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Through the lens of a naturalist: How learning about nature promotes nature connectedness via awe

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A R T I C L E I N F O

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A B S T R A C T

Environmental educators stress the importance of engaging with the wonders of the Earth in promoting nature connectedness. However, it remains unclear if learning about nature has an incremental effect beyond mere exposure to nature and what psychological mechanism can explain such a learning effect if it exists. To fill this gap, we propose a mediation model in which learning about nature promotes a sense of awe—a self-transcendent emotion associated with the recognition of vastness in nature. A sense of awe, in turn, promotes nature connectedness. Study 1 employed a cross-sectional survey and offered preliminary support for the proposed model, with participants who showed greater knowledge about nature (assessed by a species identification quiz) reporting higher levels of dispositional awe and nature connectedness, even after controlling for contact with nature. Study 2 was an experimental study that administered a two-week intervention where participants learned about nature with the help of two smartphone applications, *Google Lens* and *Seek by iNaturalist*. Results showed that there was an indirect effect of learning about nature on nature connectedness via awe among participants with higher levels of engagement with the intervention. The practical implications of our findings are discussed.

Ethical statement

Procedures performed in the study received the approval of Singapore Management University's Institutional Review Board (IRB-21-206-E070-M1(1221)/IRB-22-098-A053(822)). Participants gave informed consent before taking part in the study.

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1. Introduction

Many people are drawn to nature for its restorative benefits—taking a walk in the woods can bring about a sense of calm (White et al., 2013) and replenish fatigued reserves of attention (Berman et al., 2008; Kaplan, 1995). On the other hand, nature can also be a source of boundless mystery and excitement (Carson, 1965; Wilson, 1984). Naturalists such as Aldo Leopold, Jane Goodall, and E. O. Wilson are revered for their passion for the natural world. Through their writings, documentaries, and speeches, these scientists have let the world know about the wonders of nature and the diversity of life on Earth. They also tirelessly champion environmental causes, calling on all of humanity to do their part in protecting the world's flora and fauna.

Unfortunately, such naturalists appear to be an endangered breed themselves. Owing partly to urban living which limits access to green and blue spaces, conservation scientists note that people are missing out on opportunities to interact and form emotional bonds with nature (Miller, 2005; Soga & Gaston, 2016). This may be reflected by a lack of knowledge about nature. In a study by Balmford et al. (2002), it was found that British school children could identify more species of Pokémon than local wildlife, such as beavers and wrens. Similarly, a survey by Palmberg et al. (2015) found that just 3% of Nordic student teachers were able to identify most species of common plants and animals in their local region. Given the looming environmental crises that the planet is facing, the environment could benefit with more people following the footsteps of naturalists—that is, to learn about nature and develop a bond with it.

In this paper, we investigate how learning about nature may foster a sense of nature connectedness through a sense of awe—a self-transcendent emotion associated with wonder and fear (Keltner &

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Haidt, 2003). Awe is often experienced when one is in the presence of something vast, that is, greater than the self in terms of size or non-tangible attributes such as Intelligence or virtue. Drawing on prior empirical research (e.g., Burgess & Mayer-Smith, 2011; Toomey & Domroese, 2013) and recounts from eminent naturalists, we propose that those who learn about nature are better able to appreciate the vastness of living systems. As such, they may experience greater awe in nature and a diminished view of the self (Piff et al., 2015), which in turn could lead to a heightened sense of nature connectedness. We tested our proposed model with two studies—the first study administered a cross-sectional survey and the second study employed an experimental method involving a two-week smartphone-based learning intervention. Together, the current research sought to contribute novel knowledge on the benefits of learning about nature. Importantly, we also hope to demonstrate that everyone, not just research scientists, can be naturalists. In other words, even laypeople can be encouraged to develop an appreciation for nature's vastness through simple and accessible learning experiences. This can contribute to developing more sustainable worldviews and motivations, even as populations become more urbanized.

1.1. *Promoting nature connectedness through learning about nature*

A key question in our research is how learning about nature translates to nature connectedness. Nature connectedness is defined as an individual's sense of affiliation with nature, or the perception of the self as part of nature (Mayer & Frantz, 2004; Nisbet et al., 2009; Schultz, 2002). It is antithetical to the view of humans as masters of nature, or a superior species that has the right to exploit other life forms (Frantz et al., 2005; Richardson et al., 2015). Studies suggest that nature connectedness can be both affective (i.e., feeling a sense of attachment; Mayer & Frantz, 2004) and cognitive (i.e., involving an overlapping mental representation of self and nature; Schultz, 2002). Despite nuances in the conceptualization of nature connectedness by different scholars, the measures of cognitive and emotional ties to nature often load onto a single factor (Tam, 2013). It is unsurprising that nature connectedness is associated with biospheric values (Schultz, 2001), environmental concerns (C. Martin & Czellar, 2017) and a pro-environmental identity (Balundė et al., 2019). Relatedly, nature connectedness was found to consistently predict a wide range of pro-environmental behaviors, ranging from energy conservation to political activism (Gkargkavouzi et al., 2019; Mackay & Schmitt, 2019; Tam, 2013; Whitburn et al., 2020).

Given the link between nature connectedness and engagement in sustainable behaviors, studies have sought to investigate the psychological pathways (Lengieza & Swim, 2021) and interventions that can increase nature connectedness. A substantial body of research has shown that contact with nature alone may be sufficient to promote nature connectedness (e.g., Chan et al., 2021; H. Liu et al., 2022; Nisbet & Zelenski, 2011; Whitburn et al., 2019). Nisbet and Zelenski (2011), for example, found in an experimental study that participants who walked outdoors with views of urban nature experienced greater nature connectedness compared to the participants who walked through tunnels. Similarly, Chan et al. (2021) demonstrated that exposure to simulated nature (i.e., a virtual reality forest) could increase nature connectedness among both young and older adults. These studies suggest that merely viewing nature or visiting a green space can promote nature connectedness, at least in the short-term; it is uncertain whether the effects of nature exposure manipulations can impact sustained, trait-like nature connectedness. This is deemed a very fruitful direction for future research.

Aside from mere exposure, learning about nature can also foster nature connectedness (Balmford et al., 2002; Hungerford & Volk, 1990; Palmberg et al., 2018). In fact, Frantz and Mayer (2014) proposed that promoting nature connectedness should be a key goal of environmental education. It has been argued that environmental education should cover a broader scope beyond imparting action-oriented knowledge—knowledge about the causes of and solutions to environmental problems (see Jensen, 2002), to include nature education. Although nature learning experiences may not inform behaviors directly, they may promote sustainability by influencing how people think about the environment and the importance of protecting it. Research suggests that it is not the specific content of what is taught that matters, but the outcome of developing an appreciation for the living things and the processes that connect them (Capra, 2007; Lankenau, 2018; Orr, 1996). There is a good body of research supporting the positive relationship between learning about nature and nature connectedness. For example, it was found that students who participated in a one-day nature education program (comprising both a classroom and outdoor session) demonstrated greater increases in nature connectedness than those who did not (Kossack & Bogner, 2012). Similarly, another study showed that students who participated in a program on water at a school field center experienced an increase in nature connectedness (Liefländer et al., 2013). These findings lead to the question addressed in the current research: Does learning about nature have incremental benefits on nature connectedness beyond mere exposure to nature?

Notably, many studies on environmental education programs either adopted a within-subjects study design (e.g., Kleespies et al., 2022; Liefländer et al., 2013; Stern et al., 2008) or compared an intervention group to a control group that did not experience nature at all (e.g., Kossack & Bogner, 2012; Sellmann & Bogner, 2013). Thus, it remains unclear whether the effects of nature-based education programs are due to exposure to nature, or the educational activities that participants engaged in during their exposure to nature. Further, if learning about nature can predict nature connectedness, it would be important to examine the psychological mechanism that accounts for such a relationship. The current research set out to address these questions by testing the role of awe in the relationship between learning about nature and nature connectedness.

1.2. *Learning, awe, and nature connectedness*

Learning about and connecting to nature can go hand in hand. Psychological research on nature connectedness (e.g., Mayer & Frantz, 2004; Schultz, 2002) drew upon the works of naturalists, such as Aldo Leopold's *The Land Ethic* and E.O. Wilson's *Biophilia* when trying to define the construct. These well-respected natural science scholars share the view that people are part of nature, rather than conquerors of the Earth (Cafaro, 2001; Carson, 1965; Leopold, 1949; Wilson, 1984). To many naturalists, nature is often described as being an infinitely fascinating subject that makes life meaningful and exciting.

Rachel Carson (1965), for example, once said in her book *The Sense of Wonder*:

> "Those who dwell, as scientists or laymen, among the beauties and mysteries of the earth are never alone or weary of life." (p. 100)

Similarly, David Attenborough stressed on engaging with the wonders of nature during the 2019 World Economic Forum meeting at Davos:

> "If you lose that first wonder, you've lost one of the most greatest sources of delight and pleasure and beauty in the whole of the universe. Caring for that brings a joy and enlightenment which is irreplaceable. That is one of the great pleasures of life." (as documented in Chainey, 2019)

Expressions of fascination with nature are not just limited to research scientists. Learning experiences may help shape laypeople's perceptions of nature by bringing attention to some interesting qualities of the natural world that they might otherwise not have realized. Among children, a qualitative study found that following their experience in a mountain school, children began talking about nature with language that conveyed fear, respect, and appreciation of beauty (Burgess &

Mayer-Smith, 2011). Similarly, adults may experience an increase in appreciation of nature from educational experiences. For example, participants of a citizen science project on coyotes reported that they found the animals to be smarter and more interesting than they previously thought (Toomey & Domroese, 2013).

These fascinating feelings towards nature suggest the expression of awe. Awe is a complex emotion associated with overwhelming or mind-blowing experiences. It can be either positive, when associated with wonder and amazement, or negative, when associated with threat (Guan et al., 2019; Keltner & Haidt, 2003). Awe has been found to be related to learning, spirituality, and pro-sociality (Keltner & Haidt, 2003; Piff et al., 2015; Seo, Yang, & Laurent, 2023). Studies also showed that awe is a predictor of nature connectedness (J. Liu et al., 2023; Wang et al., 2022; Yang et al., 2018). By synthesizing the literature on the antecedents and outcomes of awe, we hypothesized a mediation model that explains the link between learning about nature and feeling connected to nature. Specifically, we discuss how awe can be induced by learning about the fascinating qualities of nature, and how the experience of awe, in turn, induces self-transcendence and nature connectedness.

1.2.1. Learning and being in awe of nature

A key theme in the experience of awe is vastness, or the perception of something as being greater than the self. To reiterate, vastness can be perceived not just in physically large objects, but also objects that are beautiful, complex, powerful, or virtuous–what laypeople may describe as mind-blowing (Keltner & Haidt, 2003; Shiota et al., 2007). For this reason, scientists often report experiencing awe, as they often examine complex matters that challenge their understanding of the world (Cuzzolino, 2021). Awe-inspiring stimuli in nature can extend beyond the physically vast, e.g., mountains and oceans, to include smaller elements. Nature is filled with objects of remarkable beauty, intricacy, and ability. By being observant and curious, it is possible to experience awe in tiny and mundane objects such as insects (Weger & Wagemann, 2021). Consider the following excerpt from E.O. Wilson's book, *Biophilia* (1984, p. 29), which shows the perception of vastness in his observation of leaf-cutter ants:

> If we magnify the scene to human scale, so that an ant's quarter-inch length grows into six feet, the forager runs along the trail for a distance of about ten miles at a velocity of 16 miles an hour. Each successive mile is covered in three minutes and forty-five seconds, about the current (human) world record.

Without any context, a trail of ants along the forest floor may not be very awe-inspiring. However, the understanding of the life science in nature helps the observer look at the insects in a completely new light. We propose that the perception of vastness in nature comes with learning more about it—the sheer diversity of life, and otherworldly adaptations that species have to survive in their environments. As a result, naturalists often experience awe (Carson, 1965; Leopold, 1949; Wilson, 1984). For urbanites especially, who lack access to physically vast nature, being able to perceive vastness in smaller, everyday nature may be important for the experience of awe.

1.2.2. Awe and connection to nature

Awe is also referred to as a self-transcendent emotion that directs attention away from the self and towards something greater. Awe is theorized to trigger the experience of a "small self", otherwise known as self-diminishment (Bai et al., 2017; Shiota et al., 2007). Using pictorial measures of self-size, Bai et al. (2017) demonstrated in a series of studies that people who were higher in awe indeed perceived themselves as being smaller. For example, they would select a smaller stick figure to represent themselves in a landscape image. As a consequence of the small-self, an individual becomes inclined to identify as part of a collective, such as a member of the global community (Piff et al., 2015; Seo et al., 2023). Similarly, another study found that experimentally induced awe increased participants' global citizenship identification and donation to humanitarian organizations (Seo et al., 2023). Taken together, these studies highlight the potential of awe in promoting collective identities and altruistic behaviors for the collective good.

Relatedly, nature can be viewed as a collective entity, and therefore the experience of awe may increase the sense of nature connectedness (J. Liu et al., 2023; Wang et al., 2022; Yang et al., 2018). For example, research suggested that showing participants video footage evoking positive awe (a snippet of BBC's *Planet Earth* documentary) or threatening awe (a video of a tornado forming) both increased nature connectedness as compared to a neutral condition (J. Liu et al., 2023). Likewise, another study found that experimentally induced awe, compared to both an amusement condition and neutral condition, increased nature connectedness and ecological behavioral intentions (Yang et al., 2018). In short, owing to its self-transcending effect, awe may promote the perception of the self as part of nature.

2. The present research

2.1. Hypotheses

Grounded on the empirical evidence as discussed, we hypothesized a mediation model in which learning about nature fosters nature connectedness through the experience of awe. The first path in the model, where learning leads to awe, draws on the idea that learning experiences can facilitate the perception of vastness in nature. The second path in the model, where awe leads to nature connectedness, is based on prior research about the self-transcendent effects of awe. During the experience of awe-induced self-diminishment, people may appraise the self as part of a broader community of nature.

2.2. Overview of studies

As aforementioned, exposure to and learning about nature often occur together. When testing the hypothesized model, we sought to distinguish between the effects of exposure and learning. Study 1 was a correlational survey to test the hypothesized mediation model. In addition to measuring prior learning about nature, we also measured exposure to nature as a control variable in the analysis. Study 2 adopted a different approach, using a between-subjects experimental pretest-posttest design to investigate whether learning about nature promotes awe and nature connectedness, beyond mere exposure to nature. The experiment involved a two-week intervention in which participants engaged in a self-directed nature learning experience with the help of smartphone applications. In the experiment, all participants in the study were instructed to interact with nature daily, but half of them were further instructed to learn more about the nature they encountered. This was to examine the difference induced by nature learning beyond nature exposure between the two conditions. In addition, Study 2 employed a novel mode of nature learning. Given that nature education is usually achieved through traditional means (e.g., documentaries, books, zoo visits, and guided programs), the intervention study could assess the feasibility of interactive digital applications in promoting nature learning and nature connectedness.

The two studies were conducted in Singapore, a small, industrialized city state in tropical Southeast Asia. It has a reputation for being a "City in Nature" (National Parks Board, 2022). Although the country is completely urbanized, parks and roadside vegetation are spread across the city. It is targeted that by 2030, all households will be within a 10-minute walk from a park. There are also pockets of land designated as nature reserves. The accessibility and wide variety of wildlife in Singapore makes it ideal to pilot self-directed interventions related to nature learning. Both studies were approved by the university's ethics committee.

3. Study 1

3.1. Method

3.1.1. Participants and procedure

251 undergraduates from a Singaporean university completed an online survey for cash reward (SGD $5). After removing participants who failed either of the two attention checks in the survey, the final sample consisted of 222 participants (76.6% female, M_{age} = 22.3, SD_{age} = 1.75). Based on an *a priori* Monte Carlo power analysis (Schoemann et al., 2017), this sample size fulfills the minimum requirement, i.e., N = 189, to detect significant indirect effects at 80% power. We assumed β = 0.3 for the regression of nature connectedness on awe (based on results from Yang et al., 2018), and a more conservative β = 0.2 for the regressions of both awe and nature connectedness on learning about nature.

3.1.2. Measures

Knowledge about nature. We measured knowledge about nature as a proxy for prior learning about nature. Participants completed a multiple-choice quiz to identify various species of organisms. Species identification is considered a foundational outcome of ecological education and can pave the way for learning more complex and fascinating concepts about biodiversity and ecology (Palmberg et al., 2018; Randler, 2008). The quiz included 18 organisms that are commonly found in Singapore (e.g., Javan mynah, otter) and 18 organisms that are recognizable internationally (e.g., manatee, chimpanzee). The organisms spanned a wide range of taxa, including plants, birds, mammals, and insects. Participants were awarded a point for each correct answer, with 36 being the highest possible score.

Awe. The mediating variable, awe, was measured using the awe subscale of the dispositional positive emotion scale (Shiota et al., 2006) which comprises six items (e.g., "I often feel awe" and "I see beauty all around me"). Items were rated on a 7-point scale (1 = *strongly disagree* to 7 = *strongly agree*). The scale showed good reliability in the sample (α = 0.81).

Nature connectedness. The dependent variable, nature connectedness, was measured by the scale developed by Mayer and Frantz (2004). The scale comprised 14 items, including "I often feel a sense of oneness with the natural world around me," and "I often feel a kinship with animals and plants." Items were rated on a 7-point scale (1 = *strongly disagree* to 7 = *strongly agree*). The scale showed good reliability in the sample (α = 0.85).

Exposure to nature. As a covariate, contact with nature was measured using two items. Participants were asked how often they visited green spaces, such as parks and nature reserves near (within a 10-min journey)/far (over a 10-min journey) from their homes. Items were rated 1 = *never*, 2 = *yearly*, 3 = *monthly*, 4 = *weekly*, 5 = *daily*.

Positive and negative affect. Nature connectedness is known to correlate positively with positive affect and negatively with negative affect (Lengieza & Swim, 2021; Nisbet & Zelenski, 2011). As a covariate to distinguish the effects of awe from other emotions, a 10-item version of the Positive and Negative Affect Scale (PANAS; Thompson, 2007) was used to measure affect. It comprises five items measuring positive affect (alert, inspired, determined, attentive, active; α = 0.79) and five items measuring negative affect (upset, hostile, ashamed, nervous, afraid; α = 0.83). Participants rated how often they experienced the affective states from 1 = *never* to 5 = *always*.

3.2. Results

Table 1 shows the bivariate correlations between the key variables in Study 1. There were significant positive correlations between prior learning about nature and awe (r = 0.19, p = .005) as well as nature connectedness (r = 0.27, p < .001). Awe and nature connectedness were also positively correlated (r = 0.47, p < .001). We also noted that exposure to nature was related to nature connectedness (r = 0.19, p = .005), but not awe (r = 0.08, p = .251).

Table 1
Means, standard deviations, and bivariate correlations of the variables in Study 1.

	M (SD)	1	2	3	4	5
1. Knowledge about nature	15.55 (5.19)	–				
2. Awe	4.64 (0.92)	.19**	–			
3. Nature connectedness	4.59 (0.78)	.27***	.47***	–		
4. Positive affect	3.21 (0.66)	−.08	.39***	.25***	–	
5. Negative affect	2.46 (0.74)	−.16*	−.06	−.02	.12	–
6. Exposure to nature	3.06 (1.04)	.11	.08	.19**	.03	−.14*

Note. *p < .05; **p < .01; ***p < .001.

We ran a mediation analysis using Model 4 of the PROCESS Macro in SPSS (Hayes, 2013). To assess indirect effects, we generated 95% bootstrapped confidence intervals with 5000 draws, following recommendations by Hayes and Scharkow (2013). All regressions in the model (Fig. 1 and Table 2) included contact with nature and positive and negative affect as covariates. According to the model paths, knowledge about nature positively predicted awe (β = 0.21, B = 0.04, SE = 0.01, p = .001), which in turn positively predicted nature connectedness (β = 0.38, B = 0.32, SE = 0.05, p < .001). The direct path, knowledge about nature predicting nature connectedness while controlling for awe, was also significant (β = 0.20, B = 0.03, SE = 0.01, p = .001). Overall, there was a significant indirect effect of knowledge about nature on nature connectedness via awe (B = 0.01, SE = 0.00, 95% CI = [0.00, 0.02]). The total effect, i.e., the sum of the direct and indirect effects, was also significant (B = 0.04, SE = 0.01, 95% CI = [0.02, 0.06], p < .001). These findings provided preliminary support for a partial mediation model in which learning about nature (assessed using knowledge as a proxy) predicts higher levels of nature connectedness through promoting awe. Overall, there is a small-to-medium effect of learning about nature on both awe and nature connectedness when all other covariates are controlled for.

4. Study 2

In Study 2, we sought to test whether a nature learning intervention can promote a sense of awe and nature connectedness. We also compared the learning intervention with a control condition that involved mere exposure to nature.

4.1. Method

4.1.1. Participants and procedure

Undergraduate students were recruited from the same Singaporean university as Study 1 for a combination of cash (SGD$15) and 2 course credits. Based on an effect size of d = 0.49 from Study 1[1], a power analysis performed with G*Power 3.1 (Faul et al., 2007) for alpha = 0.05 and power = 0.80 indicated a required sample size of n = 134 for a between-subjects design. The study was advertised on the university's online subject pool system as a study on nature-based intervention and emotions. The specific focus on learning and awe was not revealed to students. Interested students attended an online briefing to understand the study requirements. Participants were notified that they needed a smartphone with a working camera to take part in the intervention.

[1] Converted from the correlation (r = 0.24) between learning and nature connectedness in Study 1.

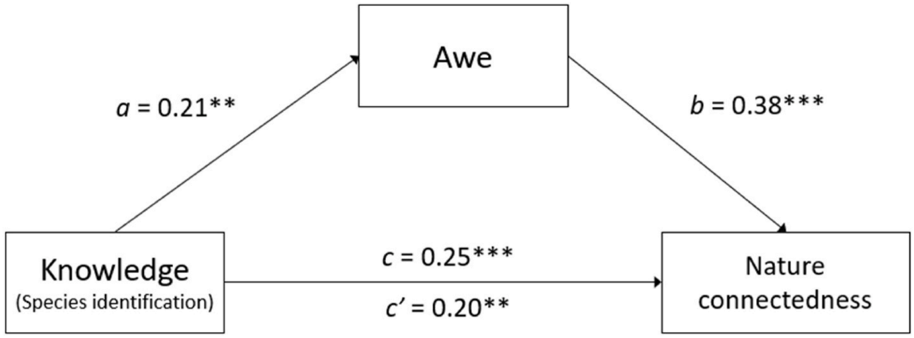

Fig. 1. Mediation model for the effect of learning about nature on nature connectedness via awe.
Note. The numbers reported are standardized coefficients. The model controlled for positive affect, negative affect, and exposure to nature as covariates. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$.

Table 2
Unstandardized and standardized coefficients for the mediation model with covariates.

Parameter	b (SE)	95% CI	β	t	p
Predicting awe					
Knowledge about nature	0.04 (0.01)	[0.02, 0.06]	0.21	3.35	.001
Exposure to nature	0.03 (0.05)	[-0.08, 0.14]	0.03	0.55	.580
Positive affect	0.58 (0.10)	[0.41, 0.75]	0.42	6.81	<.001
Negative affect	−0.08 (0.07)	[-0.24, 0.07]	−0.07	−1.09	.279
Predicting nature connectedness					
Awe	0.32 (0.05)	[0.21.0.43]	0.38	5.88	<.001
Knowledge about nature	0.03 (0.01)	[0.01, 0.05]	0.20	3.29	.001
Exposure to nature	0.09 (0.04)	[0.01, 0.18]	0.13	2.16	.032
Positive affect	0.12 (0.08)	[-0.03, 0.27]	0.10	1.60	.111
Negative affect	0.04 (0.06)	[-0.08, 0.16]	0.04	0.69	.493

They were also told that they had to complete three phases of the study: a pre-test survey, a two-week intervention (described to participants as a nature diary activity), and a post-test survey.

After attending the online briefing, participants provided their informed consent and completed a pre-test survey including measures of their baseline levels of awe and nature connectedness. Next, participants were randomly assigned into either the *nature exposure* or *nature learning* condition, and received the respective instruction sheet (see supplementary material), including the procedures for downloading the relevant phone applications. All participants were asked to use *Google Photos* to host their nature diary. Participants in the learning condition were also asked to download *Google Lens* or *Seek by iNaturalist* to facilitate their learning. Each day over the next two weeks, all participants had to post on *Google Photos* two photographs of organisms they encountered in their daily lives (e.g., plants, animals, fungi) with relevant captions for each photograph. The organisms could, for example, be of a tree seen from a window or a bird found on the way to school. All participants were required to photograph unique organisms each day instead of repeating the same organism. The key difference between the two conditions was in the captions participants were instructed to write. Participants in the exposure condition were instructed to write a general description of the organism—what it looked like, what it appeared to be doing, or where it was found. Participants in the learning condition were instructed to identify the organism and write one fun fact they learned about it. To do this, it was suggested that they could use either the *Seek by iNaturalist* or *Google Lens* apps. When using the app, participants simply pointed their phone cameras at the organism of interest, and the app would return the best match for what was spotted. Having identified the organism, participants could enter the species name into a search engine to learn more about the species. At the end of the 14-day period, participants completed the post-intervention survey within the following two days.

In total, 147 participants completed the pre-test survey. Some participants in this sample were excluded from analyses for the following reasons: uploading insufficient entries (less than 12 out of 14 days; $N = 9$), writing captions that clearly did not follow study instructions ($N = 3$), failing to complete the post-test survey ($N = 2$), failing the attention check in the post-test survey ($N = 2$) and voluntarily withdrawing from the study ($N = 4$). The final sample comprised 127 participants ($N_{exposure} = 66$, 80.3% female$_{exposure}$, $M_{age\ (exposure)} = 21.1$, $SD_{age\ (exposure)} = 2.06$; $N_{learning} = 61$, 70.5% female $_{learning}$, $M_{age\ (learning)} = 20.9$, $SD_{age\ (exposure)} = 1.78$), just slightly short of our targeted sample size.

4.1.2. Measures

In this study, learning about nature was manipulated through the experimental instructions. The measures of awe, nature connectedness, and positive and negative affect were similar to Study 1. In the post-intervention survey, we highlighted to participants that they should answer the items based on their experiences during the two-week intervention rather than a long-term period. In addition, the following measures were administered in the post-intervention survey.

Exposure to nature. Like Study 1, participants were asked how often they visited green spaces near their home and far from home. However, to adapt the measure to the intervention's duration, participants indicated the number of days (out of 14) they visited green spaces in the intervention period.

Perception of nature. This is an exploratory measure to verify that learning about nature can indeed evoke the perception of awe qualities (i.e., vastness) in nature. Participants were asked the extent to which a list of words describes nature. These words were based on how nature is typically described in psychological literature. Three items (i.e., restorative, calming, peaceful; $\alpha = 0.90$) are related to the restorative properties of nature (Berman et al., 2008; White et al., 2013), while four items (i.e., beautiful, intelligent, complex, vast; $\alpha = 0.80$) are awe-eliciting qualities (Keltner & Haidt, 2003; Shiota et al., 2007). The items were rated on a 7-point scale (1 = *does not describe at all* to 7 = *describes very well*).

Intervention experience. A manipulation check comprising six items was administered to assess various aspects of participants' subjective experiences between the two conditions. Participants rated their agreement that the intervention was enjoyable, that they were observant of their surroundings, had contact with nature every day, have learnt a lot about the natural world, looked at nature with more fascination than before, and were surprised by their observations. The statements were rated on a 7-point scale (1 = *strongly disagree* to 7 = *strongly agree*).

Engagement with the intervention. Engagement is defined broadly as the investment of energy into an activity and may influence how effective an intervention is for participants (Nahum-Shani et al., 2022). Participants rated if they felt like they were "completing the diary entries to get them over with each day". This item was rated on a 7- point scale (1 = *strongly disagree* to 7 = *strongly agree*) and reverse scored for easier interpretation.

4.2. Results

Descriptive statistics of the variables for the nature exposure and nature learning conditions are presented in Table 3.

Randomization check. In the pre-test survey, there was no significant difference in awe between participants in the exposure ($M = 4.68$, $SD = 0.93$) and learning ($M = 4.63$, $SD = 0.88$) conditions, $t(125) = 0.33$, $p = .740$. There was also no significant difference in nature connectedness between the exposure ($M = 4.24$, $SD = 0.76$) and learning ($M = 4.40$, $SD = 0.87$) conditions, $t(125) = -1.11$, $p = .268$.

Manipulation check. In terms of intervention experience, participants in the learning condition ($M = 5.48$, $SD = 1.18$), as compared to the exposure condition ($M = 4.33$, $SD = 1.46$), reported having learned more about the natural world $t(125) = -4.83$, $p = <.001$. The participants in the learning condition ($M = 5.30$, $SD = 1.41$) also reported more fascination with nature compared to those in the exposure condition ($M = 4.64$, $SD = 1.56$), $t(125) = - 2.50$, $p = .014$. However, participants in the two groups did not differ in perceived enjoyment, being more observant, having daily contact with nature, or being surprised by their observations (all $ps > .05$).

In terms of perceptions of nature, participants in the learning condition perceived more vastness ($M_{learning} = 5.53$, $SD = 0.98$ vs. $M_{exposure} = 5.05$, $SD = 1.06$, $t(125) = -2.63$, $p = .009$) in nature compared to the exposure condition. However, there were no between-group differences in the perception of restorativeness ($M_{learning} = 5.42$, $SD = 0.98$ vs. $M_{exposure} = 5.58$, $SD = 1.11$, $t(125) = 0.83$, $p = .407$).

Within-subject differences in outcomes. We conducted dependent samples *t*-tests to investigate whether awe and nature connectedness differed between pre-test and post-test for the nature exposure and learning conditions. Average self-reported awe increased significantly from pre-test to post-test in the learning condition ($t(60) = 2.26$, $p = .027$), but not the exposure ($t(65) = 1.37$, $p = .175$) condition. However, both the learning ($t(60) = 3.55$, $p = <.001$) and exposure ($t(65) = 4.11$, $p = <.001$) groups experienced significantly higher nature connectedness after the intervention.

Between-subjects differences in post-intervention outcomes. In the post-test survey, there was no significant difference in awe ($M_{learning} = 4.89$, $SD = 0.95$ vs. $M_{exposure} = 4.84$, $SD = 0.98$; $t(125) = -0.29$, $p = .774$) and nature connectedness ($M_{learning} = 4.66$, $SD = 0.90$ vs. $M_{exposure} = 4.57$, $SD = 0.75$; $t(125) = -0.58$, $p = .562$) between participants in the exposure and learning conditions.

Moderated mediation. Similar to the results of the between-groups *t*-test, there was no effect of study conditions on awe in the multiple regression ($\beta = 0.07$, $B = 0.13$, $SE = 0.14$, $p = .349$), even after controlling for covariates[2] (i.e., affect and nature contact, along with pre-test levels of awe and nature connectedness). This was contrary to the hypothesis. Therefore, we tested participants' individual characteristics to examine if the efficacy of the learning condition may differ across participants (Table 4). We first tested for interaction effects between study conditions and pre-test levels of awe ($\beta = 0.12$, $B = 0.05$, $SE = 0.15$, $p = .748$) and nature connectedness ($\beta = -0.09$, $B = -0.04$, $SE = 0.14$, $p = .786$) on post-test awe.

Neither of these traits moderated the condition effects.[3] We then added levels of participants' engagement with the intervention and the interaction between levels of engagement and study conditions in the regression model predicting awe. Although there was no main effect of levels of engagement ($\beta = 0.00$, $B = 0.00$, $SE = 0.07$, $p = .985$), there was a significant interaction between levels of engagement and study conditions ($\beta = 0.21$, $B = 0.21$, $SE = 0.09$, $p = .027$), suggesting that the learning condition showed a stronger effect (compared to the exposure condition) on promoting awe when participants were engaged.

Based on this finding, we fitted a moderated mediation model (Fig. 2 and Table 5) using PROCESS (Model 7). In the first stage of the mediation, the interaction between levels of engagement and study conditions predicting awe was significant ($\beta = 0.21$, $B = 0.21$, $SE = 0.09$, $p = .027$). There was no main effect of study conditions ($\beta = 0.07$, $B = 0.13$, $SE = 0.13$, $p = .320$) or levels of engagement ($\beta = 0.00$, $B = 0.00$, $SE = 0.07$, $p = .985$) on awe. Awe, in turn, predicted nature connectedness ($\beta = 0.34$, $B = 0.29$, $SE = 0.06$, $p = <.001$). There was no direct effect of study conditions on nature connectedness ($\beta = -0.02$, $B = -0.03$, $SE = 0.09$, $p = .718$). Based on the bootstrapped confidence intervals, the index of

Table 3
Between-group and within-group differences in Study 2 outcomes.

	Exposure *M (SD) N* = 66	Learning *M (SD) N* = 61	*t*	*p*
Experience				
I felt that the activity was enjoyable.	4.96 (1.31)	4.92 (1.38)	0.15	.879
I was observant of my surroundings.	5.80 (0.86)	5.82 (1.07)	−0.10	.923
I had contact with nature every day.	5.59 (1.31)	5.82 (1.07)	−1.07	.287
I felt like I've learnt a lot about the natural world.	4.33 (1.46)	5.48 (1.18)	−4.83	<.001
I looked at nature with more fascination than I did before.	4.64 (1.56)	5.30 (1.41)	−2.50	.014
I was surprised by some of my observations.	4.99 (1.69)	5.93 (1.53)	−1.43	.157
Engagement				
I felt like I was completing the diary entries just to get them over with each day (reversed).	3.29 (1.43)	3.25 (1.40)	0.17	.868
Perception of nature				
Restorative	5.58 (1.11)	5.42 (0.98)	0.83	.407
Vast	5.05 (1.06)	5.53 (0.98)	−2.63	.009
Affect				
Positive	3.34 (0.72)	3.31 (0.66)	0.28	.782
Negative	2.08 (0.59)	2.04 (0.60)	0.37	.710
Exposure to nature	5.61 (2.70)	5.48 (0.83)	2.23	.027
Awe				
Pre-test	4.68 (0.93)	4.63 (0.88)	0.33	.740
Post-test	4.84 (0.98)	4.89 (0.95)	−0.29	.774
Nature connectedness				
Pre-test	4.24 (0.76)	4.40 (0.87)	−1.11	.268
Post-test	4.57 (0.75)	4.66 (0.90)	−0.58	.562

[2] We assessed possible multicollinearity by looking at the correlations between pre- and post-intervention levels of awe and nature connectedness. The correlations between the predictor variables of the mediation model (pre-test awe, pre-test nature connectedness and post-test awe) were all below 0.7, suggesting no multicollinearity concern. Therefore, we included these baseline measures as controls in multiple regression.

[3] Pre-test levels of awe ($r = 0.21$, $p = .019$) and nature connectedness ($r = 0.28$, $p = .002$) were found to be moderately correlated with levels of engagement, even though they did not have direct moderation effects. This suggests that individual differences may have affected engagement in the activity. However, there may also be other situational factors (e.g., busy schedules) that have influenced engagement which were not measured in the study.

Table 4
Multiple regression models predicting awe.

Parameter	*B* (SE)	β	*p*	*B (SE)*	β	*p*	*B* (SE)	β	*p*	*B* (SE)	β	*p*
Condition (Learning vs. exposure)	0.13 (0.14)	0.07	.349	−0.11 (0.72)	−0.05	.896	0.25 (0.75)	0.13	.740	0.13 (0.13)	0.07	.320
Positive affect	0.41 (0.10)	0.29	<.001	0.42 (0.10)	0.30	<.001	0.41 (0.10)	0.30	<.001	0.41 (0.10)	0.29	<.001
Negative affect	−0.17 (0.11)	−0.11	.131	−0.17 (0.11)	−0.11	.136	−0.17 (0.11)	−0.11	.131	−0.15 (0.11)	−0.09	.191
Contact with nature	0.04 (0.02)	0.13	.087	0.04 (0.02)	0.13	.087	0.04 (0.02)	0.13	.089	0.04 (0.02)	0.12	.090
Pre-test awe	0.51 (0.09)	0.47	<.001	0.48 (0.11)	0.45	<.001	0.51 (0.09)	0.47	<.001	0.45 (0.19)	0.42	<.001
Pre-test nature connectedness	−0.00 (0.10)	−0.00	.961	−0.01 (0.10)	−0.00	.914	0.01 (0.14)	0.01	.946	−0.01 (0.10)	0.00	.899
Pre-test awe*Condition				0.05 (0.15)	0.13	.730						
Pre-test nature connectedness*Condition							−0.03 (0.17)	−0.06	.875			
Engagement										0.00 (0.07)	0.00	.985
Engagement*Condition										0.21 (0.09)	0.21	.027

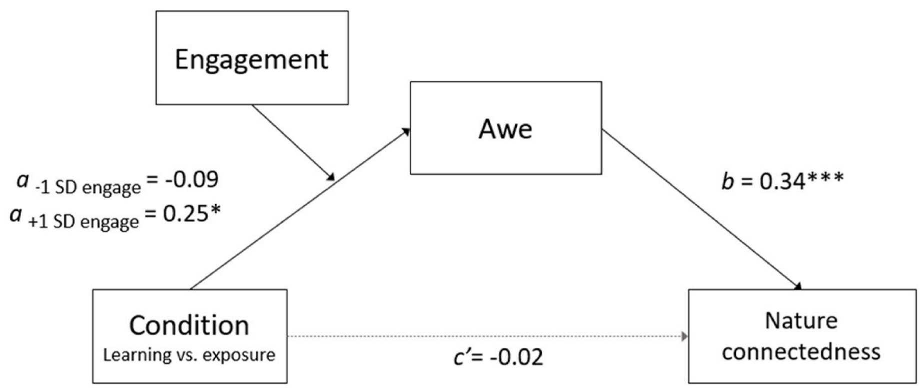

Fig. 2. Moderated mediation model for the effect of learning about nature on nature connectedness via awe.
Note. The numbers reported are standardized coefficients. The model controlled for exposure to nature, positive affect, negative affect, pre-test awe, and pre-test nature connectedness as covariates. The total effect, i.e., c path, is not reported because of conditional indirect effects.
*p < .05; **p < .01; ***p < .001.

moderated mediation was significant (moderated mediation index = 0.06, SE_{boot} = 0.03, CI_{boot} = [0.00, 0.14]). When levels of engagement were high (i.e., 1 *SD* above the mean), the indirect effect of learning condition on nature connectedness via awe was significant ($B = 0.13$, SE_{boot} = 0.06, CI_{boot} = [0.02, 0.27]). However, there was no significant indirect effect at mean ($B = 0.04$, SE_{boot} = 0.04, CI_{boot} = [−0.03, 0.13]) or low levels of engagement (i.e., 1 *SD* below the mean; *B* = - 0.05, SE_{boot} = 0.06, CI_{boot} = [−0.17, 0.07]).

Together, in Study 2 we were able to replicate Study 1's mediation effect, but only among participants who were engaged in the learning experience during the intervention. Controlling for covariates, we found a small-to-medium effect of the intervention on awe when engagement was high. Awe, in turn, had a medium-to-large effect on nature connectedness. Based on descriptive statistics, 31 out of 127 participants were sufficiently engaged (i.e., score of 5 or above out of 7) in the activity.

5. General discussion

5.1. Key findings

Overall, our study concurs with past research findings (e.g., Kossack & Bogner, 2012; Liefländer et al., 2013) that learning about nature may improve nature connectedness and suggests an explanatory mechanism for why that is the case. Learning about the intelligence and complexity of other life forms can help to trigger a sense of awe, which in turn promotes the perception of one's self as part of nature. Study 1 showed that people who knew more about nature were higher in dispositional awe and nature connectedness. Importantly, these effects remained significant even after controlling for exposure to nature. Study 2 demonstrated that learning about nature increased the experience of awe, as compared to simply observing nature, but only if participants were engaged in the learning activity. The experience of awe was, in turn, associated with higher nature connectedness, which was consistent with Study 1's findings. We acknowledge that the operationalization of the independent variable differs between the two studies. Study 1 used a species identification quiz; knowledge of nature was taken as a proxy indicator of prior learning. Study 2 directly manipulated the learning experience without assessing participants' knowledge. This was because administering the quiz pre-test might have made the hypothesis apparent to participants. Moreover, having a pre- and post-test quiz might produce increased scores due to practice effect. Participants might be prompted to look up organisms they saw in the quiz, including those in the exposure condition, which may have contaminated the experimental conditions. To assess whether our manipulation was effective, we included additional measures in the post-test survey, e.g., having learnt a lot about the natural world and perceived vastness in nature.

Our research, particularly Study 2, has several notable strengths. First, the intervention involves only free and accessible smartphone applications, which educators and individuals can download for immediate use. Second, the intervention is self-directed and suitable for implementation in urban environments, where nature is often perceived to be scarce. Third, the pretest-posttest experimental design allowed us to not only assess the effects of the nature intervention compared to the baseline level, but also how it fared compared to a condition that involved mere exposure to nature. This comparison, which has not been made in past studies to our knowledge, may help educators to understand how nature learning experiences uniquely contribute to

Table 5
Unstandardized and standardized coefficients for the mediation model with covariates.

Parameter	b (SE)	95% CI	β	t	p
Predicting awe					
Condition (learning vs. exposure)	0.13 (0.13)	[-0.12, 0.40]	0.07	1.00	.320
Contact with nature	0.04 (0.02)	[-0.00, 0.09]	0.12	1.71	.090
Positive affect	0.41 (0.10)	[0.21, 0.61]	0.29	4.05	<.001
Negative affect	−0.15 (0.11)	[-0.37, 0.07]	−0.09	−1.31	.191
Pre-test awe	0.45 (0.09)	[0.27, 0.62]	0.42	5.09	<.001
Pre-test nature connectedness	−0.01 (0.10)	[-0.21, 0.19]	−0.11	−0.13	.899
Engagement	0.00 (0.07)	[-0.13, 0.13]	0.00	0.02	.985
Engagement*Condition	0.21 (0.09)	[0.03, 0.40]	0.21	2.24	.027
Predicting nature connectedness					
Awe	0.29 (0.06)	[0.17, 0.41]	0.34	4.67	<.001
Condition (learning vs. exposure)	−0.03 (0.09)	[-0.22, 0.15]	−0.02	−0.36	.718
Contact with nature	0.01 (0.02)	[-0.02, 0.04]	0.03	0.56	.575
Positive affect	0.12 (0.08)	[-0.03, 0.26]	0.10	1.52	.130
Negative affect	0.11 (0.08)	[-0.04, 0.27]	0.08	1.45	.149
Pre-test awe	−0.21 (0.07)	[-0.35, −0.08]	−0.23	−3.15	.002
Pre-test nature connectedness	0.71 (0.07)	[0.57, 0.84]	0.69	10.22	<.001

individuals' nature connectedness. Fourth, the study used small, mundane nature for inducing awe, contrasting with past research that featured physically vast nature, such as sweeping landscapes and tall mountains (Gordon et al., 2017; Yang et al., 2018), as stimuli. People who live in cities often lack access to physically vast nature, so it was encouraging to find that urbanites could perceive awe in unassuming natural elements when provided with the opportunity to learn about them. Our results support the proposition that urban nature holds potential for fostering nature connectedness and pro-environmental attitudes (Dunn et al., 2006).

The findings of Study 2 suggest that the effect of learning about nature on awe (relative to mere exposure) and nature connectedness may vary in magnitude, in part depending on levels of participant engagement. In Study 2, only a quarter of participants were sufficiently engaged in the intervention to experience its intended effect. In retrospect, this makes sense because since students were participating for cash and course credit, some may have simply gone through the study activity to fulfil the research participation requirements. For example, participants in the learning condition may simply copy a plain fact from the first search result that appears in the search engine. This meant that the facts they reported might not have been interesting or fascinating, and even if they were, the participant might not have thought much about it. Furthermore, if participants were withholding their investment of emotional energy in this intervention, their experience of awe may be impeded even if they encountered fascinating stimuli. Overall, Study 2 suggests that having an educational component in a nature experience only offers additional benefits relative to mere exposure if participants feel engaged. Future studies in environmental education could explore how to improve participant engagement. For instance, creating a conducive setting for learner-learner interaction may help build a sense of community for those involved in a learning experience together (F. Martin & Bolliger, 2018). In the case of our digital intervention, having the participants keep a shared diary with a few others, or encouraging them to post about their observations on the social media may make the experience feel more social, rather than a solitary assignment. This is just one among many possibilities. As important as content is in education, finding ways to ensure that participants are motivated and engaged is also key to achieving the desired outcomes.

Also notable in Study 2, the pre- and post-intervention comparisons found increases in nature connectedness, yielding small-to-medium effect sizes, for both the exposure and learning groups. This implies that both learning and mere exposure to nature promoted nature connectedness among our participants. This corroborates past research which showed that nature connectedness is associated with time spent in nature (Cheng & Monroe, 2012; Nisbet et al., 2009). The biophilia hypothesis (Wilson, 1984) posits that people have an innate tendency to bond with nature, implying that it does not take very complicated or effortful interventions to promote nature connectedness. For instance, it is possible that having people interact with the nature that exists in their backyard can already yield increased nature connectedness. We cannot take for granted, however, that city dwellers would notice nature despite having access to urban greenery. The urban environment is filled with other stimuli that demand directed attention, such as traffic, crowds, and billboards, which may distract people from the natural features in cities (Amati et al., 2018). Digital tools, such as the photo diary we used in Study 2, may motivate participants to take notice of the nature they would have otherwise overlooked in their daily lives. Our findings highlight the possibility that technology can facilitate nature exposure and promote nature connectedness. This contrasts with other studies which found that using mobile devices consumed people's attention and distracted them from natural stimuli, thereby reducing nature exposure and connectedness (Jiang, Schmillen, & Sullivan, 2019; Wang et al., 2023). Palpably, whether technology connects or divides humans and nature depends on how it is used.

Relatedly, we found a significant direct effect of learning about nature on nature connectedness in Study 1, but not Study 2. There are several plausible explanations for this. First, both experimental conditions in Study 2 promoted nature connectedness among participants. There was only a slight difference in post-test nature connectedness between the learning and exposure groups as both conditions managed to yield an increase in nature connectedness from the pre-test measurements. A larger sample size may be required to detect such a small direct effect. Second, there may be a bidirectional relationship between learning about nature and nature connectedness. Although learning about nature may foster nature connectedness, it is also possible that nature connectedness promotes learning about nature. People with high nature connectedness may be more interested in learning about the natural environment. The direct relationship found in Study 1, being a correlational result, may be attributed to the effect of nature connectedness on learning. Third, the difference in results may be attributed to how learning about nature was operationalized across the two studies. Study 1 measured participants' biodiversity knowledge that might have accumulated over years of learning through a broad range of educational experiences. In contrast, Study 2 was a one-off, unstructured learning intervention. As such, Study 1 might have assessed more in-depth learning (i.e., involving more complex contents) which could not be captured by the short-term learning intervention in Study 2. Learning about nature, especially when it involves higher-order ecological knowledge beyond mere species identification, can help individuals understand how humans are part of nature (Palmberg et al., 2018). Examples include understanding food webs or carbon cycles, which may inspire individuals to develop mental representations of how humans are interconnected with nature. In other words, learning about nature may promote nature connectedness not just because it opens one to how fascinating and vast nature can be, but it may also promote understanding of exactly how humans and other species on Earth are interrelated.

5.2. Study limitations and future directions

We acknowledge some limitations of our studies. First, it is difficult to establish the causal chain of learning experiences leading to awe and, subsequently, nature connectedness. A mediation analysis is insufficient for establishing a causal mechanism (Spencer et al., 2005). Notably, we did not manipulate the mediator, i.e., awe. Therefore, we cannot confirm if awe causes nature connectedness as per our theorizing. However, we note that separate research has found increases in nature connectedness following the experimental manipulation of awe (Yang et al., 2018; J. Liu et al., 2023).

Second, we used a single-item measure of engagement in Study 2. We included it as an additional moderator for exploratory analysis and found that it was important in determining the efficacy of the intervention. As mentioned, engagement can be broadly defined as the investment of energy into an activity. There are different types of energy, namely physical, affective, and cognitive energy (Nahum-Shani et al., 2022). Physical energy investment is, simply put, participating in an activity or following directions (Newton et al., 2020). Some studies on digital interventions have assessed physical activity investment by tracking usage duration and frequency. However, in our case, all participants had to post frequently on their diaries and carry out the study instructions, so we believe that variation in physical energy investment was quite small in our sample. Instead, our participants may have differed in affective energy investment, which refers to feeling positive affect regarding the activity, such as pride or enthusiasm (Bowden et al., 2021). They may also have varied in cognitive energy investment, which is about paying attention to and processing information that is related to the activity (Kahn, 1990). The feeling of getting something over with, as we have used to measure engagement, may be related to both a lack of cognitive and emotional energy investment. Considering that engagement may be multi-dimensional, future studies can consider using more extensive measures of engagement to clarify the effects of each type of energy investment.

Third, we cannot confirm if the hypotheses and results are generalizable to other populations. Environmental education studies, especially those involving nature experiences, often focus on younger populations (e.g., Burgess & Mayer-Smith, 2011; Kossack & Bogner, 2012; Liefländer et al., 2013). In our case, we recruited undergraduate samples. However, it is also important to consider whether learning interventions can work on the general public as part of public education initiatives. Research suggested that people may become less curious as they age (Chu et al., 2020; Robinson et al., 2017). Older populations may be less motivated to process the novel information in learning interventions, thus affecting their level of engagement. This implies that receptiveness to learning experiences may differ across age and this can affect the efficacy of learning interventions for younger vs. older populations. It is possible that learning interventions are more effective (i.e., yielding higher effect sizes) at promoting nature connectedness through awe among younger populations. Older populations, on the other hand, may experience increased nature connectedness from other nature activities that are less cognitively effortful. This, of course, is a generalization; there are many older adults who engage in lifelong learning. We also note that our samples comprised a majority of female participants. Some studies suggest that females have stronger nature connectedness (Lengieza & Swim, 2019) and interest in biological sciences compared to males (Baram-Tsabari & Yarden, 2008). It is possible that females may be predisposed to show higher levels of engagement in our tested intervention, thereby yielding higher effect sizes than if we had a gender-balanced sample. However, we do not mean to make sweeping assumptions based on age or gender; our intention is to highlight that efforts to promote nature connectedness should consider not only which interventions work, but also on whom they are the most effective. While some people may feel more connected to nature through learning experiences, others may benefit more from interventions that involve mindfulness or aesthetic appreciation. For instance, individuals may differ in their propensity to engage with natural beauty (see Diessner et al., 2008), and this may affect their potential for developing nature connectedness through noticing nature's aesthetic qualities. The concept of person-intervention fit in promoting nature connectedness has yet to be explored. We believe that future studies on matching individual variables (e.g., age, gender, dispositional affect, cognitive styles, and engagement with beauty) to the mode of engaging with nature will be practically valuable, as they can help to maximize participant engagement and the benefits of intervention efforts.

6. Conclusion

In sum, the present research serves to promote further understanding of the different pathways to nature connectedness. More than just an inexplicable feeling, nature connectedness can attest to how humankind perceives their relationship with the natural world—are *Homo sapiens* an exceptionally intelligent species positioned at the top of the hierarchy of life, or are they just a small part of infinitely complex living systems? It may be difficult to answer these questions through mere exposure to nature. Learning about and developing an appreciation for the diversity and complexity of nature could be key to help people recognize that they are part of something greater, and that their well-being is intimately connected to the flourishing of other species on Earth. Perhaps, such a view of the world is why learners of natural sciences remain so committed to environmental protection. Beyond simply learning about why and how to behave pro-environmentally, we believe that educating people about the natural world can promote pro-environmentalism by shaping views on human-nature relationships.

CRediT authorship contribution statement

Shu Tian Ng: Conceptualization, Methodology, Writing – original draft, Formal analysis. Angela K.-y. Leung: Conceptualization, Methodology, Writing – review & editing, Supervision. Sarah Hian May Chan: Methodology, Writing – review & editing.

Declaration of competing interest

We have no conflicts of interest to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2023.102069. Other materials related to this research (i.e., dataset and codebook) are available at https://osf.io/6ra2h/.

References

Amati, M., Ghanbari Parmehr, E., McCarthy, C., & Sita, J. (2018). How eye-catching are natural features when walking through a park? Eye-Tracking responses to videos of walks. *Urban Forestry and Urban Greening, 31*, 67–78. https://doi.org/10.1016/j.ufug.2017.12.013

Bai, Y., Maruskin, L. A., Chen, S., Gordon, A. M., Stellar, J. E., McNeil, G. D., Peng, K., & Keltner, D. (2017). Awe, the diminished self, and collective engagement: Universals and cultural variations in the small self. *Journal of Personality and Social Psychology, 113*(2), 185–209. https://doi.org/10.1037/pspa0000087

Balmford, A., Clegg, L., Coulson, T., & Taylor, J. (2002). Why conservationists should heed Pokémon. *Science, 295*(5564). https://doi.org/10.1126/science.295.5564.2367b, 2367–2367.

Balundė, A., Jovarauskaitė, L., & Poškus, M. S. (2019). Exploring the relationship between connectedness with nature, environmental identity, and environmental self-identity: A systematic review and meta-analysis. *Sage Open, 9*(2), Article 2158244019841925. https://doi.org/10.1177/2158244019841925

Baram-Tsabari, A., & Yarden, A. (2008). Girls' biology, boys' physics: Evidence from free-choice science learning settings. *Research in Science & Technological Education, 26*(1), 75–92. https://doi.org/10.1080/02635140701847538

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science, 19*(12), 1207–1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x

Bowden, J. L.-H., Tickle, L., & Naumann, K. (2021). The four pillars of tertiary student engagement and success: A holistic measurement approach. *Studies in Higher Education, 46*(6), 1207–1224. https://doi.org/10.1080/03075079.2019.1672647

Burgess, D. J., & Mayer-Smith, J. (2011). Listening to children: Perceptions of nature. *The Journal of Natural History Education and Experience, 5*, 27–43.

Cafaro, P. (2001). Thoreau, Leopold, and Carson: Toward an environmental virtue ethics. *Environmental Ethics, 23*(1), 3–17. https://doi.org/10.5840/enviroethics200123135

Capra, F. (2007). Sustainable living, ecological literacy, and the breath of life. *Canadian Journal of Environmental Education, 12*(1), 9–18.

Carson, R. (1965). *The sense of wonder: A celebration of nature for parents and children.* Harper Perennial.

Chainey, R. (2019). *Top quotes from prince william's interview with sir David Attenborough at Davos 2019.* World Economic Forum. https://www.weforum.org/agenda/2019/01/top-quotes-from-prince-william-sir-david-attenborough-interview-at-davos-2019/.

Chan, S., Qiu, L., Esposito, G., Mai, K., Tam, K.-P., & Cui, J. (2021). Nature in virtual reality improves mood and reduces stress: Evidence from young adults and senior citizens. *Virtual Reality*. https://doi.org/10.1007/s10055-021-00604-4

Cheng, J. C.-H., & Monroe, M. C. (2012). Connection to nature: Children's affective attitude toward nature. *Environment and Behavior, 44*(1), 31–49. https://doi.org/10.1177/0013916510385082

Chu, L., Tsai, J. L., & Fung, H. H. (2020). Association between age and intellectual curiosity: The mediating roles of future time perspective and importance of curiosity. *European Journal of Ageing, 18*(1), 45–53. https://doi.org/10.1007/s10433-020-00567-6

Cuzzolino, M. P. (2021). "The awe is in the process": The nature and impact of professional scientists' experiences of awe. *Science Education, 105*(4), 681–706. https://doi.org/10.1002/sce.21625

Diessner, R., Solom, R. D., Frost, N. K., Parsons, L., & Davidson, J. (2008). Engagement with beauty: Appreciating natural, artistic, and moral beauty. *Journal of Psychology, 142*(3), 303–332. https://doi.org/10.3200/JRLP.142.3.303-332

Dunn, R. R., Gavin, M. C., Sanchez, M. C., & Solomon, J. N. (2006). The pigeon paradox: Dependence of global conservation on urban nature. *Conservation Biology, 20*(6), 1814–1816. https://doi.org/10.1111/j.1523-1739.2006.00533.x

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Frantz, C. M., & Mayer, F. S. (2014). The importance of connection to nature in assessing environmental education programs. *Studies In Educational Evaluation, 41*, 85–89. https://doi.org/10.1016/j.stueduc.2013.10.001

Frantz, C., Mayer, F., Norton, C., & Rock, M. (2005). There is no "I" in nature: The influence of self-awareness on connectedness to nature. *Journal of Environmental Psychology, 25*, 427–436. https://doi.org/10.1016/j.jenvp.2005.10.002

Gkargkavouzi, A., Halkos, G., & Matsiori, S. (2019). A multi-dimensional measure of environmental behavior: Exploring the predictive power of connectedness to nature, ecological worldview and environmental concern. *Social Indicators Research, 143*(2), 859–879. https://doi.org/10.1007/s11205-018-1999-8

Gordon, A. M., Stellar, J. E., Anderson, C. L., McNeil, G. D., Loew, D., & Keltner, D. (2017). The dark side of the sublime: Distinguishing a threat-based variant of awe. *Journal of Personality and Social Psychology, 113*(2), 310–328. https://doi.org/10.1037/pspp0000120

Guan, F., Zhao, S., Chen, S., Lu, S., Chen, J., & Xiang, Y. (2019). The neural correlate difference between positive and negative awe. *Frontiers in Human Neuroscience, 13*. https://www.frontiersin.org/articles/10.3389/fnhum.2019.00206.

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach.* Guilford Press.

Hayes, A. F., & Scharkow, M. (2013). The relative trustworthiness of inferential tests of the indirect effect in statistical mediation analysis: Does method really matter? *Psychological Science, 24*(10), 1918–1927. https://doi.org/10.1177/0956797613480187

Hungerford, H. R., & Volk, T. L. (1990). Changing learner behavior through environmental education. *The Journal of Environmental Education, 21*(3), 8–21. https://doi.org/10.1080/00958964.1990.10753743

Jensen, B. B. (2002). Knowledge, action and pro-environmental behaviour. *Environmental Education Research, 8*(3), 325–334. https://doi.org/10.1080/13504620220145474

Jiang, B., Schmillen, R., & Sullivan, W. C. (2019). How to waste a break: Using portable electronic devices substantially counteracts attention enhancement effects of green spaces. *Environment and Behavior, 51*(9–10), 1133–1160. https://doi.org/10.1177/0013916518788603

Kahn, W. A. (1990). Psychological conditions of personal engagement and disengagement at work. *Academy of Management Journal, 33*(4), 692–724. https://doi.org/10.2307/256287

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology, 15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

Keltner, D., & Haidt, J. (2003). Approaching awe, a moral, spiritual, and aesthetic emotion. *Cognition & Emotion, 17*(2), 297–314. https://doi.org/10.1080/02699930302297

Kleespies, M. W., Feucht, V., Becker, M., & Dierkes, P. W. (2022). Environmental education in zoos—exploring the impact of guided zoo tours on connection to nature and attitudes towards species conservation. *Journal of Zoological and Botanical Gardens, 3*(1). https://doi.org/10.3390/jzbg3010005. Article 1.

Kossack, A., & Bogner, F. X. (2012). How does a one-day environmental education programme support individual connectedness with nature? *Journal of Biological Education, 46*(3), 180–187. https://doi.org/10.1080/00219266.2011.634016

Lankenau, G. R. (2018). Fostering connectedness to nature in higher education. *Environmental Education Research, 24*(2), 230–244. https://doi.org/10.1080/13504622.2016.1225674

Lengieza, M. L., & Swim, J. K. (2021). The paths to connectedness: A review of the antecedents of connectedness to nature. *Frontiers in Psychology, 12*. https://www.frontiersin.org/articles/10.3389/fpsyg.2021.763231.

Leopold, A. (1949). *A sand county almanac: With essays on conservation from Round River.* Ballantine Books.

Liefländer, A. K., Fröhlich, G., Bogner, F. X., & Schultz, P. W. (2013). Promoting connectedness with nature through environmental education. *Environmental Education Research, 19*(3), 370–384. https://doi.org/10.1080/13504622.2012.697545

Liu, J., Huo, Y., Wang, J., Bai, Y., Zhao, M., & Di, M. (2023). Awe of nature and well-being: Roles of nature connectedness and powerlessness. *Personality and Individual Differences, 201*, Article 111946. https://doi.org/10.1016/j.paid.2022.111946

Liu, H., Nong, H., Ren, H., & Liu, K. (2022). The effect of nature exposure, nature connectedness on mental well-being and ill-being in a general Chinese population. *Landscape and Urban Planning, 222*, Article 104397. https://doi.org/10.1016/j.landurbplan.2022.104397

Mackay, C. M. L., & Schmitt, M. T. (2019). Do people who feel connected to nature do more to protect it? A meta-analysis. *Journal of Environmental Psychology, 65*, Article 101323. https://doi.org/10.1016/j.jenvp.2019.101323

Martin, F., & Bolliger, D. U. (2018). Engagement matters: Student perceptions on the importance of engagement strategies in the online learning environment. *Online Learning, 22*(1). https://doi.org/10.24059/olj.v22i1.1092

Martin, C., & Czellar, S. (2017). Where do biospheric values come from? A connectedness to nature perspective. *Journal of Environmental Psychology, 52*, 56–68. https://doi.org/10.1016/j.jenvp.2017.04.009

Mayer, F. S., & Frantz, C. M. (2004). The connectedness to nature scale: A measure of individuals' feeling in community with nature. *Journal of Environmental Psychology, 24*(4), 503–515. https://doi.org/10.1016/j.jenvp.2004.10.001

Miller, J. R. (2005). Biodiversity conservation and the extinction of experience. *Trends in Ecology & Evolution, 20*(8), 430–434. https://doi.org/10.1016/j.tree.2005.05.013

Nahum-Shani, I., Shaw, S. D., Carpenter, S. M., Murphy, S. A., & Yoon, C. (2022). Engagement in digital interventions. *American Psychologist, 77*(7), 836–852. https://doi.org/10.1037/amp0000983

National Parks Board. (2022). City in nature. https://www.nparks.gov.sg/about-us/city-in-nature.

Newton, D. W., LePine, J. A., Kim, J. K., Wellman, N., & Bush, J. T. (2020). Taking engagement to task: The nature and functioning of task engagement across transitions. *Journal of Applied Psychology, 105*(1), 1–18. https://doi.org/10.1037/apl0000428

Nisbet, E. K., & Zelenski, J. M. (2011). Underestimating nearby nature: Affective forecasting errors obscure the happy path to sustainability. *Psychological Science, 22*(9), 1101–1106. https://doi.org/10.1177/0956797611418527

Nisbet, E. K., Zelenski, J. M., & Murphy, S. A. (2009). The nature relatedness scale: Linking individuals' connection with nature to environmental concern and behavior. *Environment and Behavior, 41*(5), 715–740. https://doi.org/10.1177/0013916508318748

Orr, D. (1996). Ecological literacy. In M. A. Cahn, & R. O'Brien (Eds.), *Thinking about the environment: Readings on politics, property and the physical world* (pp. 227–234). Routledge. https://doi.org/10.4324/9781315698724.

Palmberg, I., Berg, I., Jeronen, E., Kärkkäinen, S., Norrgård-Sillanpää, P., Persson, C., Vilkonis, R., & Yli-Panula, E. (2015). Nordic–Baltic student teachers' identification of and interest in plant and animal species: The importance of species identification and biodiversity for sustainable development. *Journal of Science Teacher Education, 26*(6), 549–571. https://doi.org/10.1007/s10972-015-9438-z

Palmberg, I., Hermans, M., Jeronen, E., Kärkkäinen, S., Persson, C., & Yli-Panula, E. (2018). Nordic student teachers' views on the importance of species and species identification. *Journal of Science Teacher Education, 29*(5), 397–419. https://doi.org/10.1080/1046560X.2018.1468167

Piff, P. K., Dietze, P., Feinberg, M., Stancato, D. M., & Keltner, D. (2015). Awe, the small self, and prosocial behavior. *Journal of Personality and Social Psychology, 108*(6), 883–899. https://doi.org/10.1037/pspi0000018

Randler, C. (2008). Teaching species identification – a prerequisite for learning biodiversity and understanding ecology. *Eurasia Journal of Mathematics, Science and Technology Education, 4*(3), 223–231. https://doi.org/10.12973/ejmste/75344

Richardson, M., Hallam, J., & Lumber, R. (2015). One thousand good things in nature: Aspects of nearby nature associated with improved connection to nature. *Environmental Values, 24*(5), 603–619. https://doi.org/10.3197/096327115X14384223590131

Robinson, O. C., Demetre, J. D., & Litman, J. A. (2017). Adult life stage and crisis as predictors of curiosity and authenticity: Testing inferences from Erikson's lifespan theory. *International Journal of Behavioral Development, 41*(3), 426–431. https://doi.org/10.1177/0165025416645201

Schoemann, A. M., Boulton, A. J., & Short, S. D. (2017). Determining power and sample size for simple and complex mediation models. *Social Psychological and Personality Science, 8*(4), 379–386. https://doi.org/10.1177/1948550617715068

Schultz, P. W. (2001). The structure of environmental concern: Concern for self, other people and the biosphere. *Journal of Environmental Psychology, 21*(4), 327–339. https://doi.org/10.1006/jevp.2001.0227

Schultz, P. W. (2002). Inclusion with nature: The psychology of human-nature relations. In P. Schmuck, & P. W. Schultz (Eds.), *Psychology of sustainable development* (pp. 61–78). Springer US. https://doi.org/10.1007/978-1-4615-0995-0_4.

Sellmann, D., & Bogner, F. X. (2013). Effects of a 1-day environmental education intervention on environmental attitudes and connectedness with nature. *European*

Journal of Psychology of Education, 28(3), 1077–1086. https://doi.org/10.1007/s10212-012-0155-0

Seo, M., Yang, S., & Laurent, S. M. (2023). No one is an island: Awe encourages global citizenship identification. *Emotion, 23*(3), 601–612. https://doi.org/10.1037/emo0001160

Shiota, M. N., Keltner, D., & John, O. P. (2006). Positive emotion dispositions differentially associated with Big Five personality and attachment style. *The Journal of Positive Psychology, 1*(2), 61–71. https://doi.org/10.1080/17439760500510833

Shiota, M. N., Keltner, D., & Mossman, A. (2007). The nature of awe: Elicitors, appraisals, and effects on self-concept. *Cognition & Emotion, 21*(5), 944–963. https://doi.org/10.1080/02699930600923668

Soga, M., & Gaston, K. J. (2016). Extinction of experience: The loss of human–nature interactions. *Frontiers in Ecology and the Environment, 14*(2), 94–101. https://doi.org/10.1002/fee.1225

Spencer, S. J., Zanna, M. P., & Fong, G. T. (2005). Establishing a causal chain: Why experiments are often more effective than mediational analyses in examining psychological processes. *Journal of Personality and Social Psychology, 89*(6), 845–851. https://doi.org/10.1037/0022-3514.89.6.845

Stern, M. J., Powell, R. B., & Ardoin, N. M. (2008). What difference does it make? Assessing outcomes from participation in a residential environmental education program. *The Journal of Environmental Education, 39*(4), 31–43. https://doi.org/10.3200/JOEE.39.4.31-43

Tam, K.-P. (2013). Concepts and measures related to connection to nature: Similarities and differences. *Journal of Environmental Psychology, 34*, 64–78. https://doi.org/10.1016/j.jenvp.2013.01.004

Thompson, E. R. (2007). Development and validation of an internationally reliable short-form of the positive and negative affect schedule (panas). *Journal of Cross-Cultural Psychology, 38*(2), 227–242. https://doi.org/10.1177/0022022106297301

Toomey, A. H., & Domroese, M. C. (2013). Can citizen science lead to positive conservation attitudes and behaviors? *Human Ecology Review, 20*(1), 50–62.

Wang, C., Geng, L., & Rodríguez Casallas, J. D. (2022). Mindfulness to climate change inaction: The role of awe, "Dragons of inaction" psychological barriers and nature connectedness. *Journal of Environmental Psychology, 84*, Article 101912. https://doi.org/10.1016/j.jenvp.2022.101912

Wang, C., Geng, L., & Rodríguez-Casallas, J. D. (2023). The role of nature-deficit disorder in the associations between mobile phone overuse and well-being and mindfulness. *Current Psychology, 42*(2), 894–905. https://doi.org/10.1007/s12144-021-01453-9

Weger, U., & Wagemann, J. (2021). Towards a conceptual clarification of awe and wonder. *Current Psychology, 40*(3), 1386–1401. https://doi.org/10.1007/s12144-018-0057-7

Whitburn, J., Linklater, W., & Abrahamse, W. (2020). Meta-analysis of human connection to nature and proenvironmental behavior. *Conservation Biology, 34*(1), 180–193. https://doi.org/10.1111/cobi.13381

Whitburn, J., Linklater, W. L., & Milfont, T. L. (2019). Exposure to urban nature and tree planting are related to pro-environmental behavior via connection to nature, the use of nature for psychological restoration, and environmental attitudes. *Environment and Behavior, 51*(7), 787–810. https://doi.org/10.1177/0013916517751009

White, M. P., Pahl, S., Ashbullby, K., Herbert, S., & Depledge, M. H. (2013). Feelings of restoration from recent nature visits. *Journal of Environmental Psychology, 35*, 40–51. https://doi.org/10.1016/j.jenvp.2013.04.002

Wilson, E. O. (1984). *Biophilia*. Harvard University Press.

Yang, Y., Hu, J., Jing, F., & Nguyen, B. (2018). From awe to ecological behavior: The mediating role of connectedness to nature. *Sustainability, 10*(7), 7. https://doi.org/10.3390/su10072477