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RESEARCH ARTICLE

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Getting hands-on with hedges—Does experiential engagement in plant science experiments affect secondary school pupils' environmental perceptions?

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Societal Impact Statement

In towns and cities, vegetation growing around streets and buildings can lessen the risks posed by extreme heat, rainfall and poor air quality. However, the urban public (and particularly, youth) have limited awareness of these environmental benefits. Our study engaged 14–15-year-old school pupils in online and in-person learning interventions to enhance their awareness of the environmental benefits of hedges and assess impacts on their attitudes and intentions. We show that enhancing hands-on learning opportunities exploring how greenery regulates local environments can shift pupils' perceptions about the value of plants. Such educational activities are increasingly important for today's young people, who need knowledge and understanding to help them adapt to our changing climate.

Summary

- Increasing green infrastructure in cities has the potential to mitigate some of the negative impacts of air pollution and climate change on local population health, but this is currently under-recognised. Urban youth are particularly vulnerable to poor environmental quality but can limit this by engaging in actions that protect and increase green infrastructure near where they live.
- This paper reports the findings of a preliminary study that assessed the impact of hands-on and online green infrastructure learning interventions on environmental awareness and behavioural intentions amongst secondary school pupils in the United Kingdom. The study also assessed the influence of prior gardening experience on their environmental attitudes. We used a pretest, posttest quasi-experimental research design and statistically analysed the resulting data sets.
- Our findings suggest a combination of online and hands-on learning interventions can effectively shift the perceived efficacy of green infrastructure adaptations, whereas stand-alone online interventions may be less effective.
- Importantly, they also indicate that gardening experience is associated with pro-environmental attitudes in young people, and plant-related learning

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interventions within schools may particularly influence pupils who have not experienced gardening outside of school.

KEYWORDS
air quality, climate change, environmental education, experiential learning, green infrastructure for air quality plus, pro-environmental behaviour change, urban greening

1 | INTRODUCTION

In urban contexts, green infrastructure (henceforth GI, such as street trees, parks, gardens, hedgerows, green roofs and green walls) helps regulate local environmental conditions, increasing urban liveability. For example, GI mitigates some negative impacts of climate change and air pollution by reducing flood risk and extreme temperatures and trapping airborne particulate pollution (Blanusa et al., 2019; Hewitt et al., 2020; Koc et al., 2017). However, presently, public awareness of the environmental quality improvements that GI can deliver is limited (Borysiak & Stepniewska, 2022; Collins et al., 2019; Tsantopoulos et al., 2018). Strong public demand is needed to ensure local and national authorities prioritise urban GI provision (Liberalesso et al., 2020). This necessitates shifts in public understanding and perception, so that local populations are motivated to champion GI for wellbeing in urban environments.

Today's children are physiologically more vulnerable to poor air quality and will suffer greater exposure across their lifetimes to climate change-related extreme weather like heatwaves and flooding (Künzli et al., 2000; Manisalidis et al., 2020; Perera & Nadeau, 2022). As such, teaching interventions, which increase pupils' awareness of the benefits of GI, which promote pro-environmental attitude formation and which motivate environmentally responsible behaviours, may particularly benefit them throughout their lives (Rudd et al., 2020; van de Wetering et al., 2022). Parental influence, nature contact and environmental education are key factors that shape environmental attitudes and risk perceptions in young people, along with direct and indirect experiences of negative environmental impacts (Eilam & Trop, 2012; Olsen et al., 2024; Rosa & Collado, 2019; Tranter & Skrbis, 2014; van de Wetering et al., 2022). Studies show that environmental education (particularly when it enhances hopes for the future) can increase both pro-environmental behaviour and subjective wellbeing (Kerret et al., 2020). Research suggests timing environmental education experiences to harness the openness of young people to attitude change, before perceptions become more entrenched in later adulthood (Casaló & Escario, 2016). Some researchers have also highlighted a moral obligation for education to provide young people with 'capabilities so that they can act *for* the environment' (Dunlop & Rushton, 2022 p. 1094, our emphasis).

Environmental education and psychology research is beginning to focus on the mental health impacts of growing up in the context of the climate and biodiversity crisis (Pfenning-Butterworth et al., 2024) and implications for climate- and eco-anxiety (Jarrett et al., 2024; Léger-Goodes et al., 2022). Relevant reviews indicate that most young people are worried about the environment (Hickman et al., 2021), and as such, educators have a responsibility to provide climate education. However, they also highlight that greater awareness of the climate crisis may lead to poor mental health outcomes if pupils do not feel empowered to take effective action to ameliorate the situation (Léger-Goodes et al., 2022).

In the UK context, recognition of the increasing underexposure of children and young people to nature (Howlett & Turner, 2023) is driving appetite for embedding nature connectedness and environmental awareness through formal education, as epitomised in the UK National Education Nature Parks initiative (Rushton & Walshe, 2022). However, debate remains over the role of environmental education within UK national curricula (Dunlop & Rushton, 2022; Rushton & Walshe, 2022; Sneed et al., 2021; Sprague et al., 2022). Whilst meta-analysis shows environmental education improves environmental knowledge, attitudes, intentions and behaviours amongst young people, its optimal delivery mode (e.g., whether in traditional classroom or natural outdoor settings, and whether face-to-face or online) remains unclear (van de Wetering et al., 2022). In addition, rather than being taught separately, environmental education in England currently only forms parts of Programmes of Study in Key Stage three Geography (12–14 year olds) as well as Key Stages three and four (12–16 year olds) science (Biology and Chemistry) and the focus is predominantly on learning *about* the environment, rather than learning *in* the environment (Glackin & King, 2020). Analysis has found that levels of belief in climate change and environmental concern, and willingness to engage in actions that seek to address environmental threats, are lower amongst UK youth than amongst children in other countries (many of which have, to date, been more directly impacted by climate disasters [Lee et al., 2020]); hence, it is important to increase understanding of how environmental education in the United Kingdom can play a role in addressing this difference and help to empower young people.

In addition to the capacity of urban GI to mitigate negative climate impacts, a growing body of research (termed GI4AQ—Green Infrastructure for Air Quality) evidences the air quality benefits of adding GI in urban environments around school perimeters (Bermudez et al., 2023; Sheikh et al., 2023). Some researchers have also begun to highlight further co-benefits of GI4AQ (including safety, wellbeing, community engagement, habitat development and environmental sustainability messaging) designating such studies as GI4AQ+ (de la Osa et al., 2024; del Carmen Redondo-Bermúdez et al., 2022).

In this study, we build on the GI4AQ+ approach by investigating the impact of teaching interventions using newly planted GI4AQ hedging within a secondary school's grounds on pupils' perceptions of environmental risks and the benefits of GI in addressing them. This paper answers the following four questions:

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1. What were the pupils' environmental attitudes, risk perceptions and knowledge of green infrastructure like prior to the teaching interventions?
2. How did the teaching interventions affect the pupils' environmental attitudes, risk perceptions and their knowledge of green infrastructure?
3. Were the pupils' previous experiences of gardening associated with their initial environmental attitudes, risk perceptions and knowledge of green infrastructure prior to the interventions?
4. Did previous experience of gardening make any difference to the pupils' responses to the teaching interventions?

2 | MATERIALS AND METHODS

2.1 | Theoretical background and survey design

Studies suggest a combination of attitudinal and logistical factors determines motivations to undertake pro-environmental actions. These factors include underlying environmental attitudes and cognition and wider structural drivers such as social norms, capabilities and opportunities (Stern, 2000). Cognitive determinants include risk perceptions, norms and perceived efficacy (both of the action itself and of the individual's ability to undertake it) (van Valkengoed et al., 2022). Drawing on this, our survey investigated the following three areas: (1) the pupils' environmental attitudes (assessed via their nature-connectedness and environmental concern [Kaiser et al., 1999]), (2) their environmental risk perceptions (assessed using structured questions based on Protection Motivation Theory (PMT) [Rogers, 1975]), and (3) their environmental knowledge of GI. The survey also collected information about the pupils' prior GI exposure, such as whether they had a garden at home or had gardened before, and how much time they spent in green space per week. Table 1 provides an overview of the research questions, survey measures and statistical tests we used to analyse the data obtained with the survey.

2.1.1 | Environmental attitudes assessed via measures of nature connectedness and environmental concern

Nature connectedness

Researchers have highlighted connection to nature as an important determinant of both wellbeing and pro-environmental behaviour (Liu et al., 2022; Mackay & Schmitt, 2019). The decline in nature connection experienced by urban populations (particularly children and adolescents) is frequently raised as an issue of concern with negative ramifications for population health, and for the natural world itself (Soga et al., 2016). Nature connection research rests on the assumption that the more closely a person identifies with nature, the more likely they are to minimise harm to the natural world (Arnocky et al., 2007; Schultz, 2002). We employed Schultz's 7-point Self in Nature (INS) scale to assess pupils' nature-connectedness, due to its pictorial nature, brevity and reliability when used with children (Barthel et al., 2018).

TABLE 1 Research questions and methods overview.

Research questions	**What were the pupils' environmental attitudes, risk perceptions and knowledge about GI like prior to the teaching interventions?**	**How did the teaching interventions affect the pupils' environmental attitudes, risk perceptions and knowledge of green infrastructure?**	**Were the pupils' initial environmental attitudes, risk perceptions and knowledge about GI prior to the interventions associated with previous experience of gardening?**	**Did previous experience of gardening make any difference to the pupils' responses to the teaching interventions?**
Factors measured by the survey	• **Environmental attitudes** • **Environmental risk perceptions** • **Environmental knowledge of green infrastructure** • **Background experience with gardening/time spent in green space**			
How the survey measured these factors	1. Nature connectedness (INS self in nature scale) 2. Environmental concern (Schultz's scale) *Rationale: Value belief norm theory*	Question set evaluating perceptions of local environmental risks and the efficacy of responses involving green infrastructure. *Rationale: Protection motivation theory*	Multiple choice question set about the environmental science of green infrastructure. *Rationale: Knowledge-deficit model*	Binary (yes/no) and ordinal (3 ordered categories) question set to measure exposure to green space and gardening
Statistical analysis used	Descriptive stats overview of pretest results including mean scores for environmental attitudes, risk perception and green infrastructure knowledge *t*-tests and analysis of variance (ANOVAs) to assess differences in mean pre-intervention test scores for environmental attitudes, risk perceptions or environmental green infrastructure knowledge Analysis of covariance (ANCOVA) to assess whether the teaching interventions significantly altered the pupils' environmental attitudes, risk perceptions or green infrastructure knowledge *t*-Tests of the mean differences between pretest and posttest scores for environmental attitudes, risk perceptions and knowledge for pupils in the hands-on intervention group depending on prior experience of gardening			

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Environmental concern

Environmental concern is an important indirect determinant of pro-environmental behaviour (Bamberg, 2003), which affects environmental intent (Stern, 2000). Multiple scales have been developed to measure perceptions around the consequences of human behaviour for the environment (Fransson & Gärling, 1999). Here, we used another 7-point scale, also developed by Schultz (2001), which is considered the most reliable and is also the briefest of the commonly used instruments (Cruz & Manata, 2020). It assesses different reasons for environmental concern, measuring biospheric concern (concern about environmental problems because of impacts on animals and plants), altruistic concern (concern because of impacts on other people) and egocentric concern (concern because of impacts on oneself) (Schultz, 2001). As such, the scale provides insights into the respondents' underlying values. We used a slightly modified version of the scale validated for use with children from 9 years up (Bruni et al., 2012).

2.1.2 | Environmental risk perceptions assessed using PMT measures

The next section of our survey included questions structured in accordance with PMT (Rogers, 1975). PMT is a conceptual framework that highlights two cognitive pathways via which individuals assess whether to employ a protective behaviour against a threat. The first, risk appraisal, is a compound variable made up of the degree to which an individual perceives that the negative impacts of a threat would be severe and their perceived likelihood that such an impact would occur. Risk appraisal sometimes also includes a third component measuring emotional response. The second pathway, adaptation appraisal, is made up of the perceived efficacy of employing an adaptation and perceived self-efficacy to employ the adaptation in question (Milne et al., 2000).

We asked the pupils to indicate the degree to which they perceived, and worried about, risks from climate change and air pollution in their local area and then took the average of these scores to produce a measure of environmental threat appraisal. To measure adaptation appraisal, we asked about the degree to which pupils considered that adding more plants to the local environment would be an effective strategy for reducing the impacts of these risks, and about their own ability and capacity to engage in projects geared towards protecting and increasing green infrastructure locally. At the end of this section, we included a question to measure intent regarding involvement in green infrastructure projects: 'How likely are you to get involved with projects that aim to make a difference to greenery in your local area in future?' Pupils responded to this section of the survey using a sliding scale from 0 to 100. The questions used within the PMT part of the survey, along with the list of the PMT components they assess, are summarised in Table 2.

2.1.3 | GI knowledge assessment

Interventions designed to promote environmental behaviour change are sometimes based on the 'knowledge-deficit model', which assumes that behaviours are (or are not) undertaken due to a lack of knowledge and understanding about a particular issue, in this case, the environmental impacts of GI (van Valkengoed et al., 2022). We included nine multiple choice questions to test the pupils' understanding of the environmental science of green infrastructure. This section included questions such as: 'Which two characteristics give plants greater potential for capturing air pollution?' (a) smooth leaves, (b) large canopy of branches and leaves, (c) hairy leaves, (d) deep root systems. All the facts that formed these 'knowledge questions' were provided to pupils during the intervention work.

2.1.4 | Assessing pre-existing exposure to green infrastructure

Higher exposure to nature (e.g., in the form of neighbourhood green space) is positively associated with pro-environmental behaviour (Alcock et al., 2020). Additionally, studies have found that gardening has significant impacts on aspects of environmental identity such as biophilia (Vanderstock et al., 2022) and altruism (Oh et al., 2022). As such, we included a section in the questionnaire that gauged how long pupils spent weekly in green space, and their prior exposure to gardening. In the UK context, domestic/home gardens are prevalent, and gardening is one of the most popular national pastimes (Horticultural Trades Association, 2025). As such, gardens and gardening constitute an important nature contact mechanism for the UK population (Cameron et al., 2012), and UK youth grow up in a national context where gardening is culturally valued.

The Ethics Committee of the School of Agriculture, Policy and Development at the University of Reading approved the survey used for this research (SAPD Ethical Clearance Application Reference Number: 01927). Several weeks prior to carrying out the survey, a letter to parents and guardians was distributed via the school, which provided information about the survey and offered the possibility to opt out. One pupil withdrew before the survey was administered. Pupils were informed of their right to withdraw from submitting the survey both in writing at the beginning and end of each online survey form, as well as verbally by their teacher. Finally, pupils were made aware that by clicking submit/finish they consented for their anonymised responses to be used as part of the research.

The survey was piloted with three similarly aged pupils from a different school to check for clarity and duration, resulting in minor linguistic adjustments.

2.2 | Study context

We conducted this research as part of a larger study investigating the environmental benefits of mixed urban hedges (representing a range of plant characteristics which can positively impact the environment [Blanusa et al., 2019]). The larger study consisted of experimentally measuring rainfall run-off, ambient temperatures, and particulate matter (PM) capture year-round in both a controlled field research setting

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TABLE 2 Questions and structure for generating the protection motivation scores.

Protection motivation survey questions and structure		
Survey question	**Protection Motivation Theory component measured by question**	**Final Protection Motivation Theory component measure**
Are climate change impacts likely to affect your local area negatively?	Perceived likelihood of a threat (probability that negative impacts will occur)	Threat/ risk appraisal
Is poor air quality likely to affect the health of people and wildlife in your area?	Perceived likelihood of a threat (probability that negative impacts will occur)	Threat/ risk appraisal
How severe are the impacts of air pollution for the health of people, plants and animals in your area?	Perceived severity of that threat (degree of severity of those negative impacts)	Threat/ risk appraisal
How severe are the negative impacts of climate extremes in your local environment?	Perceived severity of that threat (degree of severity of those negative impacts)	Threat/ risk appraisal
How concerned are you about the negative impacts of climate change in your area?	Emotional (affective) response to the threat (feelings about the negative impacts)	Threat/ risk appraisal
How worried are you about air quality in your local environment?	Emotional (affective) response to the threat (feelings about the negative impacts)	Threat/ risk appraisal
Would adding more plants to the local area be an effective way to reduce harmful air pollution?	Adaptation efficacy (perceived efficacy of the adaptation)	Adaptation/ coping appraisal
How much can plants help to limit negative climate impacts from climate extremes?	Adaptation efficacy (perceived efficacy of the adaptation)	Adaptation/ coping appraisal
How much of a difference would you be able to make to the provision of greenery in your area by getting involved with projects to care for nature at home/school/in your local community?	Self-efficacy (perceived personal capacity to employ the adaptation)	Adaptation/ coping appraisal
How much of your time would you be able to contribute to helping look after greenery in your local area?	Self-efficacy (perceived personal capacity to employ the adaptation)	Adaptation/ coping appraisal

and a real-life setting within a school. For the latter, we planted two mixed hedgerows in a part of a school playing field close to a busy road where they could function as a barrier to PM and provide other environmental benefits.

An additional study objective was to investigate opportunities for, and barriers to, introducing hedges (a simple and relatively affordable form of GI) into school settings. The selected school was keen to involve pupils (see Section 2.3), so we co-devised a programme to engage the pupils with the environmental science of hedges and measure whether participation affected the pupils' environmental attitudes, including their perceptions of the value of GI for mitigating air quality and climate risks.

2.3 | Participants and their school surroundings

We selected a secondary school in Woking (Surrey, south east England, UK) as a study site due to strong support from school leadership to include our work in science lessons and a desire to reach secondary school-aged children who are traditionally more difficult to engage in gardening activities (in line with a shift in their social behaviours away from time spent with adults and towards peers). Several studies report a decline in nature connection during adolescence compounded with increasing screen use in this age group, which highlights the importance of reaching teenage school pupils with hands-on, field-based environmental learning experiences in school (Madera et al., 2025).

The site provided a good case study due to its proximity to a major arterial road connecting the urban centres of Woking and Guildford and linking to the M25 and M3 motorways. Parts of the school grounds also suffer from a high water table and localised flooding; road traffic-related air pollution and flash flooding both being environmental issues which GI interventions can mitigate.

The school is a mixed-gender, nonselective, state secondary. It has large (circa 5.5 Ha) landscaped grounds—with some ornamental shrubs on the approach to the school and a line of trees separating it from the A road on its perimeter. Nevertheless, air pollution at this

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location is still comparatively high (in the 75th percentile nationally) and exceeds three recommended World Health Organisation levels for $PM_{2.5}$, PM_{10} and NO_2 (COPI, 2024).

Fifty-nine pupils from three Year 10 (aged 14 to 15 years old) mixed-ability classes took part in the study. Year 10 pupils were deemed to have sufficient prior knowledge and maturity to engage with the study topics and were not yet burdened with the imminent pressure of national exams (which happen in Year 11).

2.4 | Intervention work with pupils

Randomly allocating pupils into experimental groupings was unfortunately not possible due to teaching arrangements at the school; hence, the study design utilised three existing pupil groupings/classes (Table 3). One group, a ‘control’, received no intervention (25 pupils in one class). One group received a ‘virtual only’ intervention involving an online green infrastructure game (18 pupils) and one group (‘hands-on plus virtual’) participated in four hands-on sessions and one online game session (16 pupils). We summarise details of the experimental and educational activities carried out with each group in Table 3.

2.4.1 | Online educational game

The game content was developed as an RHS pilot with the aim of aiding young visitors' engagement with plants and their potential to improve the environment (GMCA, 2024). It reflected the learning topics of the hands-on sessions and revolved around GI's role in reducing urban temperatures, reducing flood risks and improving air quality. During one whole science lesson in school (in March 2023) the game was shared with two classes of pupils. The game tasked pupils with selecting greening interventions to reduce environmental impacts in an imaginary school. Their choices were scored using an underlying ranking system (developed based on expert knowledge and relevant literature [Blanusa et al., 2019]). The aim was to obtain points by using the most efficient interventions (e.g. adding a hedge as a barrier to pollutants rather than a green roof in the air quality scenario).

2.4.2 | Hands-on science intervention work with pupils

There were four in-person sessions from January and March, each lasting an hour:

i. A lecture and Q&A session on RHS research concerning plant traits and ecosystem services provision (e.g., cooling, flood mitigation and air quality improvements). The lecture made links to Biology topics taught in this year group's curriculum (e.g., plants' stomata and transpiration).
ii. School Hedge field measurement session where every pupil used specialised science equipment. Measurements included soil moisture content (using SM150 soil moisture probes, Delta-T Devices, Cambridge UK); estimation of leaf water loss (using AP4 porometer, Delta-T Devices, Cambridge UK; leaf temperatures) (using thermal camera, FLIR C5, Teledyne FLIR, USA); and canopy dimensions (branch numbers and canopy size, using tape measure)
iii. A classroom-based activity in groups to assess the deposition of airborne pollutant particles on leaf surfaces (via leaf washing and filtration, using specialist equipment)
iv. A classroom-based data analysis and interpretation session, which involved pupils graphing collected data and drawing conclusions on differences between measured plant species.

Each session filled what would have otherwise been a regular timetabled science lesson. Whilst the science teacher was present, delivery of the activity was provided solely by the RHS research team.

Procedure

In the week of 16 January 2023, the ‘baseline’ survey was administered in the three participating classes. The ‘follow up’ survey (identical to the ‘baseline’) was administered in the last week of March 2023. The survey was created on the platform Survey Monkey, and responses were downloaded and pseudonymised immediately following completion.

TABLE 3 Details of pupil experimental groupings.

TIME (16 January–28 March 2023) →		
Pre-intervention survey	Experimental grouping	Post-intervention survey
	Control group ($n = 25$) Pupils received no intervention	
	Virtual intervention group ($n = 18$) Pupils played an online game where they added green infrastructure to a school to reduce problems like overheating, flooding and poor air quality (see Section 2.4 for further details).	
	Hands-on science + virtual intervention group ($n = 16$) Pupils received the virtual intervention above as well as a series of hands-on environmental science learning sessions with an RHS scientist (described in Section 2.4.)	

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2.5 | Statistical analysis

We used SPSS version 29.0 (IBM, 2022) to statistically analyse the survey data, producing descriptive statistics of the pretest data set and obtaining mean scores for all key measures. We then used *t*-tests to assess whether there were significant differences in any of the pretest scores between pupils with prior experience of gardening and those without. For our environmental concern and nature connectedness scores, where the midpoint of the scale was 4, we interpreted scores from 3 to 5 as indicative of moderate levels of concern, 1–2 as low and 6–7 as high. For the PMT scores, we interpreted scores between 40 and 60 as moderate, with scores falling below this as low, and those falling above as high.

To assess whether either intervention significantly changed any of the scores, we used ANCOVA. ANCOVA is recognised as a statistically appropriate method for analysing pretest posttest data in quasi-experimental designs, especially when randomisation is not feasible (Baleghizadeh & Masoun, 2013; O'Connell et al., 2017). By using the pre-intervention scores as covariates, ANCOVA adjusts the post-intervention scores for baseline differences, which is particularly important if initial group equivalence cannot be guaranteed (Valente & MacKinnon, 2017). This improves internal validity and offers more reliable attribution of observed differences in outcomes to the interventions, rather than to pre-existing differences. In the broader context of quasi-experimental educational research, ANCOVA is a common methodological choice because it aids in achieving a balanced assessment of treatment efficacy (Gopalan et al., 2020). Such methodological flexibility particularly suits real-life settings where controlling for variables is often not straightforward.

Finally, we created a new variable (pretest posttest 'difference scores') by calculating the difference between each pupil's pretest and posttest scores. We then assessed whether there were any significant associations between these 'difference scores', again using *t*-tests.

2.6 | Methodological limitations

Conducting a study in a working school inevitably brings limitations (Bonnell et al., 2018; Greener, 2018). In our case, these included that pupils in the three test groups were taught by three different science teachers and intervention opportunities were ultimately determined by school staff. The pupils were, however, at a similar stage in the curriculum content, and all classes were unstreamed (i.e., of mixed academic ability).

Another limitation was that, due to data protection and ethical considerations, we were unable to collect socio-economic data from the pupils. However, the school is based in an area where indicators of deprivation are below the national average (Surrey County Council, 2025), which may have increased the proportion of pupils in the study sample with private gardens at home.

3 | RESULTS

3.1 | Sample overview

In total, 56 pupils returned a complete set of responses to the survey questions concerning their levels of exposure to green infrastructure. The sample had a relatively even gender split (45% female and 55% male). Most pupils (46%) spent between 3 and 7 h in green space per week, with about a third (34%) spending between 1 and 3 h per week. Very few pupils spent more than 7 h, or less than one, per week (11% and 9%, respectively). Most (93%) pupils indicated having a garden at home, with 77% indicating that their families did gardening, and 66% indicating that they themselves had done some gardening in the past (which we subsequently refer to as prior experience of gardening). These results are displayed in Table 4.

Although the number of pupils indicating having no garden at home was low (only four out of the 59 pupils involved in the study), notably, these four pupils reported spending considerably less time in green space per week than pupils from households with private gardens. Three spent under an hour per week and one spent 1–3 h per week. This contrasts with those who had gardens at home, where nearly two thirds (61.5%) of pupils spent over 3 h in green space per week.

It was also notable that there was a strong association (Fisher's exact test, $p = <.001$) between a pupil indicating that their family gardened and indicating that they themselves had prior experience of gardening. Less than a quarter (23%) of pupils from families that did not garden indicated personal prior gardening experience, compared with 80% of those from families who did garden.

TABLE 4 Overview of the sample. Three pupils had missing data for one or more of the categories listed, so only the 56 pupils who returned complete responses are included in the table.

	Count	Percentage
Gender		
Male	31	55%
Female	25	45%
Time spent in green space per week		
<1 h	5	9%
1–3 h	19	34%
3–7 h	26	46%
>7 h	6	11%
Has a garden at home		
Yes	52	93%
No	4	7%
Family does gardening		
Yes	43	77%
No	13	23%
Has done gardening themselves		
Yes	37	66%
No	19	34%

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3.2 | What were the pupils' environmental perception scores prior to the teaching interventions?

In pretest scores, environmental concern levels were moderate amongst the pupils. Egotistic environmental concern scores (concern about the consequences of pollution for oneself, one's lifestyle and one's future) were slightly higher (with a mean of 4.9/7) than altruistic (concern for one's community, for other people and other countries, with a mean of 4.4/7), or biospheric concern (concern for plants, animals and insects, with a mean of 4.1/7). The mean 'self in nature' score (representing the pupils' average level of connection to nature) was 4.0/7.

Mean threat appraisal (perceived risk of local impacts from poor air quality and climate change) was also moderate, as was the mean adaptation efficacy score (the perceived degree to which adding plants to the local environment could help improve air quality and limit climate impacts). Respectively these scores were 48.5/100 and 53.6/100. Mean self-efficacy (how much difference pupils thought they themselves could make, and how much time they would have to get involved) was lower, at 36.8/100. The pupils predominantly considered themselves unlikely to get involved with green infrastructure projects (with a mean score of 36.7/100). The mean score for the green infrastructure knowledge quiz was 3.75/9. We found no statistically significant differences in the pretest scores between the three experimental groups for either environmental concern, PMT perceptions, green infrastructure test scores or time spent in green space/prior experience of gardening. We also found no significant difference between the groupings in terms of gender balance. Mean pre- and post-intervention scores for each experimental group are listed in Table 5 in the next section.

3.3 | How did the teaching interventions affect the pupils' environmental perceptions?

When the effect of the interventions on pupils' posttest scores was compared using a one-way ANCOVA whilst controlling for the effect of the pretest scores, the hands-on teaching intervention was found to significantly increase the pupils' adaptation efficacy scores (which measured their perceptions about whether increasing GI can improve air quality and limit climate extremes), $F(2.47) = 6.410$, $p = .003$. The estimated marginal means of the posttest scores were 69.7 in the hands-on group, 57.4 in the virtual-only group and 45.8 in the control group. Pairwise comparisons showed that the hands-on posttest scores differed significantly from those of the control ($p < .001$), whilst the difference with the virtual-only group approached significance at the .05 level ($p = .084$). The posttest scores of the control and the virtual group also narrowly missed significance at the .05 level ($p = .073$). Figure 1 presents boxplots illustrating pre and posttest score distributions for the three experimental groups.

No other scores were significantly affected by the interventions.

3.4 | Were pretest environmental perception scores associated with prior experience of gardening?

Independent samples' t-tests found significantly higher mean pretest scores (at the $p < 0.001$ threshold) for altruistic and biospheric concern and environmental threat appraisal (combined scores for perceptions of the harm caused locally by poor air quality and climate impacts), for pupils who had prior gardening experience. Significance at the .001 level was narrowly missed for the self in nature score ($p = .004$), for the adaptation appraisal score ($p = .002$) and the self-efficacy score ($p = .003$). No significant differences were found between the green infrastructure knowledge test scores of those with or without prior experience of gardening (see Table 6).

3.5 | Did previous experience of gardening make any difference to the pupils' responses to the teaching interventions?

Within the hands-on group, prior experience of gardening appeared to influence the pupils' responses to the intervention. Greater

TABLE 5 Mean pre and posttest scores for each intervention group, with standard deviation provided in brackets following the mean in each table cell.

Variable	Virtual intervention ($n = 17$)	Control ($n = 20$)	Hand's on intervention ($n = 14$)
Pretest mean environmental concern	4.4 (SD = 0.8)	4.2 (SD = 1)	5 (SD = 1.3)
Posttest mean environmental concern	4.2 (SD = 1)	4.3 (SD = 1.7)	5.2 (SD = 1.1)
Pretest mean self in nature score	3.8 (SD = 1.7)	3.9 (SD = 1.3)	4.4 (SD = 1.4)
Posttest mean self in nature score	3.5 (SD = 1.8)	3.9 (SD = 1.6)	4.3 (SD = 1.1)
Pretest mean environmental threat appraisal	51.7 (SD = 19)	44 (SD = 22.5)	47.2 (SD = 21.2)
Posttest mean environmental threat appraisal	45.2 (SD = 13.2)	43.3 (SD = 21.9)	45.8 (SD = 17.3)
Pretest mean plants adaptation efficacy	54.2 (SD = 18.9)	53.6 (SD = 25.7)	50.1 (SD = 23.8)
Posttest mean plants adaptation efficacy	57.4 (SD = 21)	45.8 (SD = 22.6)	69.7 (SD = 13.4)
Pretest mean self-efficacy	37.5 (SD = 16.5)	35.4 (SD = 20.1)	35.5 (SD = 21.2)
Posttest mean self-efficacy	35.9 (SD = 19.1)	37 (SD = 19.2)	36.3 (SD = 13.5)

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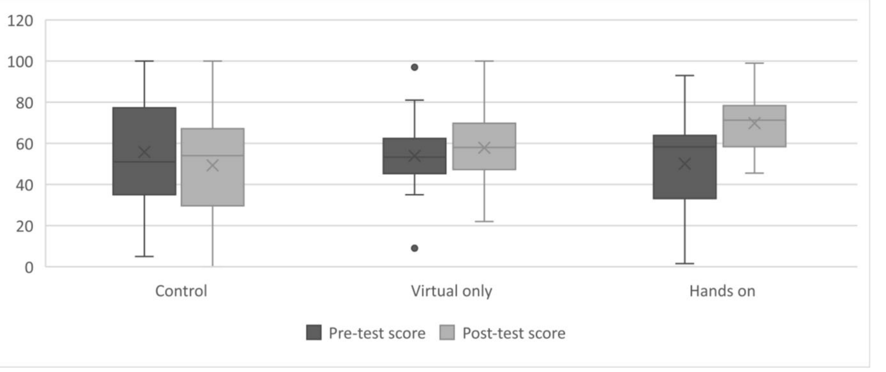

FIGURE 1 Boxplots illustrating differences between pretest and posttest scores of the three experimental groups for the perceived efficacy of adding more plants to address air pollution and climate risks.

TABLE 6 Mean scores for study measures, sample divided into pupils that had prior experience of gardening and those that did not.

Score category	Baseline variable (possible score range)	Prior gardening	N	Mean	SD	*t*	df	*p*
Environmental attitude scores (environmental concern and nature connectedness)	Egotistic env. Concern (1–7)	Yes	37	5.09	1.37	−1.971	54	0.027
		No	19	4.28	1.62			
	Altruistic env. Concern (1–7)	Yes	37	4.86	1.02	−4.467	54	<.001
		No	19	3.41	1.39			
	Biospheric env. concern (1–7)	Yes	37	4.52	1.24	−3.402	54	<.001
		No	19	3.37	1.12			
	Self in nature score (1–7)	Yes	37	4.41	1.48	=2.731	54	.004
		No	19	3.26	1.49			
Protection motivation scores	Environmental threat appraisal (climate change and air quality) (1–100)	Yes	32	56.94	18.33	−3.814	48	<.001
		No	18	34.93	21.67			
	Adaptation appraisal (1–100)	Yes	32	59.28	16.74	−3.058	48	0.002
		No	18	40.33	27.16			
	Self-efficacy (1–100)	Yes	32	42.78	15.41	−2.923	48	0.003
		No	18	27.63	20.98			
Knowledge score	Green infrastructure knowledge quiz score (0–9)	Yes	32	3.56	1.87	1.073	48	0.289
		No	18	4.22	2.4			

post-intervention increases in survey scores for the PMT measures were observed amongst pupils who indicated having never gardened before than were observed amongst the pupils in that group who indicated having prior experience of gardening.

In the hands-on group, mean environmental threat appraisal increased by 17 points (on a 100 point scale) amongst those with no prior experience of gardening, whilst it decreased by 8 points amongst those with prior gardening experience, $t = -8.444$, df (11) $p = .025$. Mean adaptation efficacy (scores for the perceived risk reduction benefits of adding more vegetation) increased by a mean of 39 points amongst those with no prior gardening experience, but only by 13 points amongst those with prior gardening experience, $t = -2.877$, df (3.342), $p = .028$. Finally, mean self-efficacy scores increased by 19 points amongst those with no prior gardening experience, but declined by 6 points amongst those with previous experience of gardening, $t = -2.860$, df (11) $p = .009$.

With only 11 participants in the hands-on group at this stage (due to several pupils in this group failing to submit complete responses to both the pre- and post-intervention surveys), it should be noted that the sample size here is small, and as such, this result should be treated cautiously. Nevertheless, the data suggest that those who had never themselves done any gardening before had a stronger positive response to the hands-on intervention than those who did have prior gardening experience. These differences are illustrated with boxplots in Figure 2.

4 | DISCUSSION

4.1 | Environmental perception scores prior to the teaching interventions

In our study, the pupils' mean Inclusion-of-Nature-in-Self (INS) score of 4.0 closely matches the mean INS score of 4.14 for the (more than 2000) 14- and 15-year-olds that responded to Natural England's Children's People and Nature survey (Natural England, 2022), suggesting

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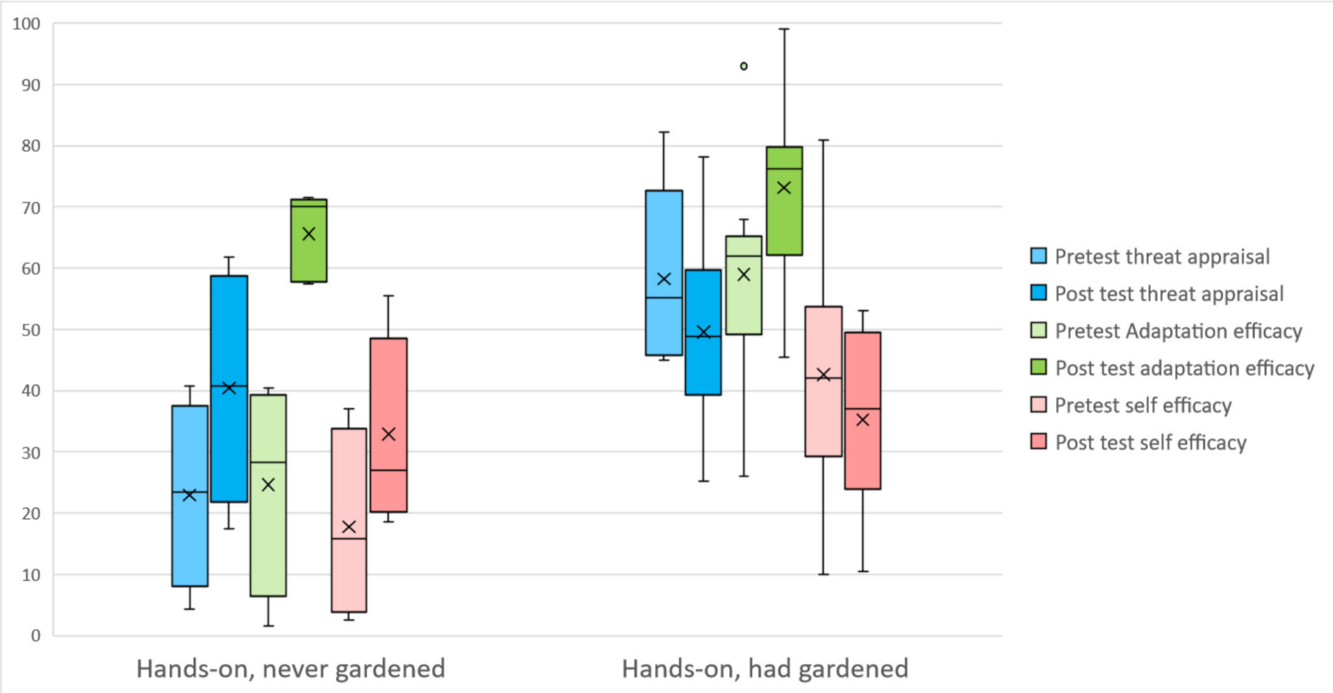

FIGURE 2 Boxplots illustrating mean differences between pretest and posttest scores for the three experimental groups, split by prior gardening experience.

pupils in the study expressed a typical degree of nature connectedness for their age set. Comparatively higher mean egocentric concern is also typical amongst adolescents (McEwan et al., 2022). Notably, studies report stronger relationships between pro-environmental behaviour and biospheric and altruistic concern than egoistic concern, which warrants interventions promoting nature connection amongst secondary school pupils.

4.2 | The impact of the interventions on environmental attitudes, risk perceptions and GI knowledge

The hands-on plus virtual intervention (including science activities with hedges and use of the online game) shifted the pupils' perceptions of how effectively GI can limit localised negative impacts from climate change and air pollution. However, the virtual intervention alone did not lead to a statistically significant shift. There were differences in the amount of class time allocated to each activity, which may have contributed to the observed difference in impacts on perceptions. Alternatively, this finding could illustrate the greater efficacy of experiential learning in a real-world versus virtual environment (Sprague et al., 2022), suggesting that, in the environmental education context, virtual interventions may be better provided as supplements to face-to-face interventions, rather than in a stand-alone fashion (Yilmaz et al., 2023).

Yet, beyond the impact which the hands-on sessions had on the pupils' perceptions of the efficacy of adding urban green infrastructure to reduce environmental risks, the interventions otherwise did not affect the pupils' environmental attitudes and risk perceptions. This may be because attitudes towards the environment can be deep-seated and slow to change (Dyehouse et al., 2017). It could also be because our study employed a focus on intellectual learning about science, and studies suggest that emotion-oriented interventions may be better at shifting environmental attitudes (Brosch & Steg, 2021; Olsen et al., 2024).

Within the results, it is particularly notable that the pupils had low self-efficacy scores and a perceived lack of time for engaging in green infrastructure projects. This may explain why their intentions to take action remained low despite increases in the perceived environmental efficacy of GI. In-depth qualitative explanations from the pupils themselves would have helped to elicit more understanding of their degree of empowerment and motivation to engage in climate adaptation actions. Whilst this form of data collection was beyond the scope of the current study, it would be valuable for future studies investigating young people's involvement in climate action to incorporate in-depth interviews and qualitative analysis. Possibly, high academic time pressures for this age set presented a barrier to engagement in extracurricular actions. Scheduling opportunities for pupils to engage in nature-based activities which improve their local environment may help enhance their agency to respond to the environmental crisis as well as their capacity to cope with it psychologically (Olsen et al., 2024; Rushton et al., 2023).

The finding of no intervention-related change to the pupils' green infrastructure knowledge test scores was contrary to our expectations. The key learning features of the face-to-face intervention,

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which revolved around the use of scientific equipment, were intended to deliver experiential learning (Morris, 2020) by enabling concrete observation of the usually invisible physical processes of air pollution capture and temperature reduction by plants. Research suggests incorporating experiential engagement in school lessons can lead to superior learning outcomes (Uyen et al., 2022), but in this case the pupils' factual knowledge did not increase as a result of the experiential hands-on engagement.

4.3 | Associations between pretest scores and gardening experience

Despite a wide number of studies exploring the impacts of nature experiences on children (Adams & Savahl, 2017; Chawla, 2020; Putra et al., 2020), very few incorporate a focus on engagement in actual gardening activities (but see Davies et al., 2015 for an interesting review of learning in gardens and other outdoor landscapes). The lack of studies focused on measuring the impacts of engagement in gardening on children is a missed opportunity. The Children's People and Nature Survey (Natural England, 2022) found that 87% of children in England lived in households with a private garden. This means that, in the United Kingdom, time spent in garden environments is a mechanism for connecting with nature that most UK children are exposed to and can easily access. We did find one study which complements our finding of an association between gardening and environmental perceptions in children. Aguilar et al. (2008) found that prior gardening experience was associated with higher environmental attitude and control scores amongst 8–11-year-old primary school children in the United States.

Research shows that gardening, as a mode of green exercise that also constitutes an active pro-environmental behaviour (Rosa & Collado, 2020), can deliver heightened health and wellbeing benefits to participants. Initiatives such as the RHS Campaign for School Gardening and the National Education Nature Park programme are geared towards supporting the delivery of these benefits through horticultural engagement opportunities for children and young people during their school years, importantly increasing access to gardening for school children who do not have gardens at home (13% of children in England (Natural England, 2022)). Our finding of a positive association between gardening experience and environmental perceptions amongst secondary school pupils lends further weight to the importance of these initiatives as strategies which can, in addition to benefiting health and wellbeing, assist the development of environmental consciousness in children and young people.

In contrast to the significant associations between environmental attitudes and risk perceptions with prior gardening experience, no association was found between prior gardening experience and green infrastructure knowledge scores. Studies indicate that the relationship between factual knowledge and underlying attitudes and perceptions can be quite weak (Toomey, 2023). As such, our finding of a link between gardening and environmental attitudes but not knowledge could indicate that engagement in gardening activates cognitive pathways which are affective rather than intellectual. Similarly, studies have highlighted the role of emotion as an important determinant of pro-environmental behaviour (Hartmann et al., 2017). Overall, this suggests that interventions seeking to raise environmental consciousness and intentions should aim to initiate emotive mental pathways rather than purely rational ones (Olsen et al. 2024). Incorporating learning that helps embed emotional connectedness to nature (Barthel et al., 2018; Hartmann et al., 2017) could thus be more effective at engendering pro-environmental mind-sets in youth than relying on pedagogical communication of scientific information alone (the latter being the primary strategy employed in our study).

4.4 | The differential effect of the face-to-face intervention due to prior gardening experience

The results of our study indicate that those without prior gardening experience had the greatest perception shifts following involvement in the hands-on intervention. Whilst this result is based on a small sample, we nevertheless feel it warrants further research to assess this effect in larger samples.

Gardens are the outdoor nature-based spaces where UK children most regularly spend time. Data from the UK Government's Children's People and Nature Survey found that 64% of children had spent time in a garden in the preceding week of data collection, with gardens coming top out of all outdoor space categories. From the same data set, those children who did not have access to gardens or allotment sites indicated engaging in a lower mean number of pro-environmental behaviours than the rest of the sample (Natural England, 2022). In our small study, the pupils that had no prior experience of gardening were those whose perceptions of the value of plants shifted the most in response to the intervention, suggesting that less time spent in nature, and particularly less time spent engaged closely with plants, may lead to a lower awareness of the environmental functions of plants and that this *can* be remedied through school learning interventions.

4.5 | Study limitations

There were several limitations to this study which must be considered when interpreting the findings. Firstly, the study sample size was limited. At the outset, the three largest classes in the year group were included, which equated to 90 pupils. However, this number dwindled during the research process due to pupil absences and the return of incomplete survey responses, meaning that by the end of the study, we only obtained 59 survey responses that we could include in our analysis. Due to internal organisational arrangements at the school, it was not possible to include more than three classes of pupils, which limited the number of interventions we could incorporate. A fuller study design would have included an additional intervention group where pupils only received the hands-on intervention, without exposure to the online game. The time allocation between the hands-on

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intervention and the online intervention was not well balanced, again due to logistical arrangements with the school, and finally, since the posttest survey was only carried out once, within 2 weeks of finishing the hands-on intervention work, we do not know whether the shift in perceptions of green infrastructure would have been sustained after a longer time period.

There are limitations associated with our study's quasi-experimental design, that is, the lack of random assignment to intervention groups and the absence of a truly neutral control group. Furthermore, potential ceiling effects may limit our ability to detect further improvements in pupils who already demonstrated high baseline levels of environmental concern or knowledge. Where possible, future research should aim to incorporate randomised controlled trials with selected neutral control conditions to robustly address these methodological concerns.

Finally, we acknowledge the potential influence of treatment-as-usual (TAU) effects within our no-intervention group. Specifically, regular school activities, classroom interactions and community involvement may have independently influenced pupil outcomes, potentially attenuating observable differences between the control and intervention groups. Such factors are important to consider when interpreting results from quasi-experimental designs in educational contexts.

5 | CONCLUSION

The results of our small study imply that amongst UK secondary school children, experience of gardening is positively associated with greater environmental awareness and nature connection. We investigated the impact of teaching interventions on pupils' nature connectedness, concern and environmental risk perceptions utilising both an online app and a series of hands-on science engagement activities both within and outside of the classroom. We found that the hands-on intervention where pupils worked with plants out in the school grounds and in the classroom was effective at shifting their perceptions of the value of green infrastructure for limiting environmental risks in the local area. This intervention was found to be most effective for children who did not have prior experience of gardening, compared with those who had. These findings highlight the importance that children are given the opportunity to engage in gardening both within and outside of school settings to enhance their nature connectedness and environmental awareness. They also illustrate the heightened importance of hands-on plant-based learning interventions for school pupils who may not have had the opportunity to engage closely with plants at home.

AUTHOR CONTRIBUTIONS

C.S. and T.B. planned and developed the research design, with methodological contributions from R.N. T.B. and C.S. co-designed the survey, and T.B. performed fieldwork and collected data. C.S. and J.C.G. analysed and interpreted the data and C.S., T.B. and J.C.G. cowrote the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The Ethics Committee of the School of Agriculture, Policy and Development at the University of Reading approved the survey used for this research (SAPD Ethical Clearance Application Reference Number: 01927). The University of Reading employs its Code of Good Practice in Research in undertaking ethical reviews of research projects, ensuring that the dignity, rights, safety and wellbeing of participants are at the forefront of any research study. The Code prioritises confidentiality and security of personal data. It requires that participants provide informed consent and that they are properly informed about the ways in which the data will be used.

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