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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

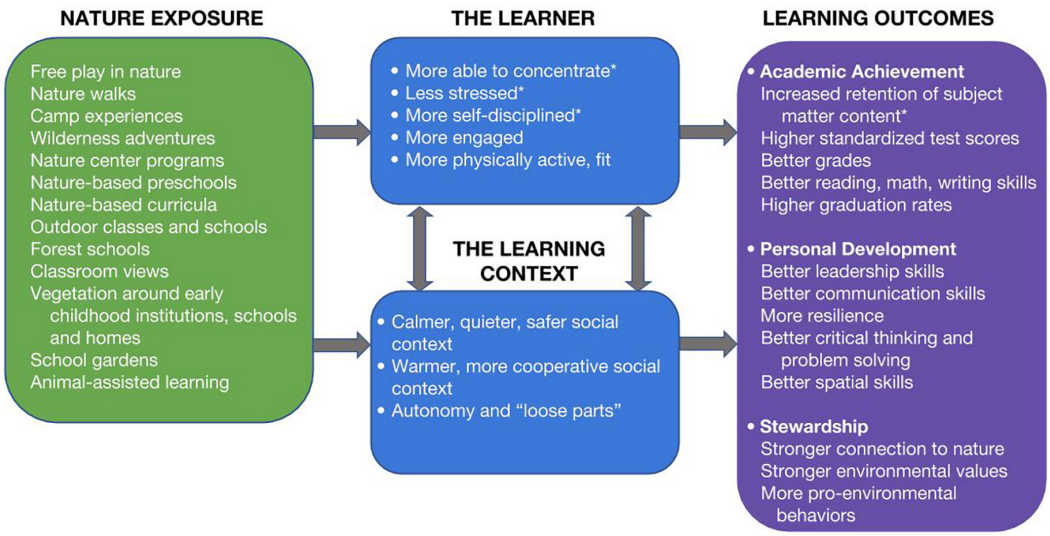

FIGURE 1 | Nature-based learning: exposures, probable mechanisms, and outcomes. This Figure summarizes the state of the scientific literature on nature and learning. The items and pathways here emerged from our review as opposed to guiding our review; thus each item listed has been empirically associated 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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