social skills, and motor development. This relationship is not necessarily linear, but moderated by different variables. Until now, few studies have examined, using rigorous methods, the role of OE in children's development and studies of preschool aged children remain lacking. The current study aimed to explore teachers' perceptions of children's developmental trajectories over 2 school years, investigating whether teachers' perceptions differed between two kindergartens, one characterized by a consolidated OE approach and the other one characterized by a more traditional method of education. The sample was composed of 20 teachers, evaluating 93 children aged 3–5 ($M = 46.95$ months, $SD = 6.73$; 42 males): 13 teachers were from a traditional kindergarten (Traditional Group- TG) and evaluated 52 children; 7 teachers were from an OE kindergarten (Outdoor Group—OE) and observed 41 children. All the teachers completed the Kuno Beller Developmental Tables (Mantovani, 1995), in order to describe specific child developmental areas in 4 consecutive moments during 2 school years (T1-T2: January-May 2014; T3-T4: October 2014-May 2015). The 20 teachers also completed the "Outdoor Activities/Trips Diary," an instrument created for this study to collect qualitative data on the characteristics of outdoor activities. Results showed that, in all the developmental areas, OE teachers perceived higher scores over time were found for the Outdoor Group compared to the Traditional one. Specifically, GLM ANOVAs Repeated Measures revealed a significant interaction of the 2 variables Time and Groups ($p < 0.001$): contrast analyses showed that OE children, compared to the TG children, were perceived by their teachers with higher levels in all developmental areas at T1 and T2, but not at T3 and T4. The findings suggest that the OE activites, compared to indoor ones and according to teachers' perceptions, offer greater opportunities to promote the child's development at different levels, especially when children are younger. Future studies are recommended analyzing possible moderating variables and long term effects of OE.

Keywords: outdoor education, child development, kindergartens, longitudinal study, teachers, Italy

INTRODUCTION

Outdoor Education: the Benefits for Child Development

In recent years, the scientific literature in the field of pedagogy, education, developmental, and educational psychology has dedicated increasing attention to the study of Outdoor Education (OE) and its implications for child development, both on physical and psychological levels.

OE has been described as "an environment focused educational approach characterized by action-centered and thematic learning processes frequently involving outdoor activities" (Dahlgren and Szczepanski, 1998, p. 3). Higgins (1995) refers to OE as education "in" (outdoor activities), "through" (personal and social education), "about" (environmental education), and "for" (sustainability) the natural environment. These definitions emphasize the strong link between OE and the outdoor environment where the activities take place. In fact, the beneficial effects of OE on child development are substantiated by more general evidence that spending time within a natural environment offers a range of health benefits for the human being. For children, some effects may be due, at least in part, to their greater neuronal plasticity (Wells and Evans, 2003).

In detail, the non-structured and constantly changing natural context represents the ideal environment for improving child health and development. Literature has indicated that promoting outdoor play can have a significant impact on children's physical activity (Harrington and Brussoni, 2015), which in turn improves blood pressure, cholesterol, and bone density (Lewicka and Farrell, 2007; Copeland et al., 2012), contributing to the reduction and prevention of child obesity (Raustorp et al., 2012). Children are more physically active when playing outdoors. Indeed, Kneeshaw-Price et al. (2013) reported that 6- to 11-year-old children were active 41% of time outdoors compared to 18% indoors. Also, physical activity in outdoor places may lead to additional positive effects compared to indoor physical activity (Thompson Coon et al., 2011; Pesce et al., 2016), such as a lower risk for developing chronic illnesses (Strong et al., 2005) and poor mental health (Mitchell, 2013).

In addition, it has been reported that children's movement and physical activity in nature may promote favorable health behaviors and attitudes about physical fitness (Bandura, 2004; Barnett et al., 2006), by producing higher levels of physical activity in adulthood (Calogiuri, 2016).

Outdoor activities also provide the possibility of experimentation and exploration (Weber, 2010; Mahdjoubi and Akplotsyi, 2012). Exploratory behaviors in nature strengthen the locomotor and immune systems and children are therefore less prone to illness, and consequently more balanced.

Exploratory activities may also contribute to the development of self-esteem and resilience (Ceciliani and Borsari, 2009) and may foster the development of imagination and sense of wonder, promoting creative knowledge (Cobb, 1977; Dahlgren and Szczepanski, 1998; Ewert et al., 2014). In line with these findings, McAnally et al. (2018) have evaluated the effects of a 15-week outdoor education program with no access to electronic media among 14-year-old boys, reporting an improvement in creative thinking and wellbeing.

In social-relational terms, outdoor activities promote social cohesion, reduce the tendency toward conflicts and stimulate the development of a sense of autonomy and self-sufficiency (Kaplan and Kaplan, 1994; Moore, 1996). In terms of cognitive development, OE stimulates intelligence and enhances mental focus, attention, reflection, and memory (Basile, 2000; Miklitz, 2001; Hartig et al., 2003; Szczepanski, 2007).

In primary school contexts, OE has been recognized as useful in improving peer work, enhancing leadership development, improving problem-solving skills, and reducing antisocial and deviant behaviors (Fjørtoft, 2001; Pyle, 2002; Malone and Tranter, 2003).

Despite this body of research, the literature still lacks of specificity in the investigation of outdoor benefits, especially on psychological development and mental health. Definition and operationalization of psychological constructs are not easy and the mental health outcomes are often limited to self-confidence, self-esteem, or locus of control (Gustafsson et al., 2011). Few exceptions are present in literature; for example, Gustafsson et al. (2011) investigated different areas of child mental health and showed how an OE intervention, lasting 1 year, was beneficial for children aged 6–12 years, promoting, especially in boys, a decrease in different mental health problems. Furthermore, a previous study by two of the authors of this paper (Monti et al., 2017) showed positive effects of a 1-year OE intervention in nursery schools, for children aged 1–3 years: compared to children in more traditional nursery schools, following daily OE activities children showed greater improvements in cognitive, social and emotional development, motor skills, and body functions (e.g., breathing, digestion, sleeping). A study by Ulset et al. (2017) followed a cohort of 562 Norwegian children aged 3 to 7 years and measured different mental health dimensions, finding that inattention-hyperactivity symptoms tended to decrease and short-term memory (as measured by a digit span task) tended to improve as time spent outdoors in school increased.

Outdoor Education and Child Development: Moderating Variables and the Role of Teachers

Considering the beneficial influence of an OE approach on child development, it is relevant how OE is implemented in daily routines in educational contexts. Many European and non-European countries have included OE in daily activities in nurseries, kindergartens, and primary schools. For instance, in Scandinavian countries, which highly value children's outdoor play and activities as a relevant part of daily lives (Norðdahl and Einarsdóttir, 2015), many kindergartens offer high quantities of outdoor activities (Borge et al., 2003; Nilsen, 2008).

However, it is not simple to implement OE and the relationship between OE and child development outcomes is not necessarily linear. Indeed, different factors may influence this relationship and some of them may act as moderators, including child's gender, child temperament, family socioeconomic status, and parents' mental health (Ulset et al., 2017). Also, variables concerning the kindergarten or day-care center may play the role of moderating factors, such as group size and teacher-child ratio, barriers related to the natural context and/or the architectural structures (Ulset et al., 2017), and availability of specific play objects and materials in outdoor places (Brown et al., 2009).

Other important variables that may moderate the relation between activities in outdoor places and promotion of children's development include the quality of the child-teacher relationship (Tonge et al., 2017) and the parents' and teachers' perceptions and beliefs about the importance of the outdoor environment and OE (Insenberg, 1990; Kagan, 1992; Pjares, 1992; Fang, 1996). As far as parents are concerned, it has been shown that they usually understand the benefits of natural play spaces, appreciating natural environments much more than urban ones for their children's activities and learning (Wang et al., 2018). Regarding teachers' perspectives McClintic and Petty (2015), have explored the beliefs about preschool outdoor play, reporting that teachers interviewed in their study considered outdoor play essential along with the children's opportunity to experience free play. However, they perceived their role as limited to supervising children's activities and they did not fully understand the potential of the outdoor environment for child development.

Teachers have the tasks of planning activities, providing challenging and creative environments, supporting child strengths, all while remaining attuned to children's needs and avoiding disrupting or interrupting their activities (Wilford, 1996; Frost et al., 2011). Therefore, the ways that teachers explain and propose OE activities to children, recognize their natural need to move and experiment and support their attempts, sensorial experiences, and actions in the outdoor context are critical to success (Nelson, 2006; Gehris et al., 2014). However, OE is rarely held as a priority by many teachers (McClintic and Petty, 2015) and they tend to give less time and attention to outdoor activities compared with indoor activities (Wellhousen, 2002).

Based on this, the research exploring teachers' perceptions following implementation of OE is essential but still poor. There is a need to investigate more accurately whether and how teachers perceive the usefulness of OE to foster child development. It is also relevant to investigate how they promote outdoor activities, structure play and outdoor environments for different child age ranges, according to different environmental places (Hu et al., 2015).

The Current Study

The current study aimed to explore teachers' perceptions of children's developmental trajectories over 2 school years, comparing a kindergarten with an OE approach and a kindergarten with a traditional education approach (that is, using the outdoor environment only as a recreational space).

The reasons for choosing preschool age were the following: (a) during this time period, children's development is characterized by acquisition of skills such as symbolic play, differentiation of imaginary vs. real, theory of mind, story-telling, counting, and eating independently (Sheridan, 2008); (b) Outdoor Education in Italy is more frequently applied in kindergartens compared to primary schools.

More specifically, the research questions posed in this study were developed based on the literature evidence that OE contributes to motor, cognitive, social, and emotional skills development beginning in early childhood. Furthermore, research questions were developed based on a previous study by two of the authors (Monti et al., 2017), comparing OE vs. traditional educational approach in 1 to 3 year-olds in nursery schools.

Based on the results from this study, we hypothesized that, according to teachers' perception, children aged 3–5 years old attending an OE kindergarten would demonstrate greater improvement in development compared to children in a traditional kindergarten. Second, we aimed to investigate if the teachers' perception about child development would change or remain stable across a wide period of time, so we collected different time assessments during 2 consecutive school years.

We also aimed to explore the characteristics of outdoor activities in both kindergartens, e.g., duration, daily weather, and type of activity: we expected teachers from the OE kindergarten to show a greater tendency to go and stay outdoors during the 2 years, both in terms of frequency and duration of outdoor activities, and also with a different psycho-educational quality of the time spent outdoors.

MATERIALS AND METHODS

Participants

The total sample included 20 teachers working at the two kindergartens: 13 teachers worked in the kindergarten adopting traditional educational activities and represented the Traditional Group (TG), while 7 teachers worked in a kindergarten applying a continuous OE program, representing the Outdoor Education Group (OE). These 7 teachers took part in the same training in OE, characterized by a 15-day intensive training in an international Outdoor Education and Learning Centre (Sweden) and 1-year continuous training in Italy. Characteristics of the teachers in terms of years of experience in teaching are shown in **Table 1**; no significant differences were found between the two groups of teachers ($p > 0.05$).

TABLE 1 | Descriptive characteristics for teachers and children.

Teachers	**OE group (*N* = 7)**	**Traditional group (*N* = 13)**
Years of teaching, mean (SD)	8.57 (4.35)	13.61 (9.83)
Years of experience in OE, mean (SD)	8.71 (3.4)	–
Children	**OE group (*N* = 41)**	**Traditional group (*N* = 52)**
Mean age (SD)	47.20 (6.52)	46.75 (6.95)
Gender, males (%)	13 (31.7)	29 (55.7)

During the two school years, the teachers evaluated 230 children aged 3–5 years ($M = 48.7$ months, $SD = 10$; 119 males). Based on the aims of this study, only the children with 4 complete evaluations across the 2 years were considered. Therefore, the total sample of children was 93, aged 3–5 years ($M = 46.95$ months, $SD = 6.73$; 42 males). Specifically, the TG teachers evaluated 52 children ($M = 46.75$, $SD = 6.95$; 29 males), and the OE teachers observed 41 children ($M = 47.20$, $SD = 6.52$; 13 males) (**Table 1**). The children attending the two kindergartens were homogenous in terms of age, gender, and socioeconomic status. Cases of social or developmental risk were not included in the study sample.

The present study was approved by the Directors and the Teachers' Colleges of the two kindergartens, in accordance with the recommendations of school rules. Children's parents were informed about the research and volunteered their child's participation in the study, providing the written informed consent in accordance with the Declaration of Helsinki.

Procedure

The study was conducted between January 2014 and May 2015 and involved two kindergartens of Emilia Romagna region, in the North of Italy. One kindergarten was chosen because the teachers were experienced and trained in the Outdoor Education approach (OE Group) and OE represented a daily routine. The other kindergarten was characterized by a more traditional educational approach (Traditional Group) and the teachers were not trained in OE.

All the teachers involved in the study completed the Kuno Beller Developmental Tables (Mantovani, 1995) in four consecutive moments during 2 school years (T1-T2: January-May 2014; T3-T4: October 2014-May 2015). The teachers were specifically trained in the use of the Kuno Beller Developmental Tables before starting the data collection; two psychologists with expertise in using this tool held this training, which was characterized by explanations of the items, coding of children's behaviors, and accurate supervision. The training period lasted 1 month in both kindergartens for all the teachers involved in the research.

In addition to the Kuno Beller Developmental Tables, the teachers completed the "Outdoor Activities/Trips Diary" every time they went outdoors with their classes.

Measures

Child Development

All the 20 teachers completed the Kuno Beller Developmental Tables (Mantovani, 1995), in order to describe children's development according to specific areas. The Kuno Beller Developmental Tables represent a useful instrument to collect adults' (i.e., parent or teacher) perception of child development and to plan educational activities. The Kuno Beller includes the following 8 developmental areas: *Domain of Body Function, Awareness of the Surrounding Environment, Social and Emotional Development, Play, Language, Cognitive Development, Gross* and *Fine Motor Skills*. In particular, *Domain of Body Function* collects the progressive perception of the self, the child's autonomy, in terms of physical care and many body functions (e.g., sleeping, eating), while *Awareness of the Surrounding Environment* defines the progressive awareness the child has of the surrounding world.

In order to complete the Kuno Beller Developmental Tables, the adult starts answering a detailed list of items from the development phase in which the child does all the things described and stops in the phase where s/he does not see any behavior depicted. This is repeated for all the eight developmental areas. In order to complete the Kuno Beller, parents or teachers have to report what children do in daily situations, therefore the more they observe the child the more the answers to the test will be accurate. As a result, the instrument allows obtaining a picture of the level of child development for every developmental domain and of the relationships among the different domains.

Outdoor Activities

The "Outdoor Activities/Trips Diary" is an instrument created for the purposes of this study to collect qualitative data on the characteristics of outdoor activities. Specifically, the teachers used it for the 2 years after each trip, answering the following items: *Period of the year*, *Daily Weather* (sunny, cloudy, foggy, light rain, snow, windy), *Place* (schoolyard, park, urban space, other), *Group* (small, max. 5 children; big, max. 10 children; whole class), *Duration* (minutes <30, 30–60, 60–120, >120), and *Activity* (free play, guided play, free exploration, guided exploration, physical education, guided trip, other).

With regard to *Place*, the schoolyard of the two kindergartens had different characteristics: the yard of the OE kindergarten consisted of a green park with some centuries-old trees (e.g., firs, willows, maples), plants and flowers, and without any play structures. The traditional schoolyard contained grass and cement without larger plants, trees, and play structures.

With regard to *Activity*, "free play" means children play games they choose and with materials they want to play with. In contrast, "free exploration" means teachers give one simple instruction to children regarding a specific explorative task to do and children decide how to perform it. For instance, the teacher may give children magnifying lenses, suggesting that they look for ants, but letting them decide how to do it. "Guided exploration" includes teachers giving several instructions to children in order to perform a specific explorative task. "Guided trip" consists of a school trip with a specific aim that is shared with children at the moment of planning the trip (e.g., visiting a public park outside the kindergarten, or visiting an aquarium in town). The category of activity called "other" consists of all the activities not included in previous categories.

Statistical Analyses

Mixed-Model Repeated Measures analysis of variance (ANOVA) was used to analyze changes in children's development across the 4-time-points assessments in all the selected Kuno Beller domains for both groups, considering as independent variables: group (Outdoor vs. Traditional), period (T1, T2, T3, T4), and gender (males vs. females). In order to explore the characteristics of the outdoor activities for both the OE and Traditional groups, descriptive analyses were performed on the data from the Outdoor Activities/Trips Diary. Data analyses were run using the Statistical Package for Social Sciences (S.P.S.S.), version 21.0.

RESULTS

Kuno Beller Developmental Tables

Descriptive statistics of Kuno Beller Developmental Tables are reported in **Table 2**.

Results from Mixed-Model Repeated Measures analysis of variance (ANOVA) showed no significant gender differences. However, a significant main effect of Time ($p < 0.001$) on children's development was found, suggesting that children from both groups progressively increased their skills from T1 to T4, according to their teachers' perspective. This was observed for all eight developmental areas as measured by Kuno Beller: *Domain of Body Function, Awareness of the Surrounding Environment, Social and Emotional Development, Play, Language, Cognitive Development, Gross* and *Fine Motor Skills*.

In addition, significant Time by Group interactions were found for the eight Kuno Beller domains (all $p < 0.005$), indicating that children's development differed over time between the OE and the Traditional groups (**Table 3**). Specifically, contrast analyses revealed significant linear interactions, with children in the OE Group showing, at T1 and T2, significantly higher mean values compared to the Traditional Group in the following developmental areas: *Domain of Body Function* [$F_{(1, 91)} = 6.99$, $p = 0.010$] (**Figure 1A**), *Social and Emotional Development* [$F_{(1, 91)} = 14.83$, $p = 0.000$] (**Figure 1B**), *Play* [$F_{(1, 91)} = 18.27$, $p = 0.000$] (**Figure 2A**), *Language* [$F_{(1, 91)} = 19.15$, $p = 0.000$] (**Figure 2B**), *Cognitive Development* [$F_{(1, 91)} = 32.23$, $p = 0.000$] (**Figure 3A**), *Fine Motor Skills* [$F_{(1, 91)} = 16.49$, $p = 0.000$] (**Figure 3B**).

In *Awareness of Surrounding Environment* [$F_{(1, 90)} = 8.98$, $p = 0.004$] (**Figure 4A**) and *Gross Motor Skills* [$F_{(1, 90)} = 5.49$, $p = 0.021$] (**Figure 4B**), children in the OE Group showed significantly higher mean values compared to children of the Traditional group, but only at T1.

Outdoor Activities/Trips Diary

Results showed that children in the OE kindergarten went outdoors more frequently compared to the children in the traditional kindergarten: 467 times compared to 176 in 2014; 522 times vs. 236 in 2015. In analyzing the characteristics of the outdoor activities completed by both groups, we did not find any differences regarding the *weather conditions* in 2014 (**Figure 5**), as both groups went outdoors more frequently during a "sunny day" rather than during other weather conditions. During 2015, the OE Group went outdoors more frequently on sunny days compared to the Traditional Group; in contrast, on cloudy or lightly raining days, the Traditional Group went outside with higher frequency than the OE group.

The OE Group, in 2014, went out more frequently compared the Traditional Group during January, February, and in June, while the Traditional Group went out more frequently during March, April and May (**Figure 6**) ($\chi^2 = 48.318$, $p = 0.0005$). Similarly, during 2015, the OE Group went outdoors more frequently during October, November, and June, while the Traditional Group preferred to go outdoors in February, March, April, and May (**Figure 6**) ($\chi^2 = 181.532$, $p = 0.0005$).

Regarding the *types* of activities, in 2014 the OE Group more frequently chose physical education and structured exploration, while the Traditional Group preferred to go outside for free exploration (**Figure 7**) ($\chi^2 = 23.820$, $p = 0.001$). In 2015, the OE Group more frequently chose physical education and free exploration, while the Traditional Group preferred the school trip, structured play, structured exploration

TABLE 3 | Results from mixed-model repeated measures ANOVA: Values for linear Time X Group interactions.

Period X Group	df	*F*	*p*	η_p^2
Kuno domain of body function	1	6.99	0.010	0.27
Kuno awareness of surrounding environment	1	8.98	0.004	0.30
Kuno social and emotional development	1	14.83	0.000	0.38
Kuno play	1	18.27	0.000	0.41
Kuno language	1	19.16	0.000	0.42
Kuno cognitive development	1	32.23	0.000	0.51
Kuno gross motor skills	1	5.49	0.021	0.24
Kuno fine motor skills	1	16.49	0.000	0.15

TABLE 2 | Descriptive statistics of Kuno Beller developmental tables.

Domains	OE group (*N* = 41) Mean scores (SD)				Traditional group (*N* = 52) Mean scores (SD)			
	T1	T2	T3	T4	T1	T2	T3	T4
Body function	11.02 (0.81)	11.53 (0.77)	12.16 (0.71)	12.81 (0.71)	10.15 (1.03)	11.01 (1.22)	11.96 (0.94)	12.39 (1.24)
Awareness of surrounding environment	11.35 (1.22)	11.75 (0.93)	12.30 (0.91)	13.20 (0.66)	10.07 (1.80)	11.17 (1.37)	12.03 (1.11)	12.86 (1.09)
Social and emotional development	11.18 (1.09)	11.72 (0.67)	12.22 (1.01)	12.96 (0.94)	10.24 (1.14)	11.03 (1.31)	12.22 (1.03)	12.86 (0.94)
Play	11.26 (1.08)	11.87 (0.57)	12.35 (1.14)	13.15 (0.99)	9.89 (1.22)	10.88 (1.43)	11.88 (1.24)	12.78 (1.14)
Language	11.01 (1.30)	11.50 (0.73)	12.01 (1.13)	12.88 (1.03)	9.83 (1.53)	10.87 (1.48)	11.80 (1.37)	12.74 (1.24)
Cognitive development	10.94 (0.89)	11.30 (0.54)	11.78 (0.82)	12.49 (0.95)	9.63 (1.35)	10.59 (1.40)	11.43 (1.28)	12.58 (1.31)
Gross motor skills	11.79 (1.01)	11.99 (0.76)	12.72 (1.04)	13.32 (0.80)	10.87 (0.91)	11.74 (1.24)	12.37 (1.05)	12.96 (1.07)
Fine motor skills	10.86 (0.76)	11.34 (0.77)	11.86 (0.56)	12.73 (0.88)	10.01 (1.34)	10.72 (1.46)	11.73 (1.39)	12.56 (1.28)

T1, January 2014; T2, May 2014; T3, October 2014; T4, May 2015.

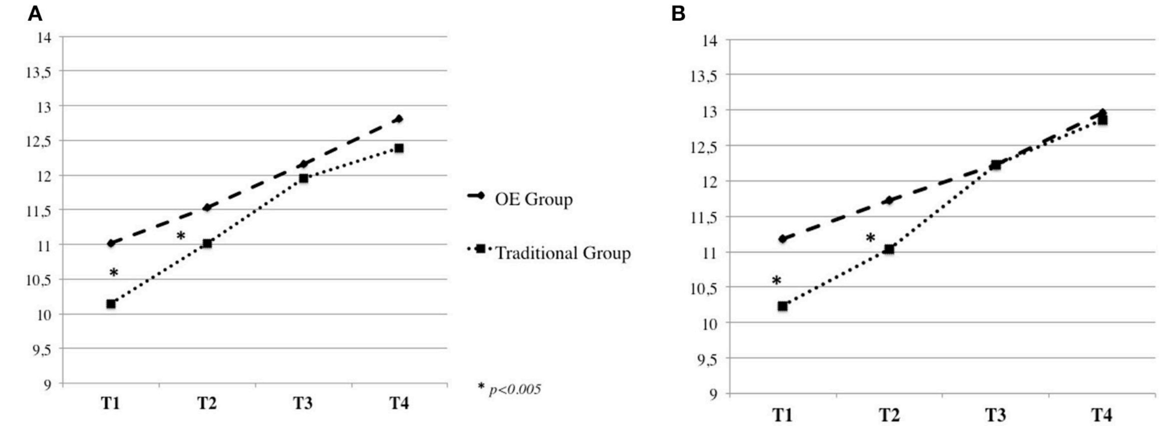

FIGURE 1 | Kuno Beller domain of body function **(A)** and social and emotional development **(B)**.

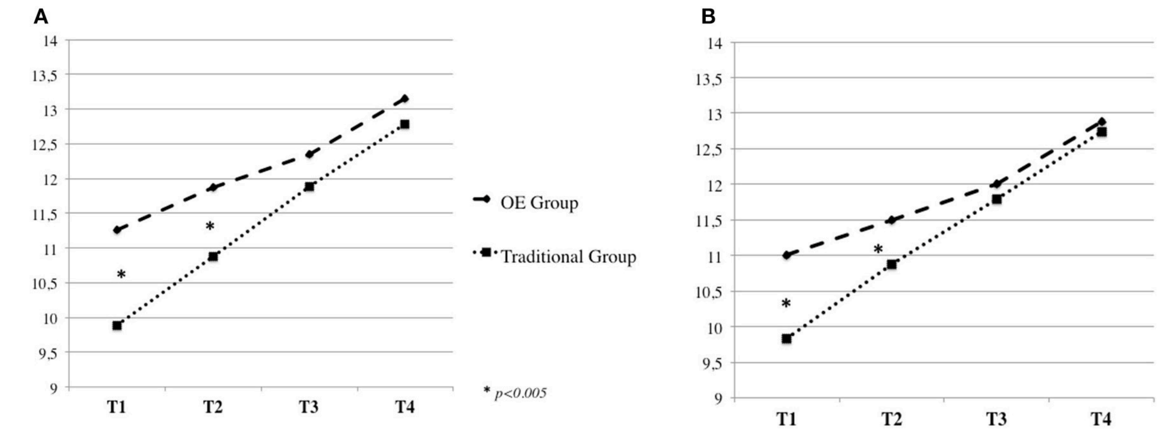

FIGURE 2 | Kuno Beller play **(A)** and language **(B)**.

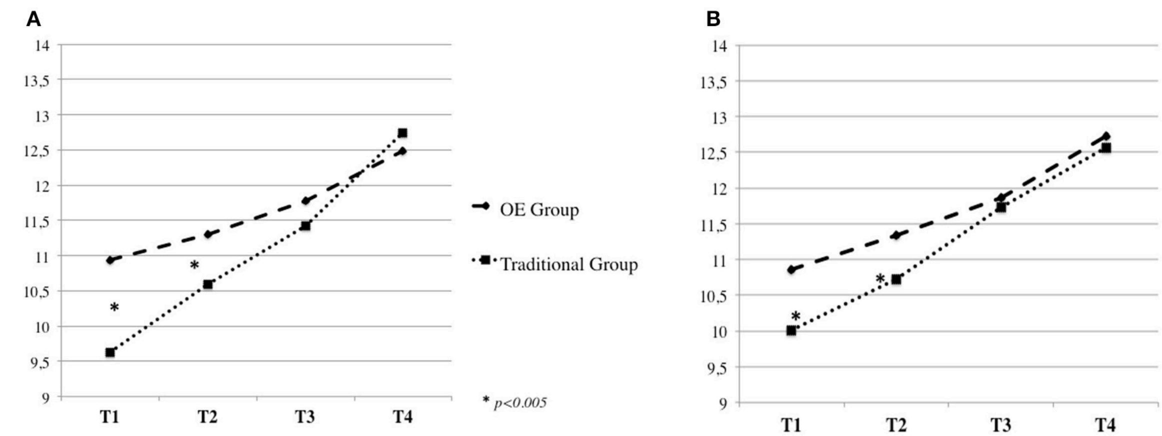

FIGURE 3 | Kuno Beller cognitive development **(A)** and fine motor skills **(B)**.

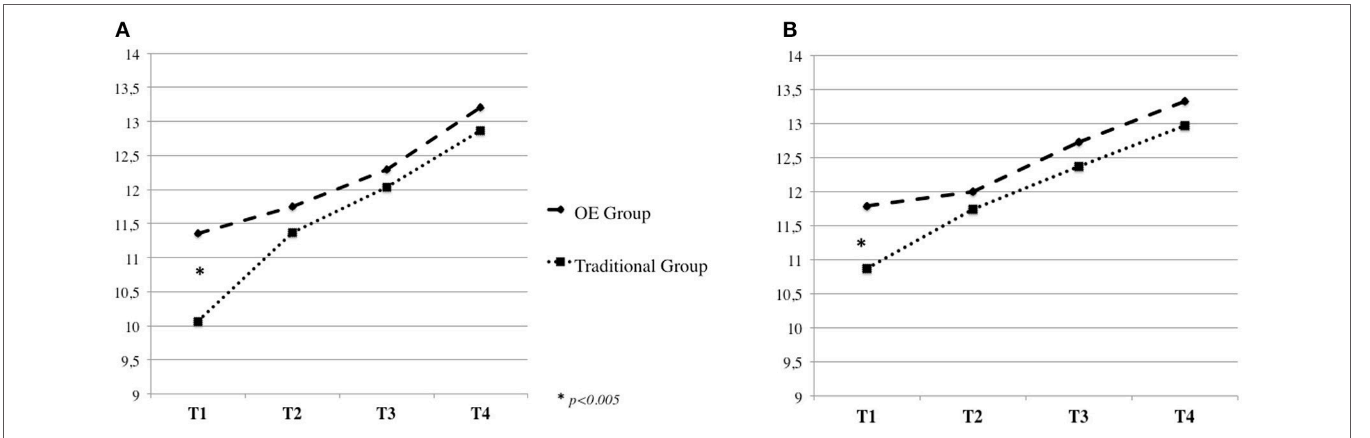

FIGURE 4 | Kuno Beller awareness of surrounding environment **(A)** and Gross Motor Skills **(B)**.

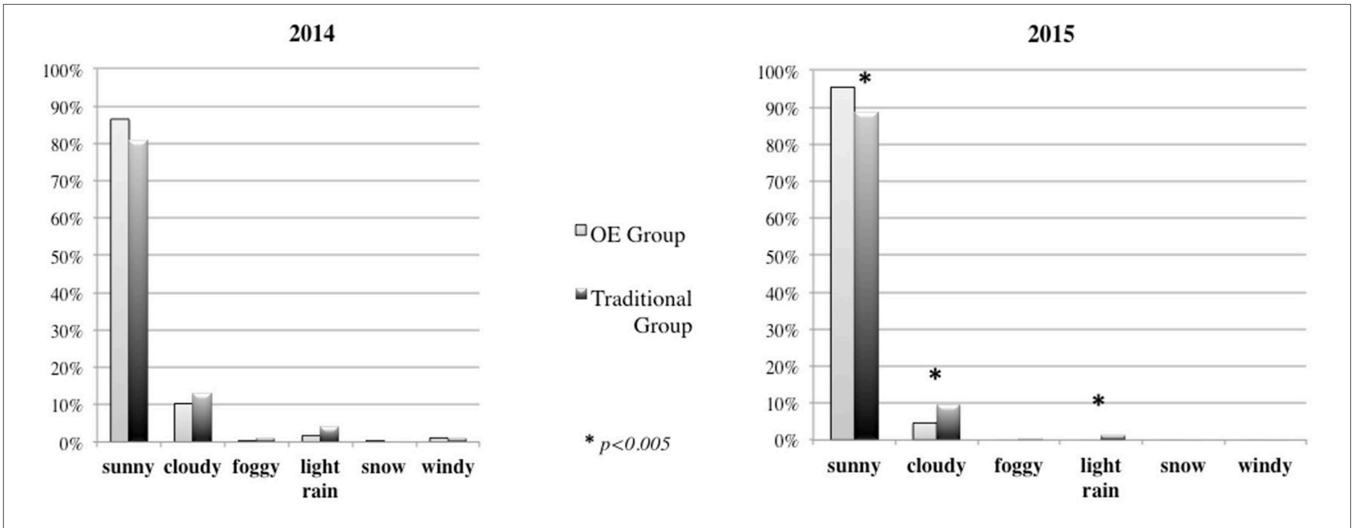

FIGURE 5 | Weather conditions during outdoor activities in 2014 and 2015.

and "other" types of activities (**Figure 7**) ($\chi^2 = 55.020$, $p = 0.0005$).

Analysis of types of activities in relation to seasons of the year demonstrated that in the spring of 2014 (March and April) the OE Group, as compared to the Traditional Group, had a stronger preference for structured exploration and physical education ($\chi^2 = 13.657$, $p = 0.018$). During summer 2014 (May and June), we did not find any significant differences between the two groups ($p > 0.05$). During fall 2014 (October and November), the OE Group showed a greater preference for free play compared to the other group, while the other group displayed a greater preference for structured exploration ($\chi^2 = 48.818$, $p = 0.0005$). During winter (December 2014-February 2015), the OE Group showed a greater preference for free play and free exploration, while the Traditional Group more frequently used structured play ($\chi^2 = 10.426$, $p = 0.034$). During spring 2015 (March and April), the OE Group more frequently engaged in free exploration and physical education, while the Traditional Group preferred free play, structured play, and structured exploration ($\chi^2 = 36.863$, $p = 0.0005$). During summer 2015 (May-June), the OE Group showed a greater preference for free exploration and physical education, while the Traditional Group preferred free play ($\chi^2 = 16.165$, $p = 0.006$).

Some differences emerged regarding the *places* used for outdoor activities. In 2014, the OE Group more frequently used the urban district compared to the Traditional Group, (**Figure 8**) ($\chi^2 = 21.745$, $p = 0.000$). In 2015, the OE Group mainly chose the schoolyard, while the Traditional Group more frequently used the public park, the urban district and "other" places (**Figure 8**) ($\chi^2 = 49.409$, $p = 0.0005$).

Finally, by looking at the variability of *time duration* for outdoor activities, we see that in 2014, the OE Group preferred to spend 1–2 h outdoors compared to the Traditional Group, which preferred to spend 30 min—1 h outdoors (**Figure 9**) ($\chi^2 = 45.298$, $p = 0.000$). In contrast, in 2015 the OE Group showed greater variability, preferring to spend less than 30 min or more than

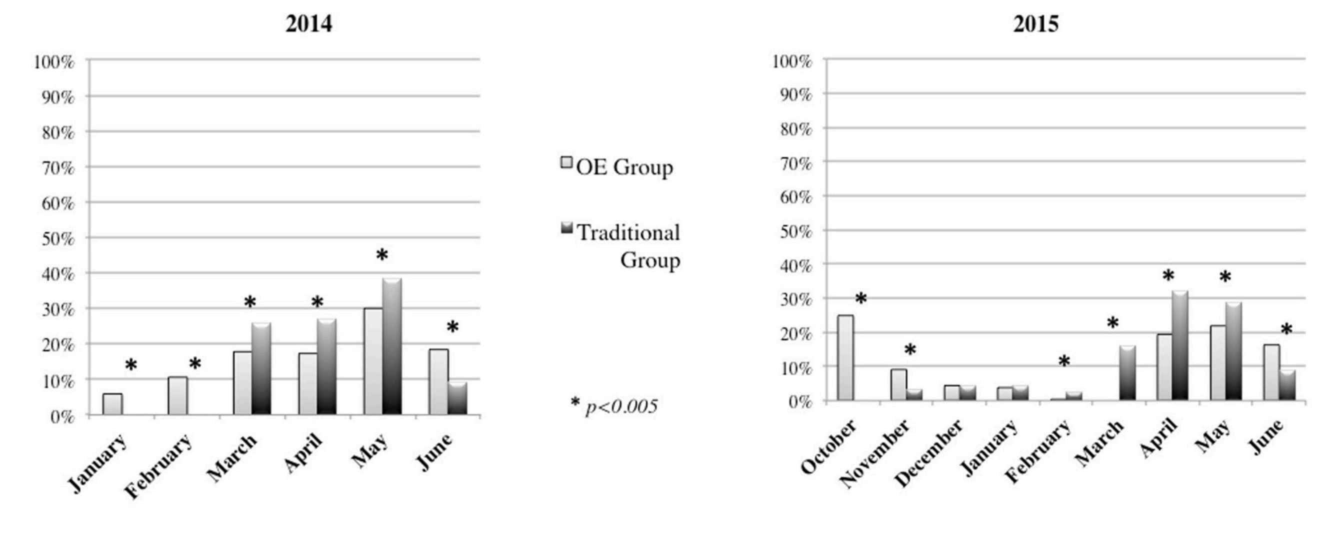

FIGURE 6 | Outdoor activities during different months in 2014 and 2015.

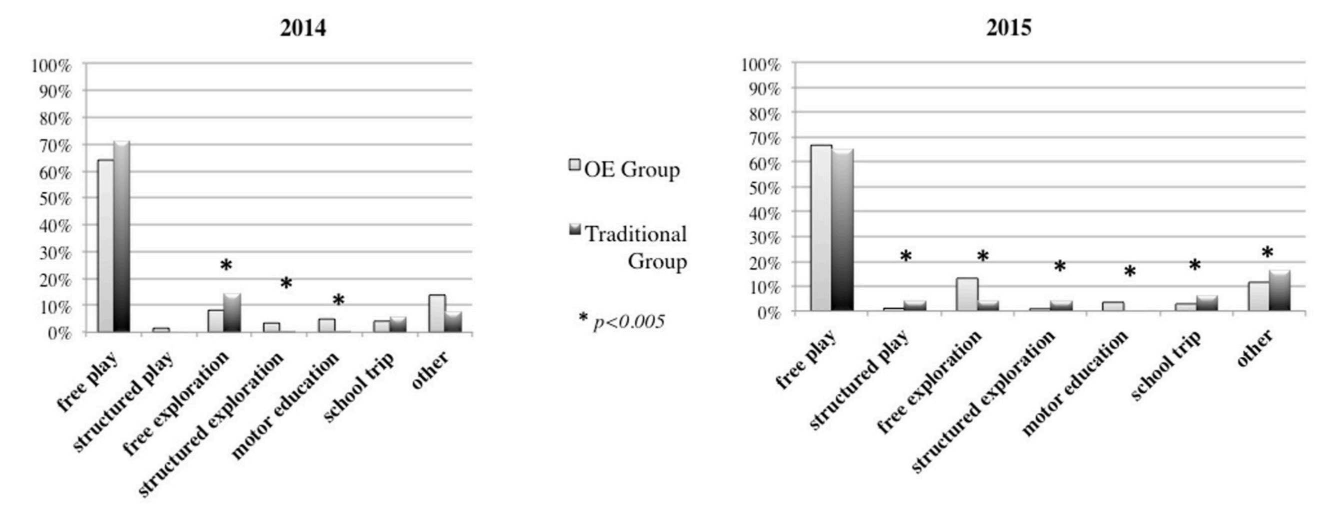

FIGURE 7 | Types of outdoor activities in 2014 and 2015.

2 h outdoors, while the Traditional Group tended to spend 1–2 h outdoors (**Figure 9**) ($\chi^2 = 34.010$, $p = 0.000$).

DISCUSSION

Literature has emphasized the potential benefits of OE for children's well-being and development, due to a joint effect of enhanced physical activity and being in a natural environment (Gustaffson et al., 2011). To promote these effects, teachers play a key role when implementing OE activities in kindergartens and adapting them to children's ages. Notwithstanding this, the literature has not sufficiently explored, up to now, how teachers perceive OE and its benefits on child development.

The main aim of this longitudinal study was to investigate how teachers perceived children's development over 2 consecutive years, comparing a kindergarten characterized by a definite OE approach to a kindergarten with a traditional educational method. Specifically, we aimed to analyze whether teachers' perceptions about child development were different according to the kind of educational method (OE vs. traditional). Second, we aimed to explore whether the teachers' perception remained stable or changed across the 2-year period of observation. Third, we aimed to investigate how teachers implemented outdoor activities in the two kindergartens.

Main results derived from the Kuno Beller Tables showed that for all eight child developmental domains, there was a significant interaction between time of assessment and group condition. This means that perceptions about child development were significantly more positive for OE teachers compared to the teachers using a traditional approach, but this was only true for the assessments at T1 and T2, not at T3 and T4, due to

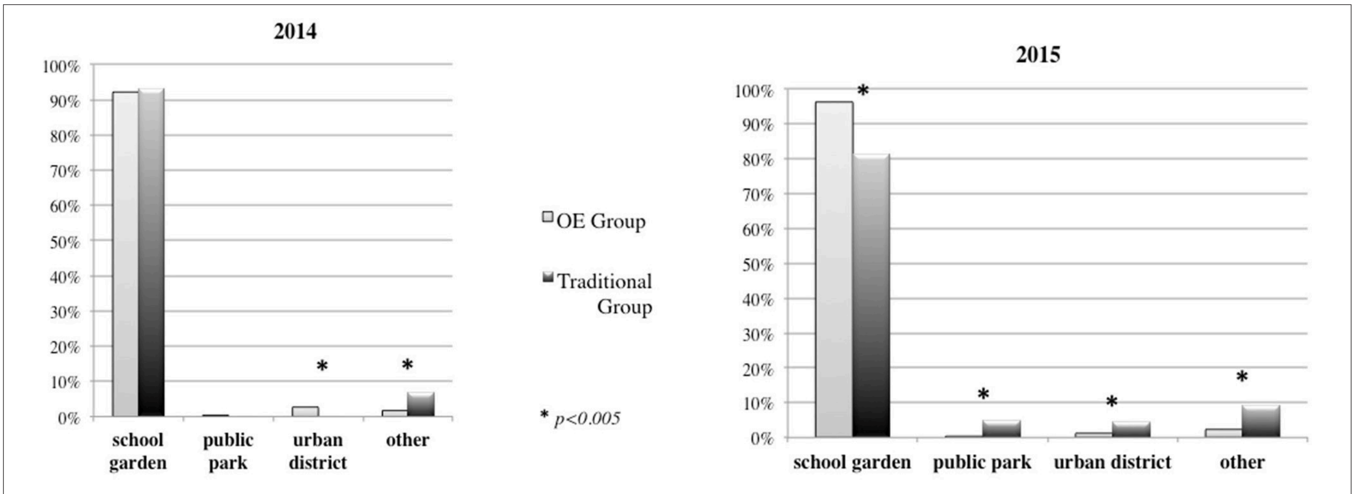

FIGURE 8 | Space used for outdoor activities in 2014 and 2015.

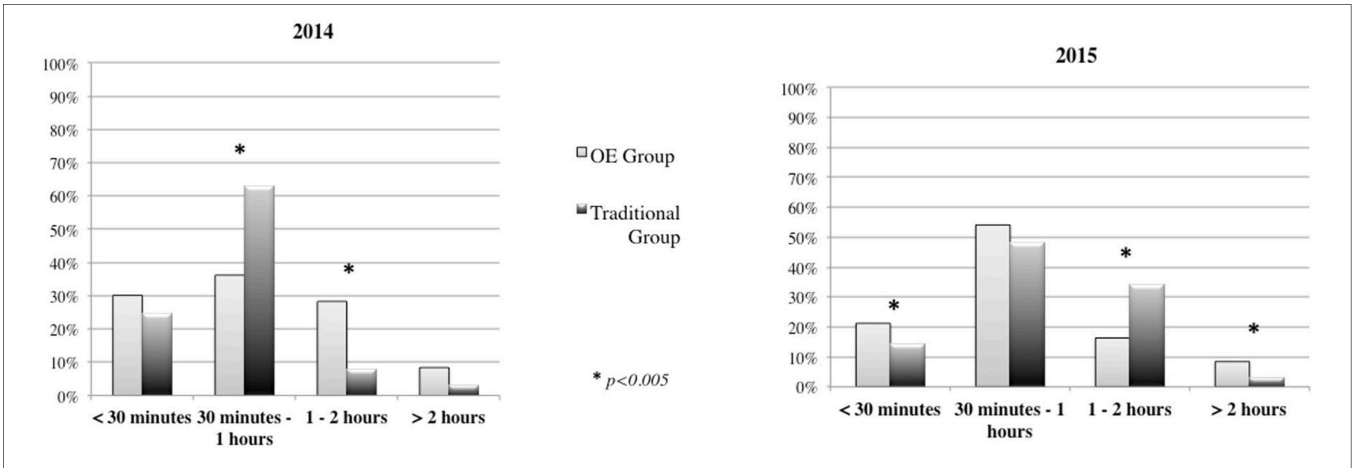

FIGURE 9 | Duration of time for each outdoor activity in 2014 and 2015.

the converging flatter slope of the OE condition and steeper slope of the traditional condition. In other words, older children, independent from the educational method, showed similar levels of development according to their teachers' perception.

In interpreting these results, several factors must be taken into consideration. First of all, when the first assessment was conducted (January 2014), the two groups of children were already showing, according to the teachers' perception of developmental characteristics, a significant difference in developmental level. We did not have the opportunity, due to constraints in the implementation of the study, to assess children's development before the children started kindergarten in order to establish whether there were pre-existing differences in developmental level. However, we are confident that the two groups of children did not differ according to measured, common socio-demographic characteristics. We also know that the OE teachers were using the daily OE activities since the beginning of the school year (September 2014).

Therefore, while we do not have a measure at baseline, we may hypothesize the following scenarios to explain the converging developmental trajectories observed in the two groups, one assuming that the children in the two groups were developmentally similar at the beginning of the school year, the other for a scenario in which the two groups had unmeasured, pre-existing differences in developmental level.

If the two groups were developmentally similar at the beginning of the school year, OE may have been quite beneficial for children's development early in the school year before data collection began. This initial developmental rate impact, if present, does not appear to sustain its pace over the next year as the rate of development (slope of the line) is flatter than for the Traditional Group, eventually intersecting with the developmental trajectory of the Traditional Group. It may be that OE is more effective for younger children compared to older ones; there may be more sensitive periods for the benefits of OE on child development, as already shown by a previous study (Monti et al., 2017). We also have to consider that teachers may be more prone to perceiving children's improvement when they are younger, as children are developing very rapidly and developmental progress may be more obvious on the Kuno Beller Table scores at younger ages than at older ages. A second interpretation is that OE has its strongest impact earlier in an intervention, regardless of at what age that intervention takes place. The slowing of the rate of development demonstrated by the OE group may therefore reflect diminishing strength of impact of OE in later stages of the intervention.

If the groups of children were already developmentally different at the beginning of the school year (as a result of unmeasured influences of demographic characteristics, for example), what we observed across the 2 years seems to reflect a slower developmental trajectory for the children in OE, possibly reflecting a ceiling effect. It is also possible that traditional kindergarten education is more effective for students of lower developmental level, reflected in a steeper trajectory, than OE is for students of higher developmental level, reflected in a flatter trajectory.

It is also important to remember that we were measuring teacher perceptions of children's development. As we reported in the aims of the study, we specifically wanted to focus on teachers' perceptions based on the perspective, evidenced by the literature, that their perceptions and attitudes, educational experiences and teaching have a significant impact on children's wellbeing, learning and development. We are aware that teachers' perceptions may be influenced by a host of variables and are not fully comparable to child development as observed by direct measures. Notwithstanding, OE teachers received the same training in the use of the Kuno Beller as did traditional kindergarten teachers. In addition, this instrument is characterized by items measuring the presence/absence of specific behaviors (e.g., the child is able to count up to 20) and is therefore based on objective benchmarks.

In our study, teacher perceptions of children's development are in line with the main evidence from the literature concerning the beneficial effects of activities in nature for children. Wardle (1997) has demonstrated that physical activities in nature help foster children's communication, emotional, social, and cognitive skills, not just motor skills. Gill (2014) has underlined how, in the outdoor environment, the child is facilitated in establishing a connection between his/her individual sensory experiences, motor activities and learning; also, his/her cognitive processes can be enhanced, with positive consequences for motor development, social skills, language, and communication, among others. In the more optimistic interpretation of the data explained above (no pre-existing developmental differences; strong initial impact of the OE intervention), these results may suggest that continuous outdoor activities provide greater opportunities for teachers' attitudes to promote children's development; this may occur when teachers perceive the natural environment as an educational and developmental setting rather than only a recreational one. When teachers hold this view about the outdoor context, specific learning experiences may be achievable.

Our results would indeed suggest how OE activities may promote an improvement in development at many different levels, at least in the short term. Similar results were obtained by a previous study with a similar research design (Monti et al., 2017): in this case, children attending nursery schools using OE showed a significant improvement in all the developmental domains (as measured by Kuno Beller) after 1 year of OE intervention, compared to a group of children following a traditional educational approach.

When analyzing the data collected through the Outdoor activities/diaries in the present study, some interesting results emerged regarding the psycho-educational quality of the activities undertaken in each kindergarten. First, the most evident result was that children from the OE kindergarten were going out for significantly more time than the children in the other kindergarten during the two school years, specifically more than twice as much time. It was clear that the children in the OE kindergarten took more advantage of the outdoors during the autumn and winter compared to children attending the traditional kindergarten. Also, a difference emerged regarding the spaces used for activities: while the OE kindergarten had a schoolyard and this represented the most used space during the 2 years, the teachers in the traditional kindergarten had to take advantage of more urban spaces or other places outside the school campus because they did not have an appropriate schoolyard. We may hypothesize that this partly influenced the kind of outdoor activities chosen, because the OE children were spending more time, somewhat dependent on the year and the season, in activities that could be easily experienced in the schoolyard, such as physical education and free/structured exploration; on the contrary, the children attending the traditional kindergarten were more frequently experiencing structured activities outside the school, always depending on the year and season. The difference in the outdoor activities was evident also regarding the duration of outdoor activities, as the OE teachers tended to go outside for longer periods, compared to those in the traditional kindergarten.

These results support and confirm the differences in usage of outdoor space by the OE teachers vs. the teachers in the traditional setting. Children show a spontaneous preference for being outside than inside and a desire to use the outdoor environment at school exploring things and enjoying what they can find in the outdoors (Norðdahl and Einarsdóttir, 2015). The activities proposed by OE teachers seem to be more in line with children's preferences. OE teachers have the possibility of proposing to children activities such as physical education and play, both free and structured. We have to remark that teachers play a key role in prompting children in play. Play is a fundamental activity and method of self-expression for children in the 3–5 year old age range and supports the child's development and his/her experience in making sense of the world (Soini et al., 2014). Literature shows that more playful activities (e.g., exploration) are associated with benefits related to physical activity and mental and emotional health (Gill, 2014). Also, free play has frequently shown significant positive effects on cognitive and social-emotional development, independence and creativity (Frost et al., 2011). Our results would seem to support these positive effects: in the first year, OE children showed, above all, higher levels of development than the traditional kindergarten children (including motor development, social, and emotional development, play).

Also, prior research suggests that less playful activities (such as field trips) are more associated with educational benefits than health benefits (Gill, 2014). Therefore, it would seem that the kind of outdoor activities proposed by teachers in the traditional kindergarten also promoted child development but not in the same manner as the activities prompted by OE teachers.

Some limitations of the study need to be acknowledged. The most important ones have been already reported: it was not possible to measure the children's development at baseline and we did not add any measure of child development rated by external observers, due to restrictions set by the school directors. Second, the teachers working in the OE kindergarten already had a high level of expertise in OE and had become accustomed to working with this kind of approach over a number of years. A more rigorous research design would have required introducing the OE intervention starting from similar baseline conditions in both kindergartens, to increase the validity of the teachers' evaluations. Third, for reasons of the same school restrictions, we could not gain access to other demographic information about the children, their families and the teachers. Therefore, since it was not possible to run statistical analyses for exploring the role of these data as possible moderating variables, the validity of our results needs to be confirmed by future studies. Fourth, in the period Feb-Mar 2015, due to maintenance work, the yard of the OE kindergarten could not be properly used, so this could have influenced the data collected. Finally, the sample included only two kindergartens; a replication of the study with a larger sample size is recommended. In summary, further research is needed comparing Kuno Beller Tables with more objective measures of child development, specifically exploring the possible benefits of OE on different age ranges, as well as the sustainability of impact of OE over time.

Notwithstanding these limitations, this study has several strengths: within this research field, where literature seems to prefer cross-sectional designs (Gustaffson et al., 2011), this study presents a longitudinal design, with a long time period of observation (2 years), including four follow-ups. Also, even if we used only one instrument, we chose a robust, objective tool, exploring in detail specific areas of child development connected to mental and physical health dimensions. Lastly, all the teachers received appropriate and rigourous training before utilizing the tool and they reported, after the use of Kuno Beller Tables, to have gained more awareness of the relevance of child development observations for their daily work.

CONCLUSION

A high frequency of outdoor activities in kindergartens represents a practical, easy, effective and cheap way to support child development (Ulset et al., 2017). OE offers a "complex learning environment where nature-based learning is being embraced by educators and can be seen in the experiences offered to children" (p. 11, Macquairre et al., 2015). How teachers perceive the natural environment and the benefits of OE are key factors for the implementation of daily outdoor activities with positive effects on child development. Teachers planning appropriate and creative use of the outdoors, in fact, support the promotion of children's well-being and mental health. Children in OE kindergartens seem to significantly take advantage of this educational approach, as they have a greater opportunity, compared to children attending more traditional kindergartens, to experience continuous and multiple OE activities during the school years, with more benefits at least in the short term.

For these reasons, social policies should engage more resources to spread OE practices starting from early childhood. At the same time, further research should be conducted to investigate the benefits of OE at different child age ranges, including the role of moderating variables, as well as the sustainability of impact beyond the short term.

AUTHOR CONTRIBUTIONS

FA was the leading author in conceptualizing and coordinating the research design and writing the manuscript. MM contributed to all the steps of the study and to writing and revising the manuscript. RM contributed to the data coding, writing and revision of the manuscript. All the authors accepted accountability for the final version of the manuscript.

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