

Article

How Nature-Based Education Promotes Sustainable Development Behavior Among University Students: A Sequential Mediation Model of Sustainability Knowledge and Attitudes

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Abstract

Nature-based education, characterized by authentic contexts and experiential learning, has increasingly been recognized as a potentially effective educational approach for fostering sustainable development literacy among university students. This study aimed to examine the influence of nature-based education on university students' sustainable development behavior. It further investigated the sequential mediating roles of sustainability knowledge and attitudes. A cross-sectional self-administered questionnaire survey was conducted among 1248 university students across 21 prefecture-level cities in China. Data were analyzed using SPSS (Version 28.0) and SmartPLS (Version 4.0). Partial least squares structural equation modeling (PLS-SEM) was employed to test the hypothesized model and assess the relationships among latent constructs. The results indicated that nature-based education was positively associated with sustainability knowledge ($\beta = 0.337, p < 0.001$) and, to a lesser extent, sustainability attitudes ($\beta = 0.106, p < 0.01$), but had no significant direct effect on sustainable development behavior. Instead, sustainability attitudes mediated the knowledge–behavior relationship, while sustainability knowledge and attitudes jointly formed a significant sequential mediation pathway.

Keywords: nature-based education; sustainability knowledge; sustainability attitudes; sustainable development behavior; structural equation modeling (SEM); mediation analysis



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1. Introduction

Within the context of the global sustainable development agenda, the capacity to enact sustainable development behaviors has become a core driver of sustainability, with education serving as the primary pathway for cultivating this capacity. The United Nations, in its 2030 Agenda, emphasizes that education plays a foundational role in achieving the Sustainable Development Goals (SDGs) [1]. As key institutions for knowledge production, talent development, and societal engagement, higher education institutions, through their integrated missions of teaching, research, and public outreach, play an indispensable role in leading societal transitions toward sustainability [2].

Sustainable behavior refers to the concrete actions individuals undertake in their daily lives, learning processes, and social practices to reduce environmental burdens, promote social equity, and support long-term sustainability goals [3,4]. Against the backdrop of intensifying climate change and escalating ecological risks [5], assessing the suitability and efficiency of renewable energy consumption has become a critical pathway for achieving sustainable development goals [6], and given that universities are critical settings for advancing education for sustainable development [7,8], investigating targeted educational interventions in higher education is essential for fostering sustainable development behaviors among university students. Understanding which types of educational interventions effectively promote behavioral change has thus become a central issue in the field of education for sustainable development.

As an experiential and context-based intervention within higher education, nature-based education has been widely demonstrated to enhance pro-environmental tendencies through immersive experiences in nature and the transmission of ecological knowledge [9,10]. A substantial body of empirical research further supports the positive association between nature-based education and pro-environmental behavior, and provides preliminary evidence for the mediating roles of nature connectedness and ecological understanding [11,12]. Meanwhile, theoretical scholarship emphasizes that authentic environmental education should guide learners to reconsider the fundamental relationship between humans and nature, rather than merely addressing human needs [13]. Nature-based education is broadly understood as an educational approach involving learning in natural environments through direct experience and ecological engagement.

In the present study, however, nature-based education was operationalized as participation frequency in nature-based educational activities, representing exposure intensity rather than the full pedagogical characteristics of nature-based education. However, existing studies have largely focused on single mediating variables, such as nature connectedness or ecological knowledge, and have not systematically elucidated the full psychological mechanisms through which nature-based education influences behavior. A critical unresolved issue is why nature-based education can effectively shape university students' sustainability-related knowledge and attitudes, yet often fails to translate directly into sustainable behavior. The formation mechanism of this "knowledge-behavior gap" in the context of nature-based education remains insufficiently understood [3].

From a theoretical perspective, prior research has provided a systematic explanatory framework for the "knowledge-attitude-behavior" pathway. The Theory of Planned Behavior posits that attitudes and perceived behavioral control are direct antecedents of behavioral intention [14]. Subsequent meta-analyses further confirm that attitudes and self-efficacy exert stable predictive effects on pro-environmental behavior [15]. Building on this foundation, recent studies have extended this framework to the field of education for sustainable development, suggesting that environmental attitudes, environmental self-efficacy, and perceived social norms constitute key psychological channels linking sustainability-related knowledge to behavior.

However, these theoretical frameworks face a common empirical challenge: knowledge alone is insufficient to directly drive behavior. A cross-national study of university students by Vicente-Molina et al. [16] found that the association between environmental knowledge and pro-environmental behavior is typically weak. Kollmuss and Agyeman [3] therefore proposed the concept of the "knowledge-behavior gap," arguing that knowledge can only be translated into sustained behavior through the joint influence of affective, attitudinal, and contextual factors. From a macro-level perspective, understanding the decoupling dynamics between land use, carbon emissions, and economic growth provides a structural foundation for interpreting how educational interventions can contribute to

systemic sustainability transitions [17]. This insight suggests that research should move beyond cognitive variables and further examine the mediating roles of psychological constructs such as attitudes in the transformation process.

Although existing studies have linked educational interventions to sustainability-related knowledge, attitudes, and behaviors, and have provided preliminary evidence for the mediating roles of variables such as attitudes and self-efficacy [18,19], two limitations remain. First, most studies treat knowledge and attitudes as parallel or independent mediators, with limited attention to their potential sequential relationship in the process through which nature-based education influences behavior. Specifically, it remains unclear whether nature-based education is closely related to higher levels of knowledge, which in turn facilitates the internalization of attitudes, thereby indirectly affecting behavior. Testing this sequential pathway would help clarify how affective factors operate following knowledge within the knowledge–behavior gap. Second, most empirical evidence is derived from samples in Western contexts or from long-term educational interventions. In the context of Chinese higher education, whether short-term nature-based educational interventions can influence sustainable behavior through the sequential transmission of knowledge and attitudes requires further empirical validation.

To address these gaps, this study investigates one overarching research question: How is participation in nature-based education associated with university students' sustainable development behavior?

To answer this question, the study examines three related sub-questions:

- (1) Whether sustainability knowledge mediates the relationship between nature-based education participation and sustainable development behavior.
- (2) Whether sustainability attitudes mediate this relationship.
- (3) Whether sustainability knowledge and sustainability attitudes jointly form a sequential pathway linking nature-based education participation to sustainable development behavior.

The hypotheses developed below are not intended to represent separate research questions, but rather to test specific components of this unified theoretical mechanism.

2. Theoretical Framework and Research Hypotheses

The hypotheses in this study are designed to examine different components of a single theoretical mechanism rather than multiple independent research questions. Specifically, the model focuses on whether participation in nature-based education is associated with sustainable development behavior through sustainability knowledge and sustainability attitudes. Although experiential learning theory describes learning as a cyclical and iterative process, the present study tests one theoretically plausible directional pathway based on the knowledge–attitude–behavior tradition and prior sustainability education research.

2.1. *Effects of Nature-Based Education on Sustainability Knowledge, Attitudes, and Behavior*

Experiential learning theory posits that learning originates from concrete experience and develops through a cyclical process involving reflective observation, abstract conceptualization, and active experimentation, ultimately leading to the reorganization and transfer of learners' cognitive structures [20]. In the context of education for sustainable development, authentic contexts and direct experiences are likewise widely regarded as critical elements for fostering sustainability [13,21]. Nature-based education is an intervention that utilizes natural environments as learning settings and adopts experiential and context-based approaches. Through observation, inquiry, experimentation, and guided interpretation, it can strengthen learners' ecological knowledge and systems thinking, thereby enhancing their sustainability knowledge [11,12]. In higher education, integrating

nature exposure and experiential tasks into curricula helps students understand ecosystems and human–environment relationships, thereby establishing a cognitive foundation for subsequent changes in attitudes and behaviors [22].

Second, research indicates that nature-based education not only influences knowledge but also exerts a direct effect on attitudes. Graf and Debrabant [23] propose that nature connectedness, as a key outcome of nature-based education, significantly predicts individuals' sustainability attitudes and behaviors.

However, the transition from attitudes to behavior is not automatic. Kollmuss & Agyeman [3] argue that when knowledge is translated into real-world action, challenges such as knowledge lag, attenuation, isolation, and misalignment between knowledge and action frequently arise. Even when individuals possess relevant knowledge, it may not effectively translate into stable behavioral intentions and practices. Mao Shiyang [24] similarly notes that a significant gap between knowledge and action exists in ecological civilization development, indicating that sustainability knowledge does not necessarily lead to corresponding behavior. Based on the above theoretical and empirical evidence, the following hypotheses are proposed:

H1. *Nature-based education has a significant positive effect on university students' sustainability knowledge.*

H2. *Nature-based education has a positive effect on university students' sustainability attitudes.*

H3. *The direct effect of nature-based education on sustainable development behavior is expected to be attenuated and become statistically non-significant when sustainability knowledge and attitudes are included as mediators.*

2.2. Effects of Sustainability Knowledge on Sustainability Attitudes and Behavior

In psychological and behavioral research, the relationships among knowledge, attitudes, and behavior have long been a central concern. The Theory of Planned Behavior (TPB) posits that behavioral intention precedes actual behavior and is jointly determined by attitudes toward the behavior, subjective norms, and perceived behavioral control [14]. As a key psychological foundation of behavioral intention, attitude is not a static trait but is formed and reinforced through experience, reflection, and value construction within specific educational approaches and learning contexts [25]. Empirical evidence suggests that a comprehensive understanding of sustainable development contributes to the cultivation of positive sustainability attitudes among university students [22]. However, some studies indicate that the role of knowledge and attitudes may be limited in directly driving behavior. It has been found that pro-environmental behavior is primarily driven by environmental practices, behavioral habits, and resource investment, whereas the effects of sustainability knowledge and attitudes are comparatively less significant. Cross-cultural and cross-sample studies further reveal that the relationship between environmental knowledge and pro-environmental behavior is often weak or unstable across different contexts [16].

Based on the above theoretical and empirical evidence, the following hypotheses are proposed:

H4. *University students' sustainability knowledge has a significant positive effect on sustainability attitudes.*

H5. *The direct effect of sustainability knowledge on sustainable development behavior is expected to be attenuated and become statistically non-significant when sustainability attitudes are included as a mediator.*

2.3. Effects of Sustainability Attitudes on Sustainable Development Behavior

Although knowledge is widely regarded as an important foundation for pro-environmental behavior, a substantial body of research indicates that increases in knowledge do not necessarily lead to behavioral change. Kollmuss and Agyeman [3] argue that when cognitive development is not accompanied by the deep internalization of attitudes, a pronounced “knowledge–behavior gap” is likely to emerge at the behavioral level. In this process, attitudes are widely recognized as a key psychological variable linking knowledge and behavior. Meta-analyses in the Theory of Planned Behavior and environmental psychology consistently demonstrate that attitudes are strong predictors of pro-environmental behavior [14,26,27]. Empirical studies focusing on university students similarly show that, compared with knowledge alone, students’ attitudes toward sustainable development more effectively predict behaviors such as energy conservation, waste reduction, and green consumption. In this context, attitudes function as a mediating mechanism between knowledge and behavior, helping to bridge the long-standing “knowledge–behavior gap” [28]. Baierl et al. [17] further emphasize that attitudes are a key driver of sustainable behavior, with attitudes toward nature significantly promoting sustainable engagement [18].

Therefore, in the context of higher education, the influence of sustainability knowledge on behavior is more likely to operate through attitudinal pathways rather than through direct effects. Attitudes act as a “value converter,” transforming abstract cognitive understanding into value orientations with behavioral relevance. Based on this reasoning, the following hypothesis is proposed:

H6. *Sustainability attitudes have a significant positive effect on university students’ sustainable development behavior.*

2.4. Mediating Roles of Sustainability Knowledge and Sustainability Attitudes

Building on the above theoretical logic, this study further proposes specific mediating pathways through which nature-based education influences university students’ sustainable development behavior. Experiential learning theory suggests that the effects of nature-based education on behavior do not occur instantaneously but unfold progressively through a process of “experience–reflection–meaning construction–behavioral externalization” [29]. Given the distinctive features of nature-based education, it may strengthen the transmission from knowledge to attitudes and from attitudes to behavior, making such a chained mediation pathway particularly salient among university students [11]. Accordingly, it is inferred that nature-based education first influences learners’ sustainability knowledge, thereby establishing a cognitive foundation for subsequent attitudinal change. Therefore, this study proposes:

H7. *Sustainability knowledge mediates the relationship between nature-based education and sustainability attitudes.*

Second, it is necessary to distinguish between the direct and indirect mechanisms through which nature-based education affects sustainable development behavior. Otto and Pensini [10], in a study of primary school students, directly verified the mediating pathway through which nature-based education indirectly influences ecological behavior via environmental knowledge [11]. Although the knowledge pathway explained only 2% of the variance, the effect was statistically significant. Li Xueying et al. [30], using a sample of national park visitors, further confirmed that perceived environmental education indirectly and positively affects pro-environmental behavior through environmental knowledge, thereby providing clear support for the “education—knowledge–behavior” pathway. Begum et al. [31], while focusing on the mediating role of nature connectedness,

also acknowledge in their theoretical framework that environmental knowledge constitutes a foundational prerequisite for the influence of environmental education on behavior. Based on the above theoretical and empirical evidence, this study proposes the following:

H8. *Sustainability knowledge mediates the relationship between nature-based education and sustainable development behavior.*

The “knowledge–attitude–behavior” sequence is a classic explanatory framework for pro-environmental behavior. Knowledge itself does not directly drive behavior; rather, attitudes, as key psychological variables linking knowledge and behavior, transform objective knowledge into subjective intentions. Sesar and Martinčević [32] confirm that sustainability attitudes mediate the relationship between knowledge and behavior; Li Xueying et al. [30] validate the chained pathway of “knowledge–affective attitude–behavior”; and Baierl et al. [18] find that the predictive effect of attitudes on behavior is significantly stronger than that of knowledge. Existing studies consistently indicate that attitudes mediate the relationship between knowledge and behavior across various educational contexts [33,34]. Accordingly, the following hypothesis is proposed:

H9. *Sustainability attitudes mediate the relationship between sustainability knowledge and sustainable development behavior.*

The unique characteristics of nature-based education not only facilitate the transmission of knowledge but also directly stimulate emotional connectedness and a sense of responsibility. Otto and Pensini [10] find that nature connectedness, as a mediator between nature-based education and ecological behavior, explains 69% of the variance in behavior [11]. Begum et al. [31] further confirm the mediating role of nature connectedness, while Li Xueying et al. [30] validate the pathway of “perceived environmental education–anticipated guilt–pro-environmental behavior.” Based on this reasoning, the following hypothesis is proposed:

H10. *Sustainability attitudes mediate the relationship between nature-based education and sustainable development behavior.*

2.5. Sequential Mediating Effect

Based on the “perception–knowledge–affect–behavior” framework, responses to educational stimuli are assumed to develop sequentially from cognition to attitudes and ultimately to behavior. Prior studies in environmental education support this mechanism. For instance, perceived environmental education has been shown to influence pro-environmental behavior indirectly through knowledge and affective variables [30].

Applied to education for sustainable development, nature-based education may first enhance sustainability knowledge, which subsequently strengthens sustainability attitudes and, in turn, is associated with sustainable development behavior. Thus, attitudes may convert abstract knowledge into behavioral commitment. Based on this reasoning, the following hypothesis is proposed:

H11. *Sustainability knowledge and sustainability attitudes jointly serve as sequential mediators in the relationship between nature-based education and sustainable development behavior.*

2.6. Effects of Gender and Place of Residence on Nature-Based Education and Sustainable Development Behavior

In addition to educational interventions and psychological mechanisms, individual background characteristics also play an important role in shaping sustainable development

behavior. Existing research indicates that differences in place of residence influence individuals' opportunities and willingness to engage in sustainable behaviors, with underlying mechanisms including the availability of natural resources, the level of environmental infrastructure, and prevailing social norms [35].

Regarding gender differences, current evidence remains inconclusive. Some studies suggest that with the expansion of higher education and the increasing convergence of youth values, gender differences related to sustainable development may gradually diminish [36]. However, other research finds that gender may still exert significant effects on sustainability awareness and related psychological dimensions [37].

Given the mixed findings, this study incorporates gender and place of residence as control variables. Based on prior evidence that urban settings provide greater access to sustainability-related infrastructure and social norms [35], we predict that urban residence is associated with higher levels of sustainable development behavior. Regarding gender, recent studies suggest that as sustainability becomes a mainstream value among younger generations, gender differences may be diminishing [36]. Therefore, we do not expect a significant gender difference in sustainable behavior among contemporary university students in China, while including gender as a control variable allows us to verify this empirically. Accordingly, the following hypotheses are proposed:

H12. *Urban residence is positively associated with university students' sustainable development behavior compared to rural residence.*

H13. Gender does not have a significant effect on university students' sustainable development behavior.

Based on the extant literature and the hypotheses formulated above, a conceptual research model is presented in Figure 1.

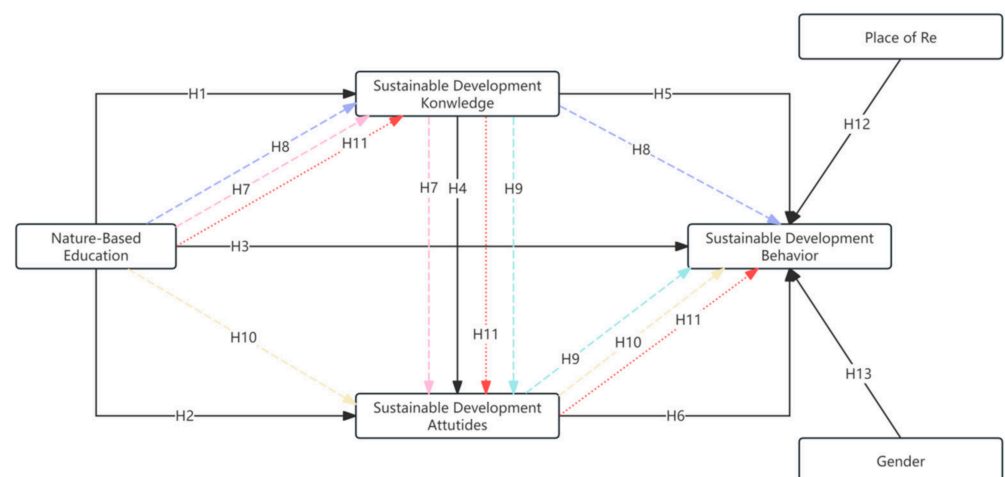


Figure 1. Conceptual framework of the proposed study (solid lines represent direct hypothesized relationships, whereas dashed lines represent hypothesized mediation pathways. Colors are used only for visual distinction and do not indicate different types of relationships.).

3. Research Methods

SPSS (IBM SPSS Statistics v30.0 (IBM Corp., Armonk, NY, USA)) was used for descriptive statistics and reliability analysis. Partial least squares structural equation modeling (SmartPLS v4.1.1.2 (SmartPLS GmbH, Bönningstedt, Germany)) was employed to test the proposed model. This choice reflects the prediction-oriented nature of the study, which prioritizes maximizing the explained variance in sustainable development behavior. The hy-

pothesized model entails sequential mediation (via sustainability knowledge and attitudes), and PLS-SEM is well-suited for estimating indirect effects without imposing distributional assumptions on the product term. The present study employs PLS-SEM to capture complex mediation pathways in education-for-sustainability research. In addition, preliminary data assessment revealed deviations from multivariate normality and a mix of Likert-type and dichotomous items, making PLS-SEM's robustness to non-normal data preferable to covariance-based alternatives.

3.1. Sampling and Data Collection

Data were collected between March and September 2025 from undergraduate students enrolled in universities across 21 prefecture-level cities in China. An online questionnaire survey was conducted, and the questionnaire was administered online. A total of 1365 questionnaires were returned, of which 1248 were valid and retained for analysis, yielding an effective response rate of 91.43%. Data collection followed institutional standards for anonymous and non-invasive social research. Participation was voluntary, and informed consent was obtained prior to data collection. No personally identifiable information was recorded. These procedures supported data confidentiality, ethical compliance, and the reliability of respondent feedback. Ethical approval was exempted under institutional guidelines.

Prior to the formal survey, expert review and a pilot study ($n = 82$) were conducted to refine items and assess preliminary reliability. All scales demonstrated acceptable Cronbach's α values, indicating satisfactory internal consistency. The pilot study showed acceptable internal consistency, with Cronbach's α values exceeding 0.70 for all multi-item constructs. Based on expert feedback, minor wording revisions were made to improve contextual clarity.

Following successful pilot validation, formal data collection was conducted using a structured questionnaire to test the research hypotheses shown in Figure 1. The questionnaire comprised four sections. The first section collected respondents' sociodemographic information. The second section measured university students' exposure to and participation in nature-based education. The third section assessed sustainability knowledge and attitudes; both constructs were measured using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The fourth section assessed sustainable development behavior, focusing on whether specific behaviors had been enacted. Accordingly, dichotomous response options (yes/no) were used.

The questionnaire items were derived from well-established measurement scales in both domestic and international literature and were culturally adapted and contextually refined to reflect the learning and living contexts of Chinese university students. Detailed information on the measurement instruments is provided in Table 1.

This study integrates and extends the Theory of Planned Behavior (TPB) and Experiential Learning Theory (ELT) to develop a conceptual model explaining how nature-based education influences university students' sustainable development literacy (Figure 1). In the model, NE is specified as the independent variable, SK and SA as mediators, and SB as the dependent variable. In addition, gender and place of residence are included as control variables to more comprehensively examine the relationships among constructs across different individual backgrounds. Given that nature-based education in Chinese universities is less formalized than in Western contexts—typically taking the form of elective field courses or volunteer activities rather than mandatory curricula—this contextual difference should be considered when interpreting the observed effect sizes and indirect pathways. Detailed information on the sample composition is presented in Table 2.

Table 1. Measurement scales and evaluation items.

Construct	Code	Item	Source
Nature-Based Education (NE)	NE	Frequency of participation in nature-based education activities during the past year.	Luo et al., 2025 [6]; Bergkvist & Rossiter, 2007. [38]
Sustainability Knowledge (SK)	SK1	I am familiar with social sustainability issues.	Braßler and Sprenger, 2021 [39]; Chen et al., 2022 [40]
	SK2	I am familiar with economic sustainability issues.	
	SK3	I am familiar with ecological sustainability issues.	
	SK4	I understand how my academic discipline can contribute to sustainable development.	
Sustainability Attitudes (SA)	SA1	When I see people living in poor conditions around the world, I feel a responsibility to do something about it.	Chen et al., 2022 [40]; Özdemir, 2021 [41]
	SA2	I am concerned about the extinction of certain species.	
	SA3	I believe that I can contribute to the improvement of environmental quality through my personal actions.	
	SA4	I am willing to make sacrifices for sustainable development.	
	SA5	I believe it is important to take action to address climate change-related issues.	
Sustainable Behavior (SB)	SB1	I donate or give away reusable items to others.	Chen et al., 2022 [40]; Leal et al., 2024 [42]
	SB2	I have participated in volunteer or public activities related to environmental protection or sustainable development.	
	SB3	In my daily life, I practice water-saving behaviors (e.g., turning off the tap while brushing my teeth).	
	SB4	When shopping, I prefer environmentally friendly products even if they are more expensive.	
	SB5	I actively reduce energy use in my daily life (e.g., turning off lights and appliances when not in use).	
	SB6	I separate waste for recycling.	

Table 2. Demographic characteristics of the study sample (N = 1248).

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	325	26.04
	Female	923	73.96
Place of Residence	Rural	335	26.84
	Urban	913	73.16

3.2. Evaluation of the Measurement Model

Nature-based education was assessed using a single item measuring the frequency of participation in nature-based educational activities during the past year. Although nature-based education is a multidimensional construct that includes pedagogical quality, duration, content, and context, the present study focused on participation frequency as a proxy for exposure intensity. This measure captures exposure intensity rather than experiential quality, reflective learning, instructional design, or perceived authenticity. Single-item measures have been shown to be acceptable for concrete, unidimensional attributes that are easily understood by respondents [39]. In this study, nature-based education was operationalized as participation frequency rather than as a multidimensional educational experience. Therefore, findings should be interpreted as reflecting exposure to nature-based education rather than its pedagogical quality.

To examine the suitability of the scale data for factor analysis, the Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s test of sphericity were conducted. As shown in Table 3, the KMO value was 0.914, which exceeds the recommended threshold of 0.80, indicating excellent sampling adequacy. Bartlett’s test of sphericity yielded statistically significant results ($\chi^2 = 5552.415$, $df = 105$, $p < 0.001$), rejecting the null hypothesis that the correlation matrix is an identity matrix. This result indicates strong correlations among the variables and provides a sound statistical basis for extracting underlying common factors. Accordingly, the data are suitable for exploratory factor analysis.

Table 3. KMO and Bartlett’s test of sphericity.

Test Statistic		Value
KMO Measure of Sampling Adequacy		0.914
Bartlett’s Test of Sphericity	Approximate χ^2	5552.415
	df	105
	p-value	<0.001

Based on these results, principal component analysis (PCA) with a varimax orthogonal rotation was conducted, and common factors were extracted using the eigenvalue criterion of greater than 1. As shown in Table 4, three factors were extracted, corresponding to the three latent constructs specified in the study: sustainability knowledge (SK), sustainability attitudes (SA), and sustainable behavior (SB). Together, these three factors explained 71.739% of the total variance, exceeding the widely accepted 60% threshold in social science research, and the EFA results provided preliminary support for the dimensional structure of the measures.

All indicators loaded strongly on their intended constructs (loadings > 0.50) with no substantial cross-loadings, supporting the convergent validity and structural coherence of the measurement model (Table 4). Taken together, the exploratory EFA results indicate that the measurement scales demonstrate adequate construct validity, with clearly defined factor structures and acceptable discriminant validity, thereby providing a reliable measurement foundation for subsequent structural equation modeling (SEM) analyses.

The measurement model was evaluated in terms of reliability and validity, including internal consistency (Cronbach’s α and composite reliability [CR]), convergent validity (average variance extracted [AVE]), and discriminant validity assessed using multiple complementary criteria (Fornell–Larcker criterion, cross-loadings, and the heterotrait–monotrait ratio [HTMT]). The structural model was subsequently assessed by estimating path coefficients and testing hypotheses using bootstrapped t-values and p-values. Testing hypotheses

using bootstrapped t-values and *p*-values. Finally, gender and place of residence were included in the structural model as control variables to account for potential demographic differences in sustainable development behavior.

Table 4. Rotated factor loadings and communalities (exploratory factor analysis).

Variable	Code	Factor 1	Factor 2	Factor 3	Communality (h ²)
SK	SK1			0.810	0.681
	SK2			0.768	0.715
	SK3			0.770	0.668
	SK4			0.635	0.580
SA	SA1		0.581		0.502
	SA2		0.681		0.599
	SA3		0.804		0.721
	SA4		0.737		0.614
	SA5		0.777		0.623
SB	SB1	0.950			0.906
	SB2	0.933			0.872
	SB3	0.869			0.759
	SB4	0.878			0.777
	SB5	0.950			0.907
	SB6	0.920			0.848
Rotated Sums of Squared Loadings	Total	5.084	3.008	2.669	
	Variance Explained (%)	33.896	20.053	17.790	
	Cumulative Variance (%)	33.896	53.949	71.739	

As shown in Table 5, all factor loadings across constructs ranged from 0.715 to 0.954, exceeding the recommended threshold of 0.70 and indicating satisfactory indicator reliability. Cronbach's α values ranged from 0.824 to 0.963, demonstrating high internal consistency reliability. Composite reliability (CR) values ranged from 0.881 to 0.970, further supporting construct reliability. The AVE values ranged from 0.597 to 0.844, all above the recommended threshold of 0.50, thereby confirming adequate convergent validity.

Table 5. Reliability and convergent validity of the measurement model.

Code	Standardized Factor Loading	Cronbach's α	CR	AVE
SA1	0.715	0.830	0.881	0.597
SA2	0.794			
SA3	0.845			
SA4	0.776			
SA5	0.724			
SB1	0.953	0.963	0.970	0.844
SB2	0.927			
SB3	0.874			
SB4	0.885			
SB5	0.954			
SB6	0.916			

Table 5. *Cont.*

Code	Standardized Factor Loading	Cronbach's α	CR	AVE
SK1	0.775	0.824	0.883	0.645
SK2	0.847			
SK3	0.816			
SK4	0.796			

Note: Cronbach's alpha coefficient, the higher the coefficient, the better the internal consistency of the scale. Generally, a Cronbach's alpha coefficient greater than 0.7 is considered acceptable in terms of reliability, with higher values indicating better reliability.

Regarding discriminant validity, the square roots of the AVE values (bolded diagonal elements) exceeded the corresponding inter-construct correlations, as shown in Table 6, satisfying the Fornell–Larcker criterion. In addition, cross-loading analysis (Table 7) demonstrated that each indicator loaded more strongly on its intended construct than on all other constructs. Furthermore, all HTMT values (Table 8) were below the conservative threshold of 0.85, providing additional support for discriminant validity. Collectively, these results confirm that the measurement model demonstrates robust reliability and validity.

Table 6. Discriminant validity assessment using the Fornell–Larcker criterion.

Construct	SA	SB	SK
SA	0.772		
SB	0.131	0.919	
SK	0.666	0.055	0.809

Note. This table presents the inter-construct correlation matrix. The bold diagonal elements represent the square roots of the average variance extracted (AVE) for each construct. Discriminant validity is established when the square root of AVE for each construct exceeds its correlations with other constructs.

Table 7. Cross-loadings of measurement indicators.

Indicator	SA	SB	SK
SA1	0.715	0.001	0.533
SA2	0.794	0.141	0.554
SA3	0.845	0.140	0.537
SA4	0.776	0.079	0.519
SA5	0.724	0.147	0.411
SB1	0.129	0.953	0.060
SB2	0.097	0.927	0.046
SB3	0.127	0.874	0.069
SB4	0.120	0.885	0.036
SB5	0.134	0.954	0.050
SB6	0.104	0.916	0.040
SK1	0.456	0.016	0.775
SK2	0.596	0.103	0.847
SK3	0.517	0.008	0.816
SK4	0.571	0.040	0.796

Note. Bold values indicate the highest standardized loading for each indicator on its associated latent construct, supporting adequate discriminant validity.

Table 8. Heterotrait–monotrait ratio (HTMT) assessment.

Construct	SA	SB	SK
SA			
SB	0.150		
SK	0.796	0.060	

Note. All HTMT values are below the conservative threshold of 0.85, indicating adequate discriminant validity among the latent constructs.

3.3. Evaluation of the Structural Model

3.3.1. Direct Effect

Table 9 reports the results based on structural path analysis, which examines the relationship between nature-based education, sustainable development knowledge, sustainable development attitude, and sustainable development behavior. As shown in Table 9, nature-based education (NE) was positively associated with the relationship between sustainability knowledge (SK) and sustainability attitudes (SA) ($\beta = 0.337$, $p < 0.001$; $\beta = 0.106$, $p < 0.01$). This indicates that participating in nature-based education was not only directly related to higher levels of college students' sustainability knowledge but also was associated with a positive attitude towards sustainable development at the value level. The path prediction of NE on SB ($\beta = 0.014$, $p > 0.1$) is not supported, suggesting that nature-based education cannot directly influence behavior.

Table 9. Results of direct effects.

Mediation Path	β	STDEV	T-Statistics	p -Values	Result
Direct Effect					
H1:NE-SK	0.337	0.049	6.928	0.000 ***	Supported
H2:NE-SA	0.106	0.036	2.930	0.003 **	Supported
H3:NE-SB	0.014	0.025	0.568	0.570	Rejected
H4:SK-SA	0.630	0.038	16.528	0.000 ***	Supported
H5:SK-SB	−0.024	0.031	0.881	0.379	Rejected
H6:SA-SB	0.075	0.031	2.347	0.019 *	Supported

Note. *, **, and *** indicate statistical significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

To provide a visual representation of the structural relationships among the constructs, the standardized path coefficients are presented in Figure 2.

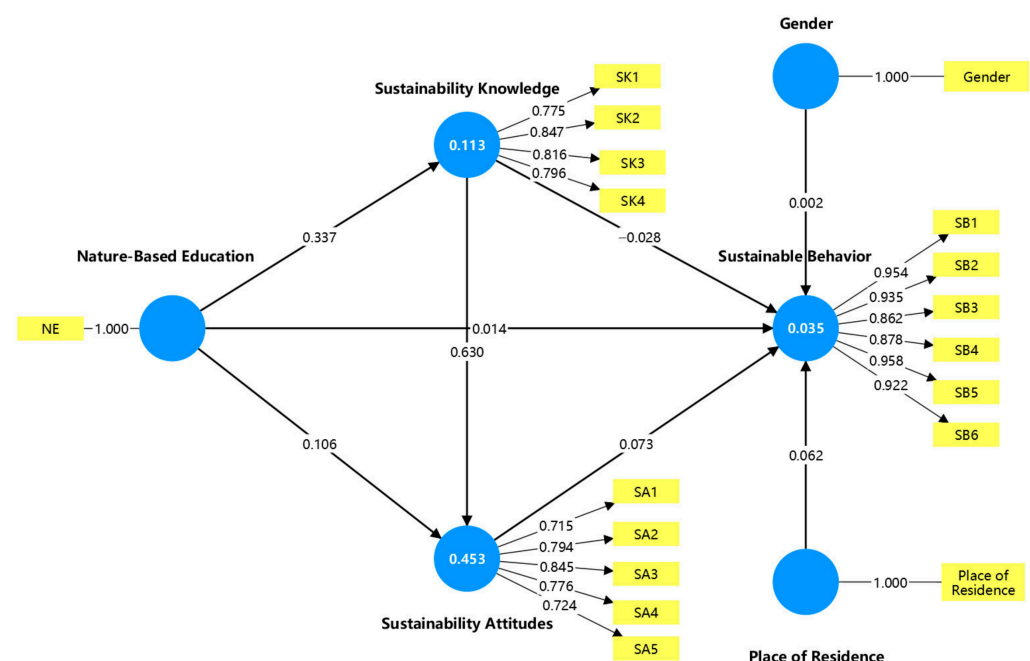


Figure 2. Structural equation model with standardized path coefficients.

Similarly, the direct effect of SA on SB was statistically significant ($\beta = 0.075$, $p < 0.05$), indicating that sustainability attitudes are positively associated with sustainable development behavior, although the effect size was modest. The hypothesis of the direct effect of SK on SB ($\beta = -0.024$, $p > 0.1$) failed the significance test of the path, indicating that merely

increasing knowledge accumulation among college students is difficult to translate into actual behavior, and it may function through an attitude mediation mechanism.

3.3.2. Mediating Effect

To examine the mechanism by which nature-based education influences sustainable development behavior, this study conducted path-specific mediation analyses using bootstrapping procedures to test the mediating roles of sustainability knowledge and attitudes. Table 10 summarizes the indirect effects generated through knowledge and attitudes via nature-based education. The NE-SK-SA pathway ($\beta = 0.212$, 95% CI [0.148, 0.276]) and the SK-SA-SB pathway showed significant results ($\beta = 0.046$, 95% CI [0.009, 0.086]), while the NE-SK-SB pathway was not statistically significant ($\beta = -0.009$, 95% CI [−0.031, 0.011]), indicating that cognitive levels alone cannot directly translate into behavioral outcomes. The indirect effect generated through the NE-SA-SB pathway was relatively moderate ($\beta = 0.008$, 95% CI [0.001, 0.019]). Consequently, the chain mediation analysis incorporating the NE-SK-SA-SB pathway ($\beta = 0.017$, 95% CI [0.003, 0.032]) demonstrated statistical significance, suggesting that the results are consistent with the possibility that nature-based education participation is associated with sustainable development behavior through sustainability knowledge and attitudes.

Table 10. Results of mediation and sequential mediation effects.

Mediation Path	β	STDEV	T-Statistics	95% Bias-Corrected Bootstrap Confidence Interval	Result
Specific Indirect Effects					
H7:NE-SK-SA	0.212	0.033	6.487	[0.148, 0.276] *	Supported
H8:NE-SK-SB	−0.009	0.011	0.862	[−0.031, 0.011]	Rejected
H9:SK-SA-SB	0.046	0.020	2.263	[0.009, 0.086] *	Supported
H10:NE-SA-SB	0.008	0.004	1.758	[0.001, 0.019] *	Supported
Sequential Mediation Effect					
H11:NE-SK-SA-SB	0.017	0.008	2.047	[0.003, 0.032] *	Supported

Note. * The significance of indirect effects was determined based on the bias-corrected bootstrap confidence interval; an indirect effect is significant when the interval does not include zero.

These results support a sustainability knowledge–attitude–behavior sequential mechanism, consistent with Experiential Learning Theory, highlighting the indirect role of nature-based education in fostering sustainable development behavior. To further assess the robustness of the proposed mediation mechanism, three alternative serial mediation models were tested. The detailed results are provided in the Supplementary Materials (Tables S1–S3).

3.3.3. Control Effects Analysis

The control variable analysis shows that place of residence has a significant positive effect on sustainable behavior ($\beta = 0.062$, $p < 0.05$), with urban students showing higher engagement in sustainable practices. This suggests that educational interventions should consider urban–rural contextual differences and strengthen experiential learning opportunities for rural students. The effect of gender on sustainable development behavior was not statistically significant ($\beta = 0.002$, $p > 0.05$), thereby supporting H13, indicating a convergence in sustainability-related behaviors across genders (Table 11).

Table 11. Results of path analysis for control variables.

Path	β	T-Statistics	p-Values	95% Bias-Corrected Bootstrap Confidence Interval	Result
H12: Place of Residence-SB	0.063	2.658	0.008 **	[0.016, 0.107]	Supported
H13: Gender-SB	−0.001	0.032	0.974	[−0.103, 0.108]	Supported

Note. ** indicates statistical significance at $p < 0.01$.

4. Discussion

4.1. Participation in Nature-Based Education and the Knowledge–Behavior Gap

NE had no significant direct effect on SB. Instead, the results were consistent with an indirect-only mediation pattern through sustainability attitudes and the sequential pathway of sustainability knowledge and attitudes. The non-significant SK-SB path is further consistent with the hypothesis that knowledge alone, even when enhanced by NE, cannot drive behavior without attitudinal mediation. This finding highlights a distinctive mechanism of nature-based education that differs from conventional classroom-based instruction. The rupture does not occur at the NE-SK stage; rather, it emerges along the direct SK-SB pathway. Why, then, does knowledge fail to directly translate into behavior? Previous studies provide important explanations. Instruction lacking authentic contextual engagement may produce short-term cognitive gains but is rarely linked to sustained behavioral change [3]. In contrast, nature-based education, by enabling students to engage directly with natural environments, participate in problem-oriented experiential activities, and engage in reflective learning, situates learning within real ecological systems. However, the findings of this study further indicate that even such deepened knowledge is still insufficient to directly drive behavior. More importantly, the direct effect of SK on SB in this study was not statistically significant (although the point estimate was negative). This non-significant finding should not be interpreted as evidence of a negative tendency; rather, it reinforces that knowledge alone, even when enhanced by nature-based education, does not reliably translate into behavior without attitudinal mediation. The statistically zero direct effect underscores the persistence of the knowledge–behavior gap and the need for attitudinal pathways [43].

4.2. Sustainability Attitudes as a Possible Bridge

This study shows that sustainability knowledge (SK) does not directly predict sustainable behavior (SB), but operates indirectly through sustainability attitudes (SA). The findings imply that attitudes serve as a motivational bridge between knowledge and action. Knowledge alone may not generate behavior unless accompanied by emotional engagement and value commitment. By contrast, attitudes capture affective concern and willingness to act, thereby helping convert knowledge into behavioral motivation. This mechanism is highly consistent with the core proposition of the Theory of Planned Behavior (TPB), which posits that knowledge influences behavior only through attitudes and behavioral intentions. However, the contribution of this study extends beyond merely validating TPB. It further provides a generative explanation of the attitudinal construct within the specific context of nature-based education: where do attitudes come from? The chain mediation model developed in this study suggests that, in nature-based educational settings, attitudes emerge as a product of cognitive processing that is subsequently transformed through emotional engagement and value internalization. In other words, the unique strength of nature-based education does not lie in the amount of knowledge it delivers, but in how it transforms knowledge into emotionally grounded identification. The results also show that the direct effect of knowledge on behavior is not significant, highlighting the

persistence of the knowledge–behavior gap. Education should not assume that knowledge automatically is linked to action; instead, greater attention should be given to the bridging role of attitudes.

4.3. Interpreting the Sequential Mediation Pathway with Caution

The sequential mediation analysis incorporating the NE-SK-SA-SB pathway ($\beta = 0.017$, 95% CI [0.003, 0.032]) demonstrated statistical significance, suggesting that nature-based education can promote sustainable development behaviors by cultivating cognitive awareness and positive attitudes. However, a critical observation regarding model explanatory power: the structural model explained only 3.5% of the variance in sustainable development behavior ($R^2 = 0.035$), indicating that 96.5% of the behavioral variance remains unaccounted for by nature-based education, sustainability knowledge, and sustainability attitudes. This strikingly low explanatory power suggests that university students' enactment of sustainable behaviors is likely shaped by a broader set of contextual and non-cognitive factors not captured in the current model. These may include habitual patterns, infrastructural constraints, economic costs, perceived social norms, convenience, self-efficacy, and cultural context. The low explained variance in sustainable behavior therefore suggests that behavioral enactment may be substantially shaped by contextual constraints, habitual patterns, and structural opportunities beyond cognitive and attitudinal variables. Therefore, while nature-based education can indirectly influence behavior through attitudinal pathways, its overall explanatory power for actual behavioral change remains limited. The significant sequential mediation effect should not be interpreted as proof of a true causal chain. The cross-sectional design restricts inference about temporal dynamics and long-term effects, highlighting the need for longitudinal research. Future research should integrate additional theoretical constructs to improve the understanding of behavior formation.

4.4. Contextual Differences in Sustainable Behavior

Based on the control variable analysis, urban students reported significantly higher engagement in sustainable development behaviors than rural students. This difference may indicate unequal opportunity structures for behavioral practice. Urban settings often offer more supportive infrastructure, richer educational resources, and stronger pro-sustainability norms [33]. By contrast, rural students may have comparable intentions but fewer opportunities to enact such behaviors. Therefore, for rural students, knowledge enhancement alone may not be sufficient; interventions should also expand accessible opportunities for sustainable practice in everyday life.

In contrast, no significant gender differences were observed. Although this finding differs from some earlier studies [25], it may reflect generational shifts among contemporary university students. As sustainability has become a more mainstream social value, sustainable behavior may now be less gender-specific than in earlier cohorts. Practically, this suggests that education for sustainable development should focus less on gender-targeted interventions and more on common structural and psychological determinants of behavior.

5. Conclusions

This study, grounded in the Theory of Planned Behavior and Experiential Learning Theory, developed and tested a chained mediation model of “NE-SK-SA-SB.” Based on empirical data from 1248 university students in China, several key findings were obtained.

The findings suggest that the weak knowledge–behavior pathway may help explain the persistent knowledge–behavior gap. Nature-based education showed no significant direct effect on sustainable development behavior, but was associated with behavior indirectly, particularly through the sequential pathway of sustainability knowledge and

attitudes. This implies that knowledge alone may not translate into action without attitudinal engagement.

Urban students reported higher levels of sustainable behavior than rural students, pointing to possible differences in opportunity structures and supportive environments. By contrast, no significant gender differences were found, suggesting that contextual factors may now be more influential than gender in shaping sustainable behavior among university students. Collectively, these findings support the relevance of Experiential Learning Theory and underscore the role of attitudes within the Theory of Planned Behavior.

From a practical perspective, the findings suggest three implications for higher education. First, nature-based education should place greater emphasis on emotional engagement and value internalization rather than knowledge transmission alone. Second, interventions should account for urban–rural disparities by combining nature exposure, contextual learning, and accessible opportunities for sustainable practice. Third, as no significant gender differences were found, educational programs may benefit more from addressing common structural and psychological barriers than from gender-targeted designs.

The mediation results should be interpreted cautiously. Because the study used cross-sectional data, temporal precedence among nature-based education participation, sustainability knowledge, sustainability attitudes, and sustainable behavior cannot be established. Although the proposed NE–SK–SA–SB pathway is theoretically plausible, alternative explanations remain possible. For example, students with stronger sustainability knowledge or more positive sustainability attitudes may also be more likely to participate in nature-based educational activities. The alternative model analyses suggest that reciprocal relationships among participation, knowledge, and attitudes may exist, which is consistent with the cyclical nature of experiential learning theory. However, only the hypothesized ordering produced a significant indirect pathway to sustainable development behavior. Therefore, the findings should be understood as statistically consistent with the proposed theoretical framework rather than as proof of causal ordering.

In summary, the findings suggest that participation in nature-based education may be associated with sustainable behavior through a knowledge–attitude pathway. Instead, its primary contribution, as supported by the significant sequential indirect effect (NE–SK–SA–SB) and the non-significant direct SK–SB path, lies in activating the attitudinal transformation mechanism that converts cognitive understanding into value-based commitment. Specifically, nature-based education first enhances sustainability knowledge ($\beta = 0.337$), which in turn fosters positive sustainability attitudes ($\beta = 0.630$), and attitudes were positively associated with sustainable behavior, although the magnitude of the effect was relatively small ($\beta = 0.075$). Although the proposed model identified statistically significant indirect pathways, its explanatory power for sustainable development behavior was limited, indicating that behavioral outcomes are likely shaped by a broader set of contextual and structural factors. Overall, this study provides empirical evidence consistent with a theoretically plausible knowledge–attitude pathway, while acknowledging that causal ordering and alternative mechanisms should be further examined in future longitudinal or experimental research.

6. Limitations and Future Research Directions

Several limitations should be acknowledged. First, the sample consisted of undergraduate students from 21 prefecture-level cities in China and was demographically skewed, which may constrain generalizability. Second, the model was examined only in the Chinese higher education context; future cross-cultural studies are needed to test its broader applicability. Third, the cross-sectional design restricts inference about temporal dynamics and long-term effects, highlighting the need for longitudinal research. Fourth, nature-based

education was operationalized using a single-item frequency measure, which may not capture dimensions such as quality, duration, or pedagogical design. The operationalization of nature-based education reflects participation frequency and does not directly assess the broader experiential dimensions emphasized in the theoretical literature. Finally, sustainable behavior was self-reported and may be influenced by social desirability bias. Future research should adopt longitudinal or experimental designs, use multidimensional measures of nature-based education, and incorporate additional mechanisms such as nature connectedness, self-efficacy, environmental identity, and perceived social norms, as well as big-data-driven approaches [44].

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