scientific reports

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Exploring the impact of nature connectedness on Chinese adolescents' climate change awareness and the mediating role of geographical synthetic thinking

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In the context of global efforts to address the climate crisis, enhancing adolescents' climate change awareness stands as a critical measure. Given the pivotal role of geography education in fostering environmental responsibility and understanding the interplay between nature and human society, this study explores how nature connectedness among adolescents influences their climate change awareness, with a specific focus on the mediating effect of geographical synthetic thinking. Based on a survey of 1,338 Chinese adolescents, the findings reveal that fostering nature connectedness significantly enhances climate change awareness. Furthermore, the mediating role of geographical synthetic thinking sheds light on the underlying mechanisms of this relationship. The research findings further highlight the value of geography education in promoting climate change awareness, offering novel implications for advancing climate change education.

Keywords Nature connectedness, Climate change awareness, Geographical synthetic thinking, Climate change education

Climate change awareness is a multidimensional construct that encompasses cognitive, emotional, and behavioral aspects[1,2]. It is strongly associated with pro-climate behaviors and a growing motivation for cleaner production practices[3,4]. However, findings from the Program for International Student Assessment (PISA) reveal that only one-fifth of adolescents actively participate in environmental actions, with an equivalent proportion remains disengaged from climate change issues[5]. Adolescents, as a generation directly experiencing the consequences of climate change, hold significant responsibility in addressing human-induced environmental challenges as future decision-makers[6].

Recent research in environmental science has increasingly emphasized the intricate relationships between human, social, and physical environments[7,8]. Within this context, the role of nature connectedness in shaping climate change awareness has attracted growing scholarly attention[9]. Defined as a subjective sense of the connection with the natural world[10], nature connectedness addresses the fundamental cause of ecological crises: the disconnection between humans and nature[11]. Evidence suggests that stronger bonds with nature are linked to pro-environmental actions and greater concern for climate-related issues[12]. However, limited research has investigated how nature connectedness influences climate change awareness[13], particularly among adolescents—a group uniquely positioned at the nexus of environmental challenges and solutions due to their long-term stake in the planet's future and their growing capacity for civic engagement and climate activism, as evidenced by youth-led movements such as Fridays for Future[14–16].

Climate change, as a critical issue in educational discourse, is often explored through geography and environmental studies. Geography education has been recognized as a critical component in enhancing secondary school students' perception of climate change[17]. Geographical synthetic thinking, as a mindset that emphasizes human-environment interactions in geography education, serves as a valuable framework for comprehending complex geographical issues[18,19]. This approach provides multifaceted benefits, fostering knowledge, empathy, motivation, and action. It is particularly essential for adolescents, equipping them with the analytical skills

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necessary to address pressing climate challenges[20]. Additionally, global employment trend reports highlight the increasing relevance of integrated thinking as a crucial competence for managing climate change.

In educational contexts, integrated thinking involves not only making connections across disciplines but also considering diverse perspectives and understanding relationships within complex systems. Systems thinking, a foundational concept in this approach, focuses on understanding the interactions, feedback loops, and dependencies within a system as a whole[21]. It emphasizes examining the structure, function, and dynamics of systems, such as recognizing how changes in one part of the system can have far-reaching effects on the whole. In geography education, geographical synthetic thinking extends this perspective by integrating systems thinking with a specific focus on human-environment interactions[22].This combination highlights the complexity and interconnectedness of geographical phenomena, encouraging students to analyze and synthesize knowledge from various domains, such as environmental science, social studies, and economics, to form coherent and comprehensive understandings of issues like climate change[23]. The process of synthesizing knowledge from different disciplines helps students see the broader context of these problems and develop critical thinking skills necessary for informed decision-making. Geographical synthetic thinking is not simply about combining disciplines but involves a detailed process of applying systems thinking to geographical contexts. For example, students might examine case studies where human actions impact environmental systems, analyze feedback loops between climate change and human society, and explore the interdependence of various factors such as resource use, social behavior, and policy decisions[24]. This integrative approach is essential for preparing students to address the complexities of global challenges.

Empirical studies further reveal a positive correlation between individuals with well-developed synthetic thinking abilities and a stronger sense of nature connectedness[25]. Moreover, this connection to nature has been identified as a significant factor influencing the development of synthetic thinking[26]. Despite these findings, the existing literature lacks a comprehensive exploration of the interplay between adolescents' nature connectedness, geographical synthetic thinking, and climate change awareness. Addressing this research gap offers a valuable opportunity to deepen our understanding of these multidimensional relationships and to provide evidence-based guidance for future educational and environmental strategies.

To fill this research gap, this study focuses on Chinese high school students in eastern regions, aiming to enhance our understanding of adolescent climate awareness through the lens of human-environment interactions[1]. The current study seeks to answer the following research questions:

RQ1. To what extent does nature connectedness influence climate change awareness?

RQ2. How does geographical synthetic thinking mediate the relationship between nature connectedness and climate change awareness?

Literature review and hypotheses development

Nature connectedness and climate change awareness

The concept of nature connectedness stems from the biophilia hypothesis, positing an innate human urge to bond with the natural world[27]. Schultz[28] further refines this idea, describing nature connectedness as the integration of nature into an individual's self-concept. People with a strong connection to nature are more likely to engage in conservation efforts and express concern for ecological changes[29].

A growing body of evidence highlights the positive relationship between nature connectedness and climate change awareness[2]. Grounded in the framework of the New Ecological Paradigm (NEP)[30], researchers have identified that individuals' endorsing NEP principles often exhibit stronger beliefs and concerns about climate change[31]. More specifically, individuals with higher levels of nature connectedness—characterized by an appreciation of nature and a deep concern for the environment—are more likely to cultivate greater climate change awareness[32].

However, understanding why and how nature connectedness is associated with climate change awareness requires a deeper exploration of the psychological mechanisms at play. Nature connectedness is not simply a passive emotional attachment to nature but a deeply rooted belief system that informs individuals' views about the world. This belief system fosters biospheric values, wherein individuals recognize the intrinsic value of the natural world and see human well-being as interconnected with the planet's health. These biospheric values can lead to a moral understanding of climate change—not only as an environmental issue but also as an ethical obligation to act[33].

To better explain this process, we draw on the Value-Belief-Norm (VBN) theory[34], which posits that environmental behaviors are driven by a chain of psychological processes beginning with individual values. These values shape ecological worldviews, such as the NEP, which in turn influence awareness of consequences, personal norms, and ultimately environmental behaviors. In the context of nature connectedness, this theory suggests that individuals who possess strong biospheric values, reinforced by their nature connectedness, are more likely to recognize climate change as a pressing moral issue that requires urgent action[35]. The deep sense of responsibility toward nature, which is central to nature connectedness, provides the cognitive and emotional motivation to engage with climate change awareness and act accordingly.

Building on this understanding of the mechanisms by which nature connectedness influences climate change awareness, we hypothesize that individuals with a stronger connection to nature will demonstrate higher levels of climate change awareness.

Hypothesis 1 Nature connectedness positively predicts climate change awareness.

Geographical synthetic thinking as a mediator

The accelerating interconnectedness of people, goods, and events across regions, driven by the backdrop of global climate change, has amplified the complexity of geographical issues and phenomena[36]. In this context,

geographical phenomena often result from the synergistic interactions among multiple geographical factors. Understanding these intricacies and their dynamic interplay with the natural environment has become a critical educational objective in secondary geography curricula. To meet this objective, it is imperative for students to develop the ability to address complex geographical challenges and recognize the interconnections between diverse geographical components[37]. Geographical synthetic thinking emerges as a fundamental cognitive framework for analyzing these interconnections. It refers to the cognitive process by which individuals understand the geographical environment from a comprehensive, systemic, and dynamic perspective, enabling them to interpret human-environment interactions holistically[38]. This approach empowers individuals to analyze the geographical environment and its relationship with human activities through an integrative lens. The interdisciplinary nature of geography, as highlighted in the International Charter on Geographical Education[39], bridges natural and social sciences to provide holistic solutions to global challenges. Similarly, the National Geography Standards in the United States[40] emphasize the role of geographical synthetic thinking in spatial analysis, while England's National Curriculum identifies it as essential for understanding global geographical patterns[41]. China values it as a core competency in geography education[42]. Furthermore, within the framework of Education for Sustainable Development (short for "ESD"), developing geographical synthetic thinking is vital for equipping adolescents to address complex global issues such as climate change[43]. This mode of thinking emphasizes the dynamic interconnections between human and the non-human systems, emphasizing the interdependence of various geographical components. As such, geographical synthetic thinking represents a critical competency for comprehending and responding to the multifaceted challenges of the modern world.

Although research directly examining the relationship between nature connectedness and geographical synthetic thinking remains limited[44], indirect evidence suggests a potential correlation. High levels of nature connectedness have been shown to foster positive emotional and cognitive engagement, such as greater attentional focus, perspective-taking, and reflective thinking[45]. These cognitive-emotional attributes contribute to a heightened sensitivity to environmental changes and support the integration of diverse information sources—key components of geographical synthetic thinking[26]. Furthermore, those who perceive nature as part of their extended self are more likely to consider the broader consequences of human-environment interactions. This self-nature integration promotes moral reasoning and long-term thinking, which are essential in constructing complex geographical understandings[46,47].

In this context, advanced cognitive structures refer not to brain changes but to developed thinking habits, such as integrating conflicting information and reasoning across time and space[48]. These characteristics support synthetic thinking and are critical for navigating complex, uncertain issues like climate change[49]. By contrast, individuals lacking such cognitive skills may constrains climate-related beliefs and diminishes pro-environmental intentions[33]. Synthetic thinking not only fosters an ecological ethic that prioritizes nature conservation, but also deepens comprehension of climate change phenomena[50]. Furthermore, integrating nature into one's emotional self-concept[28] fosters a "human-environment synthesis" perspective, which refines climate-related cognition, attitudes, and actions[51].

Taken together, these findings suggest that geographical synthetic thinking may act as a cognitive mechanism through which nature connectedness shapes climate change awareness.

Hypothesis 2 Geographical synthetic thinking plays a mediating role between nature connectedness and climate change awareness.

The research model is presented in Fig. 1.

Research methodology

Participants and procedures

The study collected data from secondary schools in eastern China, with sampling criteria based on geographic location, city type, and school level. After providing a clear explanation of the study's purpose, 1,338 students (aged 16 to 18) from eight high schools were recruited through cluster random sampling. Participation was

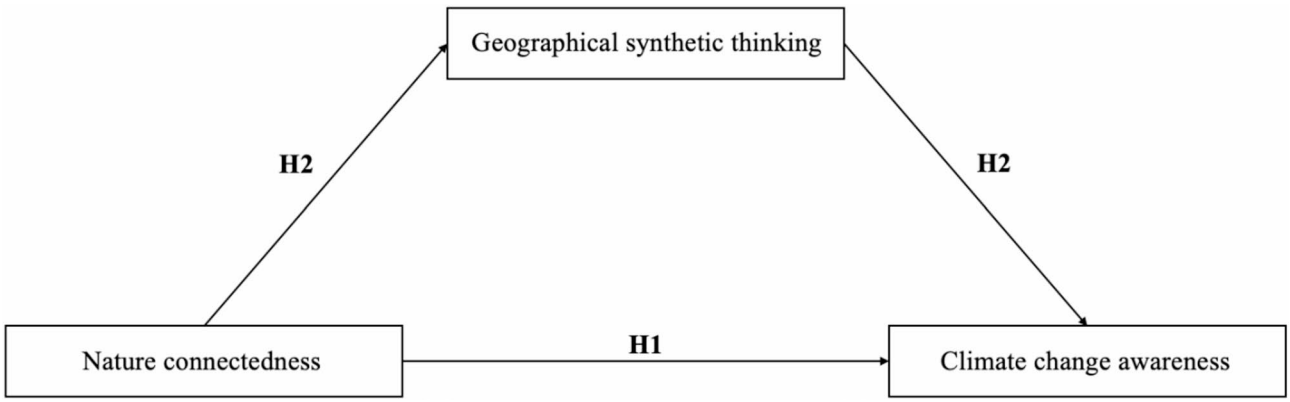

Fig. 1. Research model.

voluntary. Written informed consent was obtained from all participants and their parents or legal guardians prior to data collection. Ethical approval for the research was granted by the Ethics Committee of Zhejiang Normal University (approval number: ZSRT2023056).

Participants completed paper-based questionnaires under the supervision of researchers during breaks or independent-study periods. Following the exclusion of incomplete responses, 1,304 valid questionnaires were retained, yielding an effective response rate of 97.46%. The sample included 686 male students (52.6%) and 618 female students (47.4%), with 787 students from urban areas(60.4%) and 517 students from rural areas (39.6%).

Materials

The questionnaire used in this study consisted of four sections. The first section gathered socio-demographic information, including gender, residential address, and socioeconomic status (SES). Gender was coded as a binary variable (1 = male, 0 = female), and residential address was coded as a binary variable (0 = rural, 1 = urban). SES was assessed using a composite index based on parental education, parental occupation, and household possessions, following established approaches in the literature to ensure consistency with mainstream methods[52]. Parental education was rated on a 7-point scale (from "primary school or below" to "doctoral degree"), and occupations were categorized into twelve levels based on standard classifications. To avoid inaccurate reporting of income, we followed the PISA approach by using student-reported data on family assets (e.g., computers, smartphones, private study rooms) and number of books at home. All components were standardized and summed to calculate the SES index, ensuring the validity and reliability of the measure in line with established norms.

The remaining sections of the questionnaire included three validated scales to measure nature connectedness, climate change awareness, and geographical synthetic thinking. A full version of the questionnaire is available as a supplementary file to facilitate replication(see appendix 1).

Nature connectedness

Nature connectedness was measured using Schultz's[53] Inclusion of Nature in Self scale. It has been widely considered as a reliable measure of the emotional bond between individuals and the natural environment[54,55]. Participants were presented with a set of seven diagrams, each depicting two circles labeled "self" and "nature" with varying degrees of overlap (Fig. 2). They were instructed to select the diagram that best represented their perceived relationship with the natural environment. The scale ranged from 1 (circles touch but do not overlap) to 7 (circles completely overlap), with higher scores reflecting a stronger sense of nature connectedness.

Climate change awareness

Climate change awareness was assessed using an adapted 18-item Chinese version of the Climate Change Awareness Scale[6]. This scale evaluates five dimensions of climate change awareness: knowledge, personal concern, attitudes, climate-friendly behaviors, and multiplicative actions. Respondents rated their agreement with each item on a seven-point Likert scale, with higher scores indicating greater levels of climate change awareness.

Confirmatory factor analysis(CFA) confirmed that the scale demonstrated a satisfactory fit to the data, supporting its unidimensional structure: $\chi 2/df = 2.279$, CFI = 0.988, TLI = 0.982, RMSEA = 0.031, SRMR = 0.050. Additionally, the scale showed strong internal consistency, with a Cronbach's α of 0.871.

Geographical synthetic thinking

Geographical synthetic thinking was assessed using a scale developed by Lu et al.[23]. The scale includes 32 items measuring three dimensions: factor synthesis, spatiotemporal synthesis, and regional synthesis. Each item was rated on a seven-point Likert scale, with higher scores reflecting greater levels of geographical synthetic thinking.

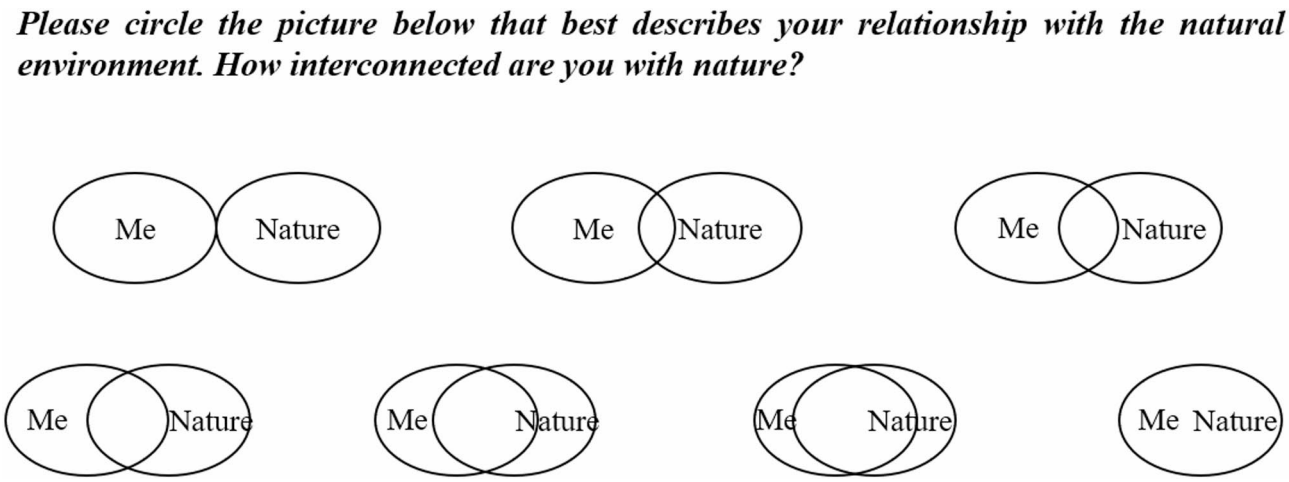

Fig. 2. Inclusion of Nature in Self Scale.

Variable	Category	*n*	%
Gender	Male	686	52.6%
	Female	618	47.0%
Residential address	Urban	787	60.0%
	Rural	517	40.0%

Table 1. Demographic characteristics of participants ($N = 1304$).

Main Variable	M	SD	1	2	3
Nature connectedness	4.140	1.589	–		
Geographical synthetic thinking	124.957	42.0492	0.249**	–	
Climate change awareness	73.397	14.1464	0.358**	0.509**	0.493**

Table 2. Descriptive statistics and pearson correlations of main variables. Note: $^{*}p < 0.05$, $^{**}p < 0.01$.

Empirically, confirmatory factor analysis results demonstrated that a single-factors model fit the data satisfactorily: $\chi 2/df = 3.587$, CFI = 0.985, TLI = 0.979, RMSEA = 0.050, SRMR = 0.045. The scale also showed excellent internal consistency, with a Cronbach's α of 0.982. Also, in this study, geographical synthetic thinking was treated as a unidimensional construct. This decision was supported both empirically and conceptually. Conceptually, it refers to an integrated cognitive ability that synthesizes multiple geographical dimensions into a coherent whole. These subdimensions are interrelated and function collectively, enabling a holistic understanding of geographical issues.

Data analysis

The data were analysed with AMOS 25.0, SPSS 23.0 and the PROCESS 4.0 plug-in[56]. First, Harman's single factor test was conducted to assess common method bias. Bivariate correlation analyses were then performed to examine the relationships among all variables. All continuous variables were mean-centered prior to analysis. Confirmatory factor analysis was carried out using AMOS 25.0 to evaluate the measurement model. Finally, the PROCESS 4.0 plug-in was utilized to test the moderated mediation model.

Results

Test of common method bias

To assess potential common method bias associated with the questionnaire survey, Harman's single-factor test was performed on the questionnaire items prior to analysis. The results revealed 11 factors with initial eigenvalues exceeding 1. The first factor accounted for 37.09% of the total variance, which is below the critical threshold of 40%[57]. This indicates that common method variance is not a significant concern in this study.

Normality and correlations

Prior to conducting parametric analyses, we examined the distributional properties of the three key variables: nature connectedness, geographical synthetic thinking, and climate change awareness.

To test for normality, we employed the Kolmogorov-Smirnov test and assessed skewness and kurtosis values. The results indicated that all three variables demonstrated approximate normality (K-S test for nature connectedness: D = 0.042, $p = 0.078$; geographical synthetic thinking: D = 0.037, $p = 0.114$; climate change awareness: D = 0.039, $p = 0.093$). Additionally, skewness and kurtosis values for each variable ranged between − 0.81 and + 0.72, within the commonly accepted range of − 1 to + 1. These findings supported the use of Pearson correlations and regression-based analyses[58].

Table 1 summarizes the demographic characteristics of the sample. Among the participants, 52.6% were male and 47.4% were female. Regarding residential address, 60.4% lived in urban areas while 39.6% lived in rural areas. Socioeconomic status (SES) was calculated as a composite index based on parental education, parental occupation, and household possessions(M = 45.39, SD = 8.44).

Table 2 presents the descriptive statistics and bivariate correlations of the main study variables. The mean score for nature connectedness was 4.14 (SD = 1.59), indicating a moderate level of emotional and cognitive affiliation with nature among participants. Geographical synthetic thinking had a mean of 124.96 (SD = 42.05), while the mean score for climate change awareness was 73.40 (SD = 14.15), suggesting relatively high awareness.

Pearson correlation analysis revealed that all three variables were significantly positively correlated. Nature connectedness was moderately associated with geographical synthetic thinking ($r = 0.249$, $p < 0.01$) and climate change awareness ($r = 0.358$, $p < 0.01$). Moreover, geographical synthetic thinking showed a strong positive correlation with climate change awareness ($r = 0.509$, $p < 0.01$). These results support the proposed associations among the variables and justify further testing of mediation effects.

Variable	Climate change awareness		Geographical synthetic thinking		Climate change awareness	
	β	*t*	β	*t*	β	*t*
Nature connectedness	0.346	13.825***	0.245	9.222***	0.239	10.446***
Geographical synthetic thinking					0.434	18.730***
Gender			0.006	0.236	−0.069	−3.140**
Residential address			0.013	0.448	−0.014	−0.571
SES			0.024	2.464*	0.028	3.426**
R^2	0.146		0.068		0.328	
F	55.723***		23.875***		126.743***	

Table 3. Predictors of climate change awareness with geographical synthetic thinking as mediator.

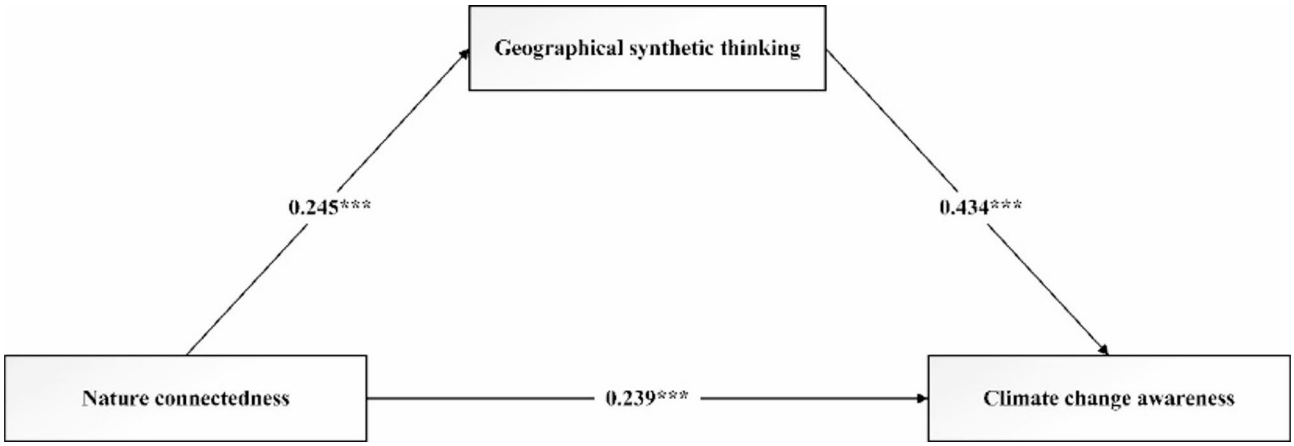

Fig. 3. Geographical Synthetic thinking as a mediator between nature connectedness and climate change awareness.

Path	Effect size	Boot SE	Boot LLCI	Boot ULCI	Ratio
Indirect effect	0.106	0.013	0.081	0.133	30.64%
Direct effect	0.239	0.023	0.195	0.284	69.36%
Total effect	0.346	0.025	0.297	0.395	–

Table 4. Effect sizes– indirect, direct and total.

Validity of measurement model

The confirmatory factor analysis (CFA) results indicated that the measurement model was valid, with fit indices demonstrating an acceptable level of the model fit($\chi 2/df = 2.837$, CFI = 0.955, TLI = 0.950, RMSEA = 0.038, SRMR = 0.047).

Test of a mediation model

Using standardized variables and the SPSS PROCESS plug-in, we examined geographical synthetic thinking as a mediator between nature connectedness and climate change awareness. The results of the linear regression analyses are presented in Table 3, and the mediating model is illustrated in Fig. 3.

The findings reveal that nature connectedness significantly and positively predicts geographical synthetic thinking ($\beta = 0.245$, $t = 9.222$, $p < 0.001$) and climate change awareness ($\beta = 0.239$, $t = 10.446$, $p < 0.001$). Additionally, geographical synthetic thinking significantly and positively predicts climate change awareness ($\beta = 0.434$, $t = 18.730$, $p < 0.001$).

Mediation effects were evaluated using non-parametric percentile bootstrap (Table 4). After controlling for gender, residence, and SES, the 95% confidence interval (CI) for the indirect path from nature connectedness to climate change awareness via geographical synthetic thinking was [0.081, 0.133], excluding 0, indicating a significant mediating effect. The mediating effect (0.106) accounted for 30.64% of the total effect. The 95% confidence interval for the direct path was [0.195, 0.284], also significant, accounting for 69.36% of the total effect. Additionally, the total effect remained significant when geographical synthetic thinking was excluded.

These findings demonstrates a positive relationship between nature connectedness and climate change awareness among adolescents, with geographical synthetic thinking serving as a mediator, thereby supporting hypotheses 1 and 2.

Discussion

Direct effect of nature connectedness on climate change awareness

Our findings confirm that nature connectedness significantly and positively predicts adolescents' climate change awareness, which is consistent with previous research[59,60]. One possible explanation for this relationship relates to the theoretical concept of the "ecological subconscious"[61], which suggests that humans possess an innate, evolving emotional bond with the natural environment. While our study did not directly assess this construct, it is plausible that individuals who feel more connected to nature are also more emotionally engaged with environmental issues, thereby demonstrating higher levels of awareness.

Supporting this interpretation, prior empirical studies have shown that immersive experiences with nature—such as caring for animals or interacting with ecosystems—can deepen emotional connectedness and promote pro-environmental behaviors[62,63]. Even virtual nature exposure has been found to enhance emotional responses and intentions toward environmental engagement[64]. Although our cross-sectional design limits causal inference, these findings together suggest that emotional connection to nature may play an important role in shaping adolescents' climate change awareness. Future longitudinal or experimental research is needed to further explore the underlying mechanisms of this association.

On the other hand, given that our study sample is drawn from China, the traditional Chinese philosophical concept of "harmony between man and nature" provides additional context for understanding our findings. This concept highlights the profound emotional connection between humans and the natural world, which in turn fosters greater awareness of environmental issues[65]. From this cultural perspective, a deep connection to nature cultivates moral responsibility for environmental preservation, which subsequently contributes to a heightened awareness of climate change. For instance, research has shown that a stronger connection to nature can promote personal norms, which in turn influence individuals' awareness of environmental issues, including climate change[66]. Similarly, when individuals' moral self-concept is threatened, their connection to nature acts as a catalyst for environmentally responsible behaviors[67]. Furthermore, environmental citizenship, which is closely tied to nature connectedness, has been shown to enhance well-being, reinforcing the connection between nature engagement and moral action[68]. These perspectives highlight that nature connectedness plays a crucial role in both increasing climate change awareness and motivating individuals to take action for the environment. Rooted in the philosophy of "harmony between man and nature", these findings further suggest that strengthening individuals' emotional bond with the natural environment can help them identify themselves as part of nature, which may in turn influence their level of concern for ecological crises such as climate change. Taken together, these findings highlight that nature connectedness—rooted in both psychological and cultural foundations—plays a vital role in shaping adolescents' awareness of climate change.

The mediating effect of geographical synthetic thinking

This study found a significant positive association between nature connectedness and geographical synthetic thinking, consistent with previous research findings[45]. The concept of cognitive restoration, supported by environmental psychology, suggests that exposure to natural environments helps individuals recover cognitive resources, such as attention[69]. This restorative effect leads to a state of "cognitive quiet", promoting greater cognitive complexity and facilitating the processing of complex information[70]. Studies have shown that nature exposure helps students recover from attention fatigue more effectively, improving both cognitive function and brain density during learning activities[71]. These restorative processes—including the recovery of attention, enhanced cognitive functioning, and improved brain activity during learning—contribute to a deeper, more integrative understanding of geographical concepts, thereby supporting the development of geographical synthetic thinking.

Furthermore, the study reveals a significant positive relationship between geographical synthetic thinking and climate change awareness. This suggests that cultivating geographical synthetic thinking among adolescents could be an effective approach to enhancing their climate change awareness. Geography education, as a foundation for developing geographical synthetic thinking, plays a crucial role in fostering students' environmental awareness[72]. Geographical synthetic thinking aligns with dialectical thinking, a theoretical approach that encourages individuals to view systems as dynamic and interconnected[73]. Through this lens, students can better understand the complex relationships between human activities and environmental processes. For example, rather than isolating events like deforestation, students are encouraged to see these as part of a broader system of interrelated causes—such as economic development, policy decisions, and global weather patterns[74]. This dialectical perspective allows students to recognize the systemic nature of climate change, where each factor influences and is influenced by others. In addition, geographical synthetic thinking encourages students to view geographic phenomena as integrated systems. This perspective integrates the spatial, temporal, and regional dimensions of environmental issues, offering students a holistic understanding of climate change. Geographic phenomena, such as weather patterns or biodiversity, are not seen as discrete events but as interconnected elements that can vary over time and space. For instance, understanding the seasonal fluctuations of the monsoon and their impact on crop production helps students grasp how climate change could influence food security in different regions[75]. This integrated, systems-based thinking encourages students to move beyond oversimplified explanations and develop a deeper, more nuanced understanding of climate change, which in turn enhances their overall climate change awareness.

Moreover, our findings reveal a positive overall association among nature connectedness, geographical synthetic thinking, and climate change awareness. This pattern suggests that students who feel emotionally

and cognitively connected to nature may be more likely to develop the integrative thinking skills necessary for understanding complex environmental issues. Previous research has indicated that nature connectedness fosters attentional focus, perspective-taking, and reflective thinking—traits that are foundational to geographical synthetic thinking. These attributes help students interpret the dynamic interplay between natural and human systems, enabling them to comprehend climate change not as an isolated phenomenon, but as part of a broader system of interconnected processes[76]. In this way, geographical synthetic thinking may serve as a cognitive mechanism that bridges emotional connection to nature with deeper understanding of environmental challenges. Students who perceive nature as part of their extended self are more inclined to consider the long-term consequences of human-environment interactions, thereby enhancing both their awareness of and concern for climate change. In sum, these findings reveal a meaningful pathway from emotional connection to nature through geographical synthetic thinking to enhanced climate change awareness, underscoring the integrative role of cognitive and affective processes.

Implications

Theoretical implications

Our research contributes to the existing body of literature on climate change awareness, particularly among younger generations[6]. It provides fresh insights into addressing climate change by emphasizing the relationship between humans and nature, as well as between humans and society, through the lens of geographical synthetic thinking[77]. In doing so, it underscores the crucial role of geography education in cultivating environmental awareness. By understanding the cognitive processes involved, we deepen our understanding of how nature connectedness influences adolescents' environmental awareness. This theoretical perspective is crucial in framing how adolescents can be equipped to confront the complexities of climate change in a holistic manner.

Practical implications

Building on our theoretical findings, this study offers two key practical implications for climate change education: one focusing on the foundational role of nature connectedness, and the other emphasizing the cognitive importance of geographical synthetic thinking. These insights provide actionable guidance for enhancing the quality and impact of environmental and geographical education in addressing the climate crisis.

First, our results underscore the central role of nature connectedness in shaping adolescents' awareness of climate change. Fostering this emotional bond should therefore be a priority in educational initiatives. One effective strategy is to integrate concepts such as environmental ethics, ecological justice, and sustainability into school curricula, particularly within geography and environmental education[78]. By updating textbooks to better reflect the interdependence between humans and nature, and embedding ethical discourse into classroom activities, students can be guided to recognize themselves as part of the natural world. Concurrently, teacher training should promote pedagogical approaches that encourage reflective thinking on the harmony between humans and nature[79]. In addition to curricular reform, incorporating nature-based learning activities—such as field trips, ecological monitoring, and community environmental projects—has proven effective in strengthening students' emotional connection to the environment[80–82]. These experiences not only provide direct engagement with nature but also foster internalization of environmental values and promote sustainable behavior[83].

Second, our findings reveal that geographical synthetic thinking mediates the relationship between nature connectedness and climate change awareness, highlighting the critical role of geography education in fostering systems-based environmental understanding. Geography equips students with a distinctive lens to conceptualize the spatial, temporal, and systemic dimensions of environmental change. This type of thinking enables learners to integrate knowledge across natural and social domains, leading to a holistic understanding of issues such as global warming, extreme weather events, and environmental injustice[84]. Research has shown that students trained in geographical thinking are better able to recognize the dynamic interactions between human and environmental systems and to make informed, context-sensitive decisions[85]. To support this cognitive development, geography curricula should address real-world climate challenges at both local and global scales, encouraging students to view climate change as an interconnected issue. Lessons should draw on both physical geography—such as carbon cycles and land-use change—and human geography—such as urbanization and climate migration—to guide students in constructing multidimensional perspectives on environmental crises. For example, modules that explore how global climate systems influence regional vulnerabilities can help students understand the uneven impacts of climate change and the interdependence of societies[86].

Although this study did not directly examine the effects of instructional technologies, existing literature highlights the value of such tools in geography education. Geographic Information Systems (GIS), for instance, have been recognized as valuable tools for enhancing spatial thinking in geography education, supporting students' understanding of complex spatial relationships and environmental systems[87]. Similarly, prior research indicates that immersive Virtual Reality (VR) experiences can enhance individuals' connectedness to nature and promote pro-environmental behavior, thereby offering promising tools for strengthening the emotional link with nature[88]. Therefore, integrating technologies such as GIS and VR into classroom instruction holds potential to promote students' spatial reasoning and systems thinking skills[89].These tools simulate complex environmental scenarios, allowing students to explore the interactions among climate, geography, and human behavior, which in turn deepens their understanding of climate change mechanisms and consequences.

However, practical implementation of these recommendations may face barriers such as resource disparities between urban and rural schools. Differences in funding, teacher training opportunities, and access to technology can limit the equitable adoption of nature-based activities, GIS, and VR tools. Addressing these challenges will require targeted policies and support mechanisms to ensure that all students, regardless of geographic location, can benefit from enhanced climate change education.

In sum, fostering nature connectedness through experiential learning and integrating geographical synthetic thinking into the curriculum can significantly enhance students' environmental awareness and their capacity to respond effectively to climate challenges. Geography education, by cultivating this unique cognitive framework, empowers future generations to view climate change as a multifaceted, systemic issue and take meaningful, informed action in addressing it.

Strengths and future directions

This study has several notable strengths. Firstly, it adopts an innovative perspective by integrating nature connectedness, geographical synthetic thinking, and climate change awareness, contributing new insights to the field of geography education and environmental psychology. Secondly, the study benefits from a large sample size of 1,338 adolescents, which enhances the statistical power and reliability of the findings.

However, there are also several limitations to consider. Firstly, the cross-sectional design limits the ability to draw causal inferences. Future research should address this by employing longitudinal and intervention-based designs. For example, researchers could conduct a three-wave longitudinal study over a period of three years, with data collected at one-year intervals, to examine how climate change awareness develops during adolescence.

Secondly, the reliance on self-reported data, such as Schultz's Inclusion of Nature in Self scale, may introduce social desirability bias. Future studies should use more objective methods, such as behavioral assessments or observational data, and incorporate qualitative methods (e.g., interviews) to gain deeper insights into the mechanisms and contextual factors influencing climate change awareness.

Thirdly, while controlling for gender, residence, and socioeconomic status (SES), other potential moderators, like educational background, parental influences, or media exposure, could also affect climate change awareness[90]. Future studies should explore these factors to better understand the complexity of the issue.

Additionally, there may be selection bias due to the voluntary nature of participation, which could have led to overrepresentation of students with higher interest in nature or geography and deeper understanding of these topics, potentially skewing the results.

Lastly, the sample was restricted to Chinese adolescents, which limits the generalizability of the results. Future research should include more diverse demographic groups across different cultural and geographical contexts to provide more comprehensive and globally relevant insights[91].

Conclusion

This study highlights the crucial role of geographical synthetic thinking in linking nature connectedness to climate change awareness among adolescents. The findings emphasize the importance of understanding human-environment relationships to enhance climate change awareness. These insights provide guidance for designing effective educational strategies and policies that equip future generations to address the climate crisis, advocating for the integration of nature-based learning and geographical synthetic thinking in education.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Received: 8 January 2025; Accepted: 11 July 2025
Published online: 20 July 2025

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Acknowledgements

We express our gratitude to all the researchers for their assistance in data collection and coding. Additionally, our thanks extend to all the principals and teachers involved in this study.

Author contributions

J.G. and Y.Y. contributed to the methodology, formal analysis and investigation, as well as data curation. Y.Y. and J.G. prepared the original draft of the manuscript. F.G. and Y.D. reviewed and edited the manuscript. F.G. and Y.D. were responsible for funding acquisition. J.G. and Y.Y. provided the resources necessary for the study. F.G. supervised the project. F.G. and Y.D. handled the project administration. All authors reviewed the manuscript.

Funding

We are pleased to announce that this research received support from National Office for Education Sciences Planning of the People's Republic of China, titled "Research on the Implementation Pathways and Collaboration Mechanisms of 'Ecological Civilization Education' in Rural Schools"(grant number: DHA210340); the Major Project of the Ministry of Education of the People's Republic of China, titled "A Study on the Normalized Monitoring of Secondary School Geography Textbook Usage" (grant number: 2024GH-ZDA-JJ-Y-06).

Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This study was approved by the Research Ethics Committee of Zhejiang Normal University (number: ZSRT2023056).

Informed consent
Informed consent was obtained from all individual participants included in the study.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-11719-y.

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