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How outdoor science education can help girls stay engaged with science

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ABSTRACT

Although gender gaps associated with K-12 science achievement have narrowed significantly, gaps in science engagement and efficacy in childhood likely explain why women remain underrepresented in science careers. Early intervention programs may address root causes of gender gaps in science careers. Outdoor science education (OSE) is one understudied but promising strategy, that provides ample opportunity for reform-based instructional practices that may benefit girls, including girls of colour. Using a pre–post, treatment-control quasi-experimental design, we evaluated how an OSE program differentially impacted the science grades, science knowledge, and science self-efficacy of fifth grade girls versus boys (n = 640). We found the OSE treatment increased knowledge and maintained science grades for girls while grades fell for girls in the control group. We also found that science self-efficacy decreased for both boys and girls in the treatment group. We did not detect direct or interaction effects of race on science outcomes. Research suggests OSE may help students associate science learning with challenge, which may help explain the decrease in self-efficacy coupled with the increase in achievement for girls. We suggest future research continue to investigate how OSE can benefit all students, including those who may become disengaged with learning in traditional classroom settings.

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Outdoor science education; girls and science; elementary education; self-efficacy; science achievement

Introduction

Decades of reform efforts have aimed to eliminate the gender gap in science, technology, engineering, and mathematics (STEM) fields, including science specifically. Encouragingly, by some measures, this gender gap has diminished, such as with science achievement in schools (Wang & Degol, 2017). However, in measures of selection of science majors in college (Bottia et al., 2015) degree completion, and matriculation into the science workforce (National Science Foundation, 2019), girls and women tend to be less represented than boys and men. These trends inhibit innovation by limiting

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contributions to science from women (Beede et al., 2011). In some areas, such as life sciences and psychology, women outnumber men in associated degree programs (National Science Foundation, 2019). However, in 2015, 47% of full-time wage and salary workers in the United States were female, but this percentage was lower in all STEM professions: 43% in life, physical, and social science; 26% in computer and mathematics; and 14% in architecture and engineering (Noonan, 2017). While it is encouraging that gender gaps seem to be shrinking in areas such as academic achievement among girls (Stoet & Geary, 2015), these trends do not hold among girls of colour (Collins et al., 2020), and because gaps persist, so should initiatives to mitigate them (Beede et al., 2011).

Addressing these gender gaps will likely require employing instructional practices that encourage girls to see themselves as scientists from a young age. On average, girls are on par with or even surpass boys in science achievement in primary school (Quinn & Cooc, 2015), but these trends are not as encouraging among girls identifying as Black (Collins et al., 2020). Numerous studies suggest that even girls who outperform boys in science academically (Wang & Degol, 2017) see science as not for them (Nation et al., 2019). Thus, addressing the gender gap in science careers requires addressing girls' self-concepts as scientists early on to encourage them to pursue science careers in the first place (Archer et al., 2012; Rhodes et al., 2019). Fortunately, research-based suggestions for ensuring science instruction effectively engages girls such as encouraging inquiry-based instruction and group learning (Brotman & Moore, 2008) were included in recent science reforms (National Research Council, 2012). In addition, research around self-efficacy (Sheu et al., 2018) and growth mindset (Yeager et al., 2019) may help shed light on how to encourage simultaneously high science achievement and among girls and persistence to science majors and careers among women. This work may be especially important for engaging girls of colour, as girls who identify as African American or Hispanic may have lower self-efficacy and less aspiration for science or math careers than their White counterparts (Britner & Pajares, 2006; Riegle-Crumb et al., 2011).

One particular instructional practice that is both understudied and promising is outdoor science education (OSE), that is, science instruction held in an outdoor setting (Carrier & Stevenson, 2017). As we discuss below, OSE employs many of the reform-based practices that support science learning for everyone, including girls. Additionally, students are given opportunity to engage in authentic science learning for which unpredictable environments, uncertainty, and trial-and-error are hallmarks (Yeager et al., 2019). Numerous studies document how OSE can push students out of their comfort zones in beneficial ways (Dillon et al., 2006; Eick, 2012), including helping them understand how science in practice requires persistence in the face of failure (Eberbach & Crowley, 2009). This quality of OSE may especially support girls remaining engaged with science. Further, benefits of OSE may differentially benefit girls of colour, who likely experience less outdoor learning opportunities prior to engagement in OSE (Kellert et al., 2017; Larson et al., 2011; Stevenson et al., 2013).

This study investigates the potential for OSE to effectively engage all students in science learning, but particularly girls. With a treatment-control, pre–post quasi-experimental design, we evaluated how an OSE program in the southeastern United States encouraged science achievement and engagement among students. Specifically, we were interested in the effects of OSE on science grades, understanding of science concepts, and science self-efficacy for all students as well as the ways the program may differentially impact girls versus boys. We begin by offering our theoretical perspective on gender and learning and a literature review of topics informing our study design, then we present our specific study context and the results of the evaluation.

Theoretical Perspectives on Sex, Gender, and Learning

Although the words 'sex' and 'gender' are used interchangeably in some contexts, they are widely understood to be distinct concepts. As Gilbert (2001) explains, *sex* is a biological term, referring to physical characteristics that make one male or female. *Gender*, however, is a cultural term, describing the behaviours, expectations, or cultural views of what it means to be feminine or masculine, that is, associated with being a woman or a man, respectively (Gilbert, 2001, 2008). Because gender – and accordingly concepts of being a girl or a boy – is culturally constructed (Gilbert, 2008), gender can change, both on personal levels (e.g. one's own gender identity: Martin et al., 2017) and broader societal levels (e.g. what types of careers are associated with men or women: Carli et al., 2016). Beliefs that science participation is a more masculine endeavour have led to girls being historically excluded from science (Carli et al., 2016). In this paper, we draw on the concepts of both sex and gender. We are interested in understanding pathways to mitigating disparities of representation by females in STEM. Accordingly, when we compare science achievement or engagement differences between male and females, we are addressing differences associated with sex. However, when considering the cultural roots of these differences, we are referring to gender, the cultural meaning often associated with sex.

Although this paper focuses on how sex and gender may impact learning, we also acknowledge the intersectionality between gender and other components of identity including race. Coined by Crenshaw (1998), intersectionality refers to the notion that we all hold multiple identities which may result in multiple layers of privilege or oppression, and, thus, it is impossible to treat any one identity as monolithic. In this context, multiple socially constructed identities linked to diverse attributes, including gender, race, sexual identity, and religion among others, interact to shape educational experiences. This complex milieu cannot be addressed in one study, but race may be particularly important to consider in the context of science education because girls of colour, including Black and Hispanic girls, may experience more biases in science classrooms than those already faced by White girls (Britner & Pajares, 2006; Hill et al., 2010; Schwartz et al., 2003; Solorzano, 1998). Accordingly, we attempt to account for potential intersections between race and the study's focal concepts of sex and gender in assessments of student learning and achievement.

In considering how sex and, gender intersect with learning, we draw on sociocultural learning theories, as pioneered by Vygotskij (1978) and further developed and operationalised by others (e.g. Barton et al., 2008; Brown et al., 1989; Carlone et al., 2011). One overarching tenant of the sociocultural perspective is that learning is a cultural process; thereby, its co-constructed, mediated, and moderated by interactions with other people and shaped by cultural context (Vygotskij, 1978). From this perspective, conceptualisations of gender, femininity, masculinity, and race can have profound influences on how students learn. For instance, numerous studies explore how girls' selfconceptualisations as scientists intersect with their understandings of the degree to which science and STEM fields are inherently masculine – that is, being related to the male gender, and so not for them (Barton et al., 2008; Carli et al., 2016; Carlone et al., 2014). In this view, girls may have the ability or interest to do well in science but avoid it because participation in science conflicts with their gender identity (Cundiff et al., 2013). Similarly, Black girls, for example, may doubly feel that science is not for them because of both their gender and racial identities (King & Pringle, 2019; Pajares & Britner, 2001; Young et al., 2017). These perspectives on how gender and race can mediate science learning are useful in helping to understand how decades of gender stereotypes that exclude girls and women from science have shown signs of decreasing, yet they still prevent women from identifying with science or pursuing careers in science (Cundiff et al., 2013; Gilbert & Yerrick, 2001; Schinske et al., 2016). This perspective also offers opportunities for educators to counteract those narratives actively through instruction. Since cultural constructs associated with gender and race impact how students learn (National Research Council, 2005), research can identify strategies to make science instruction and students' conceptualisations of science more culturally compatible with femininity, or what it means to be a girl or a woman, and thus welcoming to girls.

Literature review

Science learning as gendered

Historical and, in some cases, persistent practices in the science classroom and the broader cultural context have made science less accessible to girls and reinforced the idea that it is not for them. On a broad societal level, men were historically the ones practicing science, with women making up around 7% of the United States STEM workforce as recently as 1970 and 26% in 2011 (US Census Bureau, 2013). Those proportions are much higher in some disciplines (e.g. 61% of social scientists and 41% of life scientists were women in 2011: US Census Bureau, 2013), but science professions have largely been male-dominated. Several scholars would argue that this reality has led to a persistent association with masculinity and the practice of science (Cundiff et al., 2013; Gilbert & Yerrick, 2001; Schinske et al., 2016). For instance, studies from past decades showed considerable gender-stereotyped patterns in science textbooks (Blumberg, 2007), and more recent media portrayals of science perpetuate these ideas (Cheryan et al., 2015). These practices reflect and likely perpetuate phenomena such as parents having higher expectations of their sons than daughters in science (Andre et al., 1999) girls seeing science as for boys (Andre et al., 1999; Cheryan et al., 2015; Jones et al., 2000) and girls declining in interest in science after elementary school (Archer et al., 2010, 2014). Some scholars identify a cultural assumption that girls and women are just 'not good' at science and technical fields (Carli et al., 2016), which, they argue, has set the stage for low science self-efficacy among girls (Sheu et al., 2018), as well as bias against women in science (Robnett, 2016). This gender-related science socialisation begins in upper elementary and middle school (Archer et al., 2012; Dasgupta & Stout, 2014; Quinn & Cooc, 2015), helping explain why younger girls may understand science and achieve academically just as well, or better, than their male peers, but fewer females than males tend to continue to STEM fields, particularly outside of the life and psychological sciences (Dare & Roehrig, 2016).

Girls of colour may face additional barriers to persistence in science. Collins et al. (2020) highlight several explanatory theories for why Black girls and women continue to be underrepresented in STEM-related gifted programs (Ford, 2013) and science careers (Collins, 2018). These include underdeveloped STEM identity (Joseph et al., 2017), underdeveloped STEM talent stemming from low expectations and preparation (Collins, 2018), STEM climates that are unwelcoming to both women and people of colour (King & Pringle, 2019; Lindemann et al., 2016), and the combined impacts of the dual marginalisation of being both Black and female (Young et al., 2017). More research is needed to understand how girls of colour best navigate challenges posed by science learning contexts. Indeed, although there is growing research around how to best support Black boys in science learning (Sanacore, 2017), research addressing the same questions for girls of colour remains scant.

Reform-based strategies to engage girls in science

Decades of education research have begun to demonstrate how to make science education work better for girls. From a learning perspective, girls, as a whole, tend to be more relational and less competitive (Alexopoulou & Driver, 1997; Jones et al., 2000; Zohar & Sela, 2003) and seek deep conceptual understanding over rote memorisation (Meece & Jones, 1996; Zohar & Sela, 2003). These learning preferences may explain why open-ended and collaborative projects are particularly well-suited for girls and have been found to support feelings of empowerment and competence among preservice female teachers (Roychoudhury et al., 1995), high school girls (Howes, 1998), and among Black girls (Joseph et al., 2019). Girls also seem to benefit from hands-on or inquiry-based learning (Burkam et al., 1997; Cavallo & Laubach, 2001; Heard et al., 2000), with some studies supporting a link between classroom laboratory investigations and academic achievement among girls (Lee & Burkam, 1996). Girls are particularly interested in learning science as it relates to their daily lives and society (Häussler & Hoffmann, 2002), which may also help explain why interdisciplinary learning may particularly benefit girls (Wang & Degol, 2017).

Reforming science pedagogy to engage girls appears to help students from both genders. Reform-based science instruction focuses on active involvement in the processes of science. This involves social and situated learning in which learners are led to make direct connections between content and their daily lives (Duschl, 2008; Lave & Wenger, 1991). When students study science topics that are concretely relevant and have application to the real world, they develop science interest (Fredricks et al., 2018), a partial remedy to the science participation gaps that manifest later in life (Wang & Degol, 2017). Further, reforms support instruction that focuses on depth of content over breadth to support deep understanding of fewer concepts rather than shallow coverage of broad standards (NRC, 2012). For instance, integrating novels and writing assignments that reinforce science content can capitalise on the typically higher verbal skills of girls (Wang et al., 2013) as well as make science more relatable (Kelleher et al., 2007).

Promoting self-efficacy and a growth-mindset

As testing and failure are a hallmark of scientific practices, some research on growth mindset teaching practices has called for praising effort and persistence, rather than ability, as a means to promote both science self-efficacy and subsequent sustained engagement with science (Wang & Degol, 2017; Yeager et al., 2019). Learners then understand that science discovery and learning involves continued effort rather than innate talent (Dweck & Yeager, 2019). This approach may be particularly important for girls, who may show a tendency toward perfectionism (Flett & Hewitt, 2014). Further, girls and women tend to avoid careers that they perceive to require innate talent (Wang & Degol, 2017), and researchers continue to show that girls believe science falls under that category (Donovan et al., 2019). Accordingly, emphasising that science is inherently tied to hard work and persistence may be particularly important to sustain engagement with science among girls (Archer et al., 2010; Brotman & Moore, 2008). This growth mindset emphasis may serve as an asset-based approach to encourage girls of colour to engage in science learning (Valencia, 2015), because hard work and persistence are common cultural values in Black and Hispanic families (Chun & Devall, 2019; Young, 2017). Educators can leverage this relationship by describing hard work as an essential trait of scientists (Collins et al., 2020).

Outdoor education as a specific strategy for engaging girls in science

Outdoor science education (OSE) is a relatively understudied, but promising, form of science instruction that may engage girls in science. Most definitions of OSE focus on science instruction held in an outdoor setting, often paired with activities designed to connect learners affectively with nature (e.g. silent sits, reflection: Cheng & Monroe, 2012). Many scholars have pointed out how teaching science outdoors aligns well with the aforementioned reform-based practices that benefit all students but may be particularly effective for girls. For instance, the outdoors provides an authentic context for science learning, in which students can explore scientific content and engage in scientific practices in their schoolyards, backyards, and nearby natural spaces. The outdoors is an excellent setting for promoting observation skills and engaging in science practices such as conducting experiments in a non-controlled setting, and revising hypotheses based on unanticipated conditions or outcomes (Carrier & Stevenson, 2017; Eberbach & Crowley, 2009). These activities are almost always completed in groups, encouraging social learning which benefits all students, including girls and specifically girls of colour (Bandura, 1977; Collins et al., 2020; Dasgupta & Stout, 2014). The outdoors is also well-suited for interdisciplinary learning, where students connect science concepts across disciplines. For instance, garden programs provide opportunities for students to learn about plant biology and pollinator visitation; collect, analyse, and report quantitative data on plant growth; and support literacy connections using both non-fiction and fictional texts that support students' sense-making (Blair, 2009; Carrier & Stevenson, 2017).

OSE also provides an ideal opportunity to reinforce the notion that persistence and hard work are inherent in science learning. Outdoor contexts are more frequently novel to children, as progressively fewer are afforded opportunities for exploration in the outdoors due to increased indoor screen time and parental fears of outdoor settings

(Kellert et al., 2017; Schuttler et al., 2019). Accordingly, students have potential to be uncomfortable physically, mentally, or emotionally when learning in the outdoors (Davidson, 2016; Gray & Pigott, 2018). Exposure to novel learning contexts such as collecting data in unexpected weather provides opportunity for emphasising that success in science comes through diligence rather than innate talent (Yeager et al., 2019). Riedinger and Taylor (2016) found that girls cited outdoor experiences as useful in helping them see themselves as scientists because the outdoor experiences involved taking risks. Relatedly, another study examining how OSE impacted boys' and girls' environmental knowledge, attitudes, and behaviours, suggested girls were less comfortable in outdoor learning environments than in the classroom, but the outdoor settings fostered greater gains in environmental knowledge (Carrier, 2009). Research exploring relationships between OSE, science achievement, and gender could shed light on how outdoor settings may promote science learning for all students, particularly girls.

Because OSE is congruent with many reform-based practices, its benefits likely extend to all students, but research is needed to understand if it may hold particular promise for girls' science learning. Reviews of environmental education and nature-based learning literature reveal few studies displaying large treatment effects in science or other academic achievement across the board (Ardoin et al., 2018; Kuo et al., 2019; Stevenson et al., 2019). However, several studies suggest that learning in outdoor settings may have differential impacts for students with ADD (Faber Taylor & Kuo, 2009) or other emotional, cognitive, or behavioural disabilities (Szczytko et al., 2018), students who identify as non-binary or transgender (Braun, 2020), and students identifying as Hispanic or African American (Larson et al., 2011; Stevenson et al., 2013). In effect, OSE seems to be a successful science instructional practice for all students, but it may be particularly beneficial in supplementing classroom instruction in ways that reach students who sometimes struggle or disengage in traditional classroom settings. Accordingly, we aim to explore how OSE may additionally differentially benefit girls' science learning.

Current study

This ongoing research highlights relationships suggesting an underlying causal relationship whereby OSE helps girls better engage with science. In this study, we begin evaluating this causal relationship with an experimental evaluation of how an OSE program in North Carolina, U.S.A., impacted science achievement and efficacy among female and male students. Using a pre–post, treatment-control design, we tested several hypotheses. Because OSE is based on best practices associated with science reforms, we expected the treatment would increase (H1) science knowledge, (H2) science grades, and (H3) science efficacy for all students. Because the OSE approach may be particularly affective among females, we expected that these effects would be particularly pronounced among female students (H4–H6).

Methods

Program description

This study focused on participants of Muddy Sneakers, an OSE program focused on experiential science learning, environmental literacy, and connection to the natural world. Fifth grade teachers and students participated in the program four to ten full school days throughout the school year. The majority of schools in our sample had six day-long lessons spread across the 2016–2017 school year (e.g. one per month). The program took place both in the schoolyard and nearby natural areas such as state parks, where program educators guided activities for students using standards-based instruction. The OSE program targeted fifth-grade students and centred around North Carolina's state Essential Standards for science. Although North Carolina was a Lead State in the development of the Next Generation Science Standards (NGSS Lead States, 2013), it has not yet adopted the NGSS at the time of this publication. However, the Essential Standards have included some of the language indicative of science reform efforts (NRC, 2012). For example, its focus on 'experimentation and technological design' incorporates the language of NGSS, and the state standards have begun to reference NGSS's cross-cutting concepts and practices of science. The first lesson in the OSE program is an introduction to outdoor learning. This introductory day highlights skills and safety procedures for outdoor learning, scientific tools (e.g. compass, hand lens), and science investigations. Subsequent lessons address North Carolina's Essential Science Standards for fifth-grade science that include terrestrial and aquatic ecosystems, ecosystem interactions, inheritance and adaptation, and living systems; earth science lessons on weather and landforms; and physical science lessons of forces and motion, matter, and energy (NC DPI, 2012). Teachers select the topics that correspond with their scheduled science program to best supplement classroom instruction. The lessons typically involve a hike, a hands-on science investigation, science journaling, nature exploration, and a reflection. Students are split into small groups (maximum 12 students) for each lesson which are supervised by a chaperone (e.g. parent/guardian) and taught by the OSE program educator. The OSE program educators are trained in hands-on, inquiry-based techniques and standards-based science content. Classroom teachers typically rotate between small groups within or between lessons.

Sampling

Our initial sample consisted of 1290 fifth-grade students, ages 9–12 years old (median age of 10 years old), in North Carolina, U.S.A. We focused on fifth-grade students, as this age (i.e. 10–11 years old) is the period when students typically begin to disengage from science (Archer et al., 2010). We sampled in two stages – teachers, and then, students – within both treatment and control groups. Treatment teachers were teachers who participated in the Muddy Sneakers program. 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, an indicator of income level; racial demographics; location (e.g. in the same district or an adjacent district); and by charter or traditional school identification. 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 130 teachers, and 37 teachers responded (54% response rate) and 20 agreed to participate in the control group (43% participation rate). Although self-selection bias may exist among teachers, the unit of analysis, students, should not have been affected as students were assigned to teachers in schools independent of this study or our variables of interest.

Because we compared individual student pre- and post-assessment measures, students who did not take either the pre- or post-test or whose ID numbers could not be matched were not included in the analysis. Students who had over 50% missing data in either the pre- or post-test were also removed from the analysis. After the pre-tests had been administered, seven teachers withdrew from the study entirely representing three teachers in the treatment and four teachers in the control group. Because of this attrition, four control teachers that were matched to the treatment teachers that withdrew were also removed from the final analysis. Our final sample comprised 640 students – 403 treatment students (21 teachers) and 237 control students (12 teachers) (Table 1). Fifty-one percent of students were female. Fifty-nine percent of students identified as White, 6% as Black, 9% as Latinx, 2% as Asian or Pacific Islander, 7% as Native American, 8% as Other, and 10% as two or more ethnicities.

Instrument development and data collection

We asked teachers to provide students' science grades, and we surveyed students to measure their science knowledge and science efficacy. Teacher instruments included a question asking teachers to record a current science grade for each of their students (letter grades A–F). Student instruments included a measure of nature of science knowledge and science efficacy, which we developed using two previously validated scales: the NOSI-E (Peoples & O'Dwyer, 2014) and S-STEM (Unfried et al., 2015), respectively. We pilot tested the student scales in spring 2017 ($n = 609$). Scales were edited to ensure they were valid and reliable for our sample, to provide a shorter instrument, and to better align with the goals of the EE program. We found both edited scales to be valid and reliable in our sample for the current study (Table 2). We asked treatment and control teachers to administer online surveys to their students and to also complete their own online survey for the pre- and post-tests in September 2016 and May 2017, respectively. Teachers assigned all students anonymous ID numbers, and both teachers and students used these when filling out their surveys to facilitate matching between pre- and post-test responses while protecting the identities of participants.

Table 1. Demographic attributes of treatment and control groups. Numbers present frequency within a total sample of 640 students associated with 33 classrooms.

	Treatment	Control	Total
Number of teachers	21	12	33
Student Gender			
Male	214	100	314
Female	189	137	325
Student race and ethnicity			
White	240	136	376
African American	20	15	35
Hispanic/Latinx	41	19	60
Asian/Pacific Islander	3	7	10
Native American	27	20	47
Multiracial	32	16	48
Identity not provided by survey	40	24	64

Table 2. Item wording, means, and reliability and validity statistics for the Science Knowledge and Science Self-Efficacy scales.

Science knowledge	Pretest mean	SD	Postest mean	SD	Cronbach's alpha	Factor loading
A good way to know if something is true is to do an experiment	4.01	0.92	4.17	0.79	0.70	0.61
Experiments are used to see what happens in nature	3.73	0.94	3.78	0.93	0.70	0.60
Science helps answer questions about how something works	4.18	0.78	4.24	0.77	0.69	0.66
Scientists use what they found in the past to help explain their new findings	4.12	0.80	4.18	0.82	0.69	0.67
Conclusions can change when new evidence is found	4.11	0.81	4.20	0.79	0.69	0.67
Scientists create different types of experiments to answer their questions	4.26	0.71	4.28	0.70	0.69	0.68
If we do the same experiment many times, we may get different results	3.86	0.95	3.98	0.96	0.73	0.46
Science Self-Efficacy						
I feel good about myself when I do science	3.95	0.90	3.82	0.94	0.81	0.71
I might choose a career in science	2.82	1.21	2.74	1.28	0.82	0.68
I like learning about science	4.16	0.89	3.96	1.05	0.81	0.76
I think about science when I'm not at school	3.20	1.24	3.14	1.27	0.80	0.75
Science is one of my favourite subjects	3.70	1.21	3.61	1.30	0.81	0.75
In the future, I will be able to do more advanced science work	3.51	1.11	3.36	1.22	0.81	0.71
I talk to my family or friends outside of school about what I've learned about science	3.47	1.26	3.49	1.27	0.82	0.65

Respondents were asked to indicate whether they agreed or disagreed with each statement with choices ranging from strongly disagree (1) to strongly agree (5). Means included both treatment and control groups. Item-level Cronbach's alpha values represent what the alpha measure would be if the item were removed. Overall Cronbach's alpha was 0.73 for Science Knowledge ($n = 611$) and 0.83 for Science Self- Efficacy ($n = 607$).

Data analysis

We analysed our data using Stata software, version 14.2. We first compared means of pre- and post-test scores for science grades, science knowledge, and science self-efficacy between treatment and control groups for the entire sample and for girls and boys separately to understand magnitude and direction of change. To facilitate hypothesis testing, we relied on multiple linear regression. We chose this method so we could control for the clustered sampling design as well as for attributes of the teacher (i.e. experience, degree) that have been shown to impact science achievement and engagement among students (Carrier et al., 2013). Especially as science achievement can be subject to expectation bias teachers attribute to their students (de Boer et al., 2010), including a random effect for teacher in the analysis controls for any systematic variation among students that can be attributed to their association with a given teacher. We modelled change between pre- and post-tests in science grades, self-reported science knowledge, and science self-efficacy as a function of the respective pre-tests score to control for ceiling effect (Theobald & Freeman, 2014), membership in the treatment group, student gender, and an interaction between treatment and gender. Where the interaction effect was not significant, we excluded it from the model to avoid overparameterization. Acknowledging the intersectionality of science learning among girls of colour (Harris & Leonardo, 2018), we also controlled for student race, as well as interaction effects between race and treatment and a three-way interaction between race, treatment, and gender. None of these parameters were significant as main or interaction effects, and we accordingly excluded them from the final models. Additionally, we controlled for teachers' experience as years teaching and whether teachers had completed Bachelor or Master's degrees and included a random effect for teacher.

Ethics statement

This protocol was approved as exempt from the ethics review process by the Institutional Review Board for the Protection of Human Subjects in Research of NC State University (IRB Protocol #6533).

Results

On average, teacher-assigned science grades remained stable for the entire group (pre-test mean = 84.2 out of 100, SD = 10.4; post-test mean = 84.2, SD = 10.5), but this included an overall increase in science grades in the treatment group and decrease in grades in the control group (treatment mean change = 0.57, SD 8.0; control mean change −1.01, SD = 9.1). All students in the study increased in self-reported perceptions of science knowledge during the study period (pre-test mean = 28.3 out of 35, SD = 3.7; post-test mean = 28.8, SD = 4.0), but there was no difference in change between treatment and control groups (treatment mean change = 0.63, SD 3.9; control mean change 0.43, SD 3.7). Science efficacy decreased for the entire sample (pre-test mean = 24.9 out of 30, SD = 5.58; post-test mean = 24.1, SD = 6.25), but this decrease occurred primarily in the treatment group (treatment mean change = −1.13, SD = 0.29; control mean change 0.081, SD 0.32). When examining these differences between girls and boys, data revealed additional nuances. For science grades, boys in the treatment group remained fairly stable while those in the control group displayed a slight increase in means. However, girls in the treatment group showed a slight increase in grades while those in the control group showed a decrease in grades (Figure 1). Self- reported science knowledge gains were similar among boys between treatment and control groups, but treatment girls reported a larger increase in science knowledge than the control group (Figure 2). Changes in science efficacy scores showed less variation between boys and girls, as both girls and boys in the treatment group decreased in their science efficacy, and both groups in the control group remained fairly stable (Figure 3).

The only treatment effect we found that held for both boys and girls was the opposite of what we predicted. Specifically, membership in the treatment group predicted a

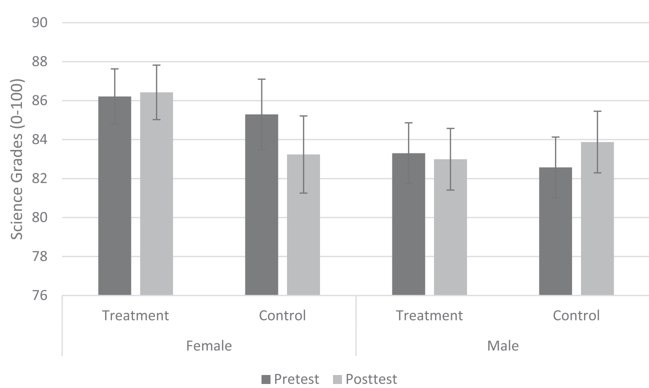

Figure 1. Difference in science academic grades between pre- and post-tests by gender. Error bars represent 95% confidence intervals.

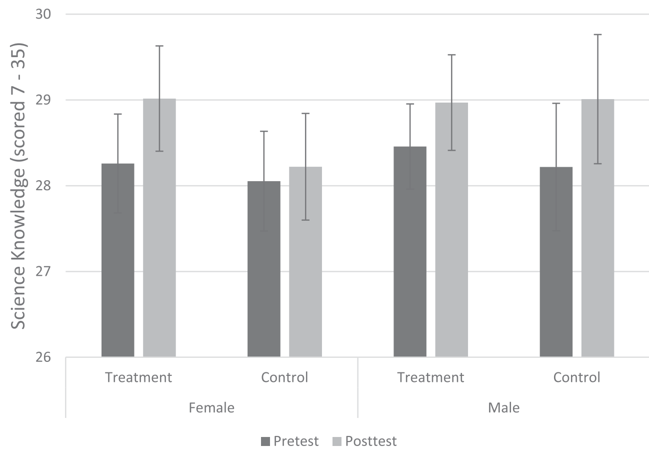

Figure 2. Difference in general science knowledge between pre- and post-tests by gender. Error bars represent 95% confidence intervals.

decrease in science efficacy for boys and girls (countering hypothesis 3; Table 3). There were no treatment effects for both boys and girls for science grades or science knowledge (hypotheses 1 and 2). However, there were positive treatment effects for girls in terms of science achievement (hypotheses 4 and 5). Specifically, we found the treatment effect for science grades was only significant among girls (treatment * girls beta = 4.58, $p < 0.001$; Table 3) and a weak positive treatment effect among girls for science knowledge emerged (treatment * girls beta = 1.04, $p = 0.078$; Table 3). The negative treatment effect held for boys and girls when predicting science self-efficacy, as the interaction term was not significant (hypothesis 6, Table 3). Teacher attributes were only significant in predicting science grades, with teachers who had more experience teaching and teachers with Master's degrees associated with greater gains in science grades among students (Table 3). Similarly, teacher-level random effects were greatest in predicting changes in science grades, as they accounted for around 11% of the variance explained, compared with 1.6% and 7.4% of the variance with science knowledge and efficacy, respectively (Table 3).

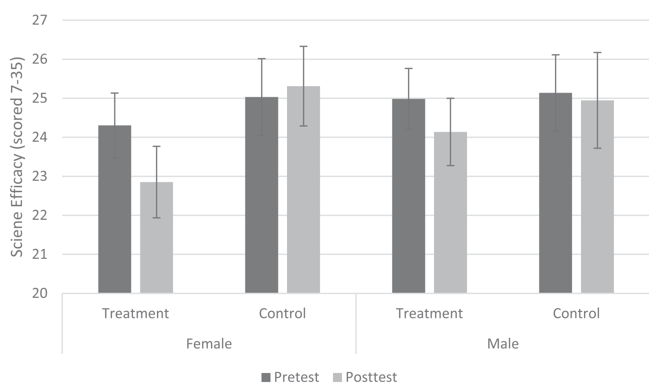

Figure 3. Difference in science efficacy between pre- and post-tests by gender. Error bars represent 95% confidence intervals.

Table 3. Predictors of change in Science Grades, Science Knowledge, and Science Self-Efficacy.

	Science grades			Science knowledge			Science efficacy		
	Beta	Std. beta	*P*-value	Beta	Std. beta	*P*-value	Beta	Std. veta	*P*-value
Pretest score	−0.265	−0.325	0.000	−0.469	−0.448	0.000	−0.351	−0.359	0.000
Treatment[a]	0.061	0.003	0.964	−0.374	−0.047	0.423	−1.707	−0.153	0.014
Gender[b]	−3.557	−0.211	0.000	−0.692	−0.090	0.135	−0.322	−0.030	0.433
Treatment * Gender	4.581	0.246	0.000	1.037	0.123	0.078			
Years Teaching	4.376	0.259	0.000	−0.330	−0.043	0.323	0.158	0.015	0.812
Masters[c]	0.293	0.191	0.002	−0.006	−0.009	0.832	0.034	0.035	0.546
Constant	16.528		0.000	14.293		0.000	8.539		0.000
	$N = 533$			$N = 593$			$N = 596$		
	R^2 overall = 0.249			R^2 overall = 0.198			R^2 overall = 0.135		
	Rho = 0.111			Rho = 0.016			Rho = 0.074		

Note: We report results for an interaction term for treatment * gender only in models where the relationship was significant to facilitate interpretation.
[a]0 = control; 1 = treatment.
[b]0 = male; 1 = female.
[c]0 = teacher has no Masters degree; 1 = teacher has Masters degree.

Discussion

Participation in OSE may have differentially benefited girls by slowing culturally-promoted disengagement with science. The drop in science grades and lack of increase of science knowledge among girls in the control group is consistent with decades of research around how girls begin to disengage with science around age ten (Archer et al., 2012; Quinn & Cooc, 2015). This disengagement may be driven by cultural norms reinforced at both classroom and societal levels – as middle grade girls are praised for being compliant and having neat notebooks, rather than raising questions (Carlone et al., 2014) – and persistent stereotypes about science being for boys and men (Carli et al., 2016). The differential treatment impacts seen here suggest that OSE may work to counter these cultural influences. Although this study does not provide data on the mechanisms whereby OSE helped girls remain engaged with science during the year, aspects of OSE do intuitively explain our findings. The OSE treatment included social and situated learning, and both may engage girls (Riedinger & Taylor, 2016). Similarly, the OSE treatment included elements to build trust and teamwork, both of which are hallmarks of OSE (Beames & Atencio, 2008) and are congruent with building the communal values linked to increased science engagement among girls and women (Dasgupta & Stout, 2014). The novel environment of outdoor settings for learning may also work to counter narratives associated with classroom learning that discourage engagement with science among girls (Carli et al., 2016; Carrier, 2009).

Potential impacts of OSE on science self-efficacy identified in this study highlight the need to re-evaluate how self-efficacy is interpreted in the context of science achievement. Traditionally, science efficacy is framed as a predictor of science achievement and engagement (Sheu et al., 2018), with the logic that people who think they will be successful at something are more likely to stick with it and be successful. These perceptions of ability (e.g. perceived mastery: Britner & Pajares, 2006) and self-worth (e.g. 'I feel good about myself when I do science,' this study), however, may not be predictive of sustained achievement (Yeager et al., 2019). In fact, research suggests science learning contexts which encourage learners to celebrate persistence after failure, rather than recognise innate ability, are more likely to result in science achievement over the long-term

(Yeager et al., 2019). Thus, traditional measures of science efficacy (e.g. feeling good about oneself in relation to science) may decline, at the same time science learning and persistence grows. Although not directly measured here, this narrative may help explain why decreases in science efficacy were coupled with increases in perceived science knowledge and higher science grades when students participated in OSE, a likely novel and challenging environment for learning.

In this study, the variation in results across classrooms supports previous research that teachers play an undeniable role in promoting science learning and achievement (Darling-Hammond, 2000) but that OSE may be a helpful strategy for engaging all students. In all of the regression models, random effects for teachers were significant, with the greatest amount of variance explained for science grades. This makes sense, as teachers often design or adapt science instruction activities, as well as assessments of student progress and mastery, which would lead to variation in grades clustered by teacher. That we found the most teacher-clustered variance associated with grades may also help explain the differential treatment impacts on girls. In as much as grades can be linked to teacher perceptions of students (de Boer et al., 2010), it could be that teachers observed girls engaging with science in the OSE setting in ways that translated to assigning higher science grades for girls in the treatment group versus the control. Further, teacher preparation (i.e. Bachelor or Master's degrees) and years of teaching experience predicted science grades, consistent with many studies linking teacher preparation and experience to student outcomes (Darling-Hammond, 2000; Stevenson et al., 2013). With respect to self-reported measures, less of the variation was explained by association with a particular teacher, and teacher preparation and experience did not matter. A key aspect of the OSE included in this study was that teachers played the supporting role rather than the role of instructor. Hence, students experienced both a likely novel learning environment (i.e. the outdoors) and novel instructor. This novelty may have helped students gain science knowledge in a new way and challenge their concept of what it means to be good at science (i.e. self-efficacy), and this helps explain why teacher attributes were less important in predicting student-reported measures than teacher-reported ones.

Our findings that race was not a significant predictor of any outcome variables of interest support promising research around benefits of outdoor education for students of colour. A 'null effect' (Stevenson et al., 2019) may be meaningful in this context because students of colour experience negative effects (i.e. fall further behind) in other contexts (Collins et al., 2020; Young et al., 2017). Recent studies suggest future research in other contexts and with larger samples may detect positive effects. An Oregon Outdoor School program enrolling 4462 students revealed students identifying as Hispanic and African American reported higher levels of overall learning than students identifying as White (Braun, 2020). Previous studies also suggest time outdoors can boost environmental attitudes and behaviours among youth identifying as Black or Hispanic (Larson et al., 2011; Stevenson et al., 2013), and a plethora of scholarship and activism has worked to counter a narrative that people of colour do not enjoy or benefit from being outdoors (Finney, 2014; Floyd, 1998, 2014; Floyd & Johnson, 2002; *Latino Outdoors*, 2020; *Outdoor Afro*, 2020; Salabert, 2019). Although the latter studies focus on general enjoyment, participation, and inclusion in outdoor recreation, rather than education, they suggest students of colour may benefit in multiple ways from OSE.

Study limitations and suggestions for future research

Our results suggesting a causal relationship between OSE and science outcomes for girls could be improved and expanded upon in several ways. First, this study does not illuminate the mechanisms whereby OSE impacted science outcomes, and future qualitative research may fill that gap. In particular, these studies might explore the processes whereby OSE helps girls see science as relevant for their lives and inclusive of their own interests. Similarly, future research could evaluate reasons OSE caused declines in science self-efficacy, as well as the alignment between science self-efficacy declines and research suggesting efficacy is needed for motivation (Sheu et al., 2018) or studies suggesting persistence in science comes from repeatedly struggling with failures (Yeager et al., 2019). Longer-term studies are needed to determine whether differential impacts of OSE identified in this study for girls persist. These studies could also focus the relationship of self-efficacy and science achievement over time and the specific role that novel experiences, such as OSE, may play in challenging elementary students' self-efficacy in science in ways that lead to growth and promote science learning and achievement. In particular, future research should examine how these dynamics intersect with race.

Conclusion

Positive OSE treatment effects for girls highlight the need for more careful examination of OSE as an instructional practice that may work to effectively engage girls in science. In a context in which every minute of the school day is carefully counted (Moses & Nanna, 2007), some teachers may shy away from OSE because they perceive it may take away from instructional time (Ernst, 2007, 2009). However, our results suggest that OSE promotes science learning for boys just as well as non-OSE instruction, and it may have particular benefits for all girls. These findings are consistent with other research highlighting differential impacts of OSE for students who may fall behind in the traditional science classroom (Stevenson et al., 2019). Given this growing body of research, we suggest future work continue to examine the magnitude of these differential impacts as well as explore the mechanisms for it, which can support efforts to maximise the impact of OSE on science engagement for all students. In addition, we would encourage schools and teachers to actively seek OSE experiences, as they seem to support science learning for students and may hold particular promise for girls.

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