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RESEARCH ARTICLE

The relationship between environmental knowledge and environmental behavior among university students in Guangxi, China: The mediating effects of environmental risk perception and environmental attitude

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ABSTRACT

Promoting pro-environmental behavior among university students is of significant importance in advancing the Sustainable Development Goals , particularly quality education and responsible consumption and production. However, the internal mechanisms by which environmental knowledge translates into pro-environmental behavior remain insufficiently understood, with limited studies conducted in the context of Guangxi, China. Based on the protection motivation theory (PMT) and a survey of 812 university students in Guangxi, this study examines the chain-mediating mechanism through which environmental knowledge influences pro-environmental behavior via environmental risk perception and environmental attitude.The study used survey questionnaires, employing standardized scales to assess environmental knowledge, risk perception, environmental attitude, and pro-environmental behavior. The following facts are revealed via structural equation modeling (SEM):Environmental risk perception ($\beta = 0.084$, $p < 0.001$) and environmental attitude ($\beta = -0.062$, $p < 0.001$) fully mediated the relationship between environmental knowledge and pro-environmental behavior. In addition, a significant chain-mediating effect was observed: environmental knowledge influences risk perception, which in turn shapes environmental attitude, ultimately leading to pro-environmental behavior ($\beta = 0.048$, $p < 0.001$).The findings indicate that environmental knowledge alone is insufficient to drive behavioral change; it is crucial to simultaneously strengthen risk perception and cultivate positive environmental attitudes. The "knowledge–perception–attitude–behavior" intervention framework proposed in this study offers empirical evidence for environmental education in universities in developing countries and has significant practical implications for advancing the SDGs.

Keywords: SDGs; environmental knowledge; environmental risk perception; environmental attitude; pro-environmental behavior

1. Introduction

Environmental education is a fundamental tool for achieving the sustainable development goal (SDG

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4.7), with environmental knowledge serving as a catalyst that facilitates the conversion of environmental concern into pro-environmental behavior[1]. However, knowledge alone does not necessarily lead to behavior change[2]. According to the protection motivation theory (PMT), risk perception and attitude are crucial factors in driving behavior change[3,4]. Environmental risk perception is vital in shaping both environmental attitudes and pro-environmental behavior[5]. It involves assessing potential negative consequences influenced by cognitive awareness, with the evaluation determining behavioral tendencies[6]. While environmental risk perception is a key driver of pro-environmental behavior[7], its influence on behavior change hinges primarily on intention or willingness[8]. Environmental knowledge can shape individuals' attitudes and intentions[9], and students with a stronger environmental knowledge base tend to demonstrate more positive attitudes toward nature and its conservation[10]. In the link between environmental attitudes and pro-environmental behavior, willingness plays a critical role[2]. Positive environmental attitudes enhance the willingness to engage in pro-environmental behaviors, thereby fostering environmental protection[11].

SDG 4.7 highlights the important role of environmental education in fostering sustainable behavior, yet existing research has primarily focused on Western countries[9]. As the nation with the largest higher education system in the world, the patterns of environmental behavior among university students in China significantly impact the achievement of SDG 12. However, research on this subject in Guangxi, a region characterized by rapid urbanization and karst landscape degradation, remains limited. To address this gap, we focus on university students in Guangxi and propose an intervention framework of "knowledge-contextual experience-behavior" for education by validating the chain-mediating effect of risk perception and attitude. This framework aims to transform abstract environmental knowledge into concrete behavioral motivation. Furthermore, the study fills a research gap on the environmental behavior in universities for developing countries and provides empirical evidence to support regional sustainable development.

2. Literature review

2.1. Environmental knowledge and pro-environmental behavior

Environmental knowledge is an effective predictor of pro-environmental behavior. It is considered to play a key role in fostering such behavior by equipping individuals with the understanding needed to face environmental challenges[12]. According to Saripah et al. (2013) and Varela-Candamio et al. (2018), environmental knowledge can be internalized into learners' environmental awareness, motivations, interests, emotions, and values, which then guide their actions and contribute to the development of positive pro-environmental behaviors[13,14]. A higher level of environmental knowledge is associated with stronger environmental concern and a greater likelihood of adopting sustainable practices, such as supporting green urban development and participating in recycling efforts. Research exploring the emotional pathways from cognition to behavior through surveys of environmental behaviors has found that students who formulate concrete action plans tend to exhibit stronger attitudes, beliefs, emotional engagement, and willingness to take environmental action[15].

Cognition shapes behavioral attitudes, and specific behaviors tend to occur in specific contexts. Research indicates that the acquisition, analysis, and application of knowledge are critical in driving action. Accumulated knowledge significantly enhances an individual's ability to act[16]. The higher a person's level of environmental knowledge, the more accurately they can assess the severity and likelihood of environmental risks, enabling a more effective evaluation of the efficiency of potential responses[17]. This increased awareness is more likely to generate protective motivation, which in turn influences the intention or likelihood of engaging in pro-environmental behavior[18]. Once a shift in protective attitudes occurs, it can

further stimulate the adoption of protective actions. Based on this reasoning, the present study proposes the following hypothesis:

H1: Environmental knowledge significantly influences pro-environmental behavior among university students in Southwest Guangxi, China.

2.2. Environmental knowledge and environmental attitudes

Environmental knowledge reflects individuals' level of understanding of the environment. Students with substantial environmental knowledge are more likely to display environmentally friendly attitudes and engage in responsible behaviors related to paper use, recycling, and energy consumption[19]. As students' environmental knowledge increases, so does the likelihood of developing positive attitudes—those with a deeper understanding of topics such as the biodiversity of large benthic organisms tend to show stronger support for river conservation[20]. Research has also shown that students who are exposed to environmental education or are more informed about environmental issues generally possess richer environmental knowledge and stronger pro-environmental attitudes. Greater environmental knowledge enhances students' sensitivity to environmental problems and strengthens their attitudes to addressing them. A significant correlation exists between students' environmental knowledge and their environmental attitudes, i.e., students with higher levels of environmental knowledge tend to hold more positive attitudes toward the environment and exhibit greater concern for environmental issues[21].

As individuals' environmental knowledge increases, their environmental attitudes tend to shift in a more positive direction. Both knowledge and attitude act as key catalysts for fostering green behavior. Within the framework of PMT, attitude plays a critical role and is defined as "an individual's favorable or unfavorable evaluation of a specific behavior." Higher environmental knowledge promotes the shift in environmental attitudes. The depth of understanding and mastery of environmental knowledge influences awareness of environmental issues, which in turn shapes emotional responses and attitudes toward the environment. Since attitudes are rooted in cognition, a well-informed understanding enables more accurate evaluation, thereby leading to more favorable attitudes. Students with strong environmental knowledge are more likely to exhibit supportive attitudes toward nature and environmental protection. Moreover, the level of environmental knowledge affects how individuals assess environmental risks, shapes the formation of protective expectations, and influences judgments about the effectiveness of responses, all of which contribute to the development of protective motivation, the driving force behind behavioral intention. Based on this analysis and PMT, the following hypothesis is proposed:

H2: Environmental knowledge significantly influences environmental attitudes among university students in southwestern Guangxi, China.

2.3. Environmental risk perception and pro-environmental behavior

Environmental risk perception is a key prerequisite for individuals to choose and engage in pro-environmental behavior. The stronger young people's perception of environmental risks, the more likely they are to adopt environmentally friendly practices. Both environmental knowledge and environmental risk perception are critical factors behind pro-environmental behaviors among the youth. Many scholars agree that environmental risk perception has a promoting effect on pro-environmental behavior, i.e., higher levels of perceived risk tend to increase environmental concern and enhance individuals' willingness to take environmentally friendly actions. Zhou and Tang (2017) found that individuals' perceived risk regarding environmental issues positively influences the likelihood of engaging in pro-environmental behavior. Wang (2019) also observed that environmental risk perception significantly promotes the public's selection of environmentally friendly behaviors: A stronger perception of general environmental risks is associated with

more frequent pro-environmental behavior; a heightened perception of pollution-related risks similarly leads to more frequent pro-environmental actions; and a stronger awareness of technology-related environmental risks also corresponds to an increase in pro-environmental behavior. Zhang and Jiang (2016) reported that risk perception among pig farmers significantly influenced their adoption of environmentally friendly behaviors. Gao and Zheng (2020) identified a perception–behavior gap between environmental risk perception and pro-environmental behavior, with this discrepancy closely related to individuals' environmental knowledge. According to PMT, behavior is influenced by perceived risk, behavioral intention, and attitude. Perception refers to how individuals recognize and assess environmental problems, while intention reflects their motivation to act. Based on this analysis and the PMT framework, the following hypothesis is proposed:

H3: Environmental risk perception significantly influences pro-environmental behavior among university students in southwestern Guangxi, China.

2.4. Environmental knowledge, environmental risk perception, and pro-environmental behavior

Environmental knowledge refers to an understanding of environmental issues and related risks, enabling individuals to assess specific environmental problems[12]. Without awareness of environmental issues, individuals are unlikely to consciously care about them[13]. It is believed that environmental knowledge can potentially lead to pro-environmental behavior, as it better prepares individuals to address environmental challenges[14]. Environmental knowledge becomes internalized as environmental awareness, motivation, interests, emotions, and values, which then guide actions and foster positive pro-environmental behavior[15]. The higher the level of environmental knowledge an individual has, the stronger their environmental concern and the greater the likelihood of engaging in pro-environmental behavior[2].

Environmental knowledge is also a key factor influencing risk perception. A lack of sufficient or appropriate knowledge can hinder one's ability to develop a rational attitude and perception of risk, with lower knowledge levels often leading to misconceptions about risks[16]. Environmental knowledge influences how individuals perceive and emotionally respond to environmental issues, thereby affecting their perception of environmental risks[17]. People's perception and assessment of environmental risks are grounded in their understanding and awareness[18]. When individuals recognize the severity of harm caused by environmental pollution, it prompts them to care more about the environment and take pro-environmental behavior[17]. As environmental knowledge increases, individuals become more concerned about the environment, and this concern motivates them to learn more about environmental issues, leading to a better understanding of the associated risks and fostering pro-environmental behavior.

Environmental risk perception is a key prerequisite for individuals to engage in pro-environmental behaviors. Both environmental knowledge and risk perception are critical factors in promoting pro-environmental behavior, particularly among young people[19]. Moreover, environmental risk perception significantly influences the choice of pro-environmental behavior by the public[20]. Gao and Zheng[21] identified a gap between environmental risk perception and pro-environmental behavior, which is linked to the environmental knowledge of individuals. Environmental risk perception acts as a mediator between environmental knowledge and sustainable consumption behavior, triggering emotional responses to environmental conditions and their degradation[22]. It also mediates the relationship between media usage and pro-environmental behavior, with the perceived severity of environmental risks positively influencing the adoption of pro-environmental behavior[23]. Dong et al.[24] found that climate risk perception plays a mediating role in cognitive reappraisal and willingness to act, with risk cognition closely connected to

attitudes, behaviors, and knowledge. Thus, environmental risk perception can also be discussed as a mediator. According to PMT, the cognitive level of individuals affects their assessment of risk severity, the likelihood of risk occurrence, and their response, with the resulting assessment leading to changes in attitudes and behaviors[3]. Based on this analysis and in conjunction with PMT, this study proposes the following hypothesis:

H4: Environmental risk perception among university students mediates the relationship between environmental knowledge and pro-environmental behavior.

2.5. Environmental knowledge, environmental attitude, and pro-environmental behavior

Environmental knowledge reflects the extent to which people understand the environment. Students with higher levels of environmental knowledge tend to exhibit more environmentally friendly attitudes and responsible behaviors[25]. As students' environmental knowledge increases, it fosters stronger positive attitudes, with greater awareness of environmental protection leading to more pronounced protective attitudes[26]. Enhancing students' environmental attitudes to improve their environmental behavior is closely associated with environmental education[27]. Students with higher levels of environmental knowledge are more likely to demonstrate positive attitudes and increased concern for the environment[28]. As people's environmental knowledge grows, their environmental attitudes shift positively, with both knowledge and attitude serving as key drivers of green behavior[29].

Fostering an environmentally friendly attitude can, to a certain extent, encourage pro-environmental behavior[30]. Individuals with a strong environmental attitude are more likely to engage in pro-environmental behavior[11]. The more environmental knowledge students possess, the clearer their environmental attitudes become, and the more evident their pro-environmental behaviors are[31]. Environmental attitudes influence pro-environmental behavior through individuals' awareness of consequences and a sense of personal responsibility for their actions[32]. Attitudes serve as the driving force behind behavior, with environmental attitudes manifesting through actions that promote environmental protection. People exhibiting pro-environmental behaviors typically display stronger attitudes toward environmental protection[33].

Environmental attitude refers to people's beliefs, influences, and behavioral intentions regarding environmental issues or activities[34]. Cultivating an environmentally conscious attitude can, to some extent, promote pro-environmental behaviors[30]. People with a positive environmental attitude are more likely to engage in pro-environmental behaviors that benefit the environment in their daily lives. A temporal cross-lag effect exists between pro-environmental behavior and environmental attitude, which may be related to the widespread attention to environmental attitudes within the new ecological paradigm[11]. Survey results indicate that individuals who engage in pro-environmental behaviors tend to have stronger attitudes toward environmental protection. That is, attitude serves as the motivation for behavior[33]. Students with positive values, attitudes, and beliefs tend to score higher in their willingness to undertake pro-environmental behaviors[2]. In his study of green purchasing behavior, Wang[20] demonstrated that environmental attitudes mediate the relationship between environmental values and green purchasing behavior, with green purchasing seen as a pro-environmental behavior. In PMT, cognitive evaluation mediates the assessment of risk, influencing the formation of protection motivation, which in turn drives changes in environmental attitudes and leads to corresponding behavioral intentions[3]. Based on this analysis and PMT, the following hypothesis is proposed:

H5: Environmental attitude mediates the relationship between environmental knowledge and pro-environmental behavior among university students.

2.6. The chain-mediating effect of environmental risk perception and environmental attitude

Risk perception refers to the cognitive process involved in evaluating the outcomes of activities, including the collection, interpretation, and assessment of information regarding the uncertain impacts of events[34]. Protection Motivation Theory, based on a protective perspective, suggests that the components of risk and the evaluation of these risks generate protective motivation, which then influences protective attitudes[3]. Environmental attitude reflects people's concern for the environment and is an emotional experience; environmental emotions can act as a significant mediator in influencing how environmental cognition affects pro-environmental behavior[36].

In PMT, when individuals perceive a threat and recognize that effective actions can be taken, they believe they are capable of implementing actions that can positively influence the situation[3]. The motivation to engage in pro-environmental behavior stems from people's evaluation of environmental threats and their assessment of the effectiveness of coping behaviors[11]. Environmental risk perception can influence pro-environmental behavior through the mediating effect of environmental emotions (i.e., environmental attitude). When individuals are able to effectively assess their response efficacy and perceive that they can take actions to mitigate environmental issues, they develop positive attitudes, which in turn enhances pro-environmental behavior[3]. People's perception of environmental risks is reflected in their attitudes and behaviors. When individuals perceive environmental issues as posing significant risks and costs, they are more likely to pay attention to environmental changes, leading to pro-environmental behavior[37]. The impact of risk perception on behavior change is primarily based on willingness or attitude[8]. Therefore, environmental knowledge may influence pro-environmental behavior through the mediating roles of environmental risk perception and environmental attitude. Based on this, the following hypothesis is proposed:

H6: Environmental risk perception and environmental attitude have a chain-mediating effect on the relationship between environmental knowledge and pro-environmental behavior among university students.

3. Research methods

3.1. Research model

Based on the literature review above and PMT, this study explores the impact of environmental knowledge on pro-environmental behavior among university students, with environmental risk perception and environmental attitude as mediating variables. The research model is shown in **Figure 1**

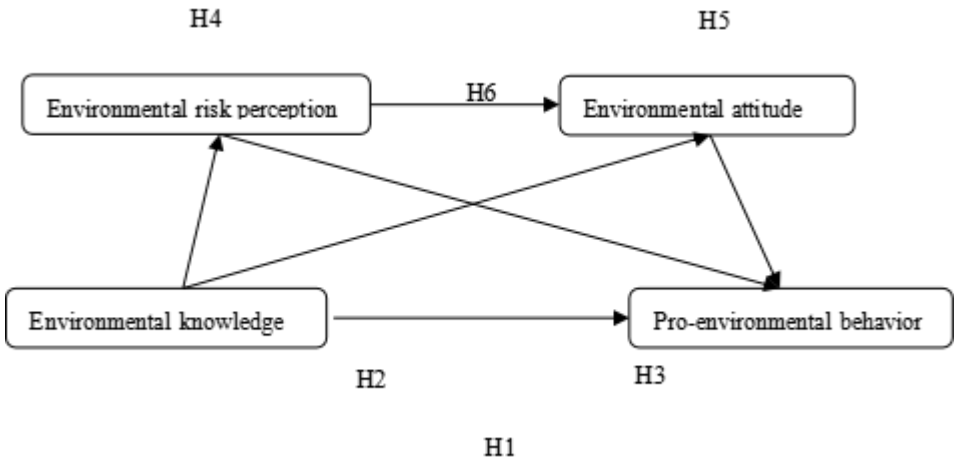

Figure 1. Research model.

3.2. Research participants

This study targeted university students in Guangxi, China, drawing participants from comprehensive universities, ethnic universities, teacher training institutions, and vocational colleges. Data were collected using a questionnaire survey through convenience sampling. A total of 850 questionnaires were distributed and returned, with 812 deemed valid, yielding an effective response rate of 95.53%. Among the participants, 228 were male (28.08%) and 584 were female (71.92%). In terms of academic discipline, 333 students (41.01%) were from the humanities, while 479 students (58.99%) were from science-related fields.

3.3. Research instruments

3.3.1. The scale of environmental knowledge

This study used the environmental knowledge scale developed by Carmi et al.[38] to assess the environmental knowledge of university students in China. The scale includes 11 items, each requiring a response of "true," "false," or "don't know." A correct response is scored as 1 point, while items based on false statements are reverse-coded. The "don't know" option is scored as 0. The total score, ranging from 0 to 11, reflects the student's environmental knowledge level. In this study, the scale demonstrated good internal consistency, with a Cronbach's α of 0.766.

3.3.2. The scale of environmental risk perception

This study employed the scale of environmental risk perception developed by Wang and Wang[39], which includes four dimensions: facts, causes, consequences, and behavioral responses. The scale consists of 13 items rated on a 5-point Likert scale. In this study, Cronbach's α for the four subscales and the overall scale ranged from 0.817 to 0.931, all exceeding the accepted threshold of 0.700, indicating strong internal consistency. Confirmatory factor analysis showed good model fit, with absolute fit indices of $\chi^2/df = 4.236$, GFI = 0.953, RMR = 0.024, SRMR = 0.031, and RMSEA = 0.063. Incremental fit indices, including RFI, CFI, NFI, IFI, and TLI, ranged from 0.968 to 0.982, thus confirming the strong reliability and validity of the scale.

3.3.3. The scale of environmental attitude

This study employed the New Ecological Paradigm Scale developed by Dunlap et al.[40] to assess environmental attitudes. The scale consists of five dimensions and 15 items, using a 5-point Likert scale for responses. The Cronbach's α for the five dimensions and the overall scale ranged from 0.813 to 0.959, and all exceeded 0.700, indicating good internal consistency. Confirmatory factor analysis demonstrated strong model fit, with absolute fit indices of $\chi^2/df = 2.480$, GFI = 0.969, RMR = 0.040, SRMR = 0.042, and RMSEA = 0.042. Incremental fit indices, including RFI, CFI, NFI, IFI, and TLI, ranged from 0.976 to 0.989, thus confirming confirming the strong reliability and validity of the scale.

3.3.4. The scale of pro-environmental behavior

This study employed the Environmental Behavior Scale developed by Carmi et al.[38], which focuses on items related to students' lifestyles and reflects varying levels of environmental commitment. The scale consists of six items, rated on a 5-point Likert scale ranging from 1 (never) to 5 (always). The Cronbach's α for the environmental behavior scale in this study was 0.845, which is above 0.700. Confirmatory factor analysis showed good model fit, with absolute fit indices of $\chi^2/df = 4.785$, GFI = 0.990, RMR = 0.025, SRMR = 0.025, and RMSEA = 0.068. Incremental fit indices, including RFI, CFI, NFI, IFI, and TLI, ranged from 0.970 to 0.992, thus confirming the strong reliability and validity of the scale.

4. Empirical analysis

4.1. Descriptive statistics of the sample

The distribution of background variables, including gender, academic year, and major, is shown in **Table 1**. Of the respondents, 228 were male (28.079%) and 584 were female (71.921%). In terms of the academic year, 319 were freshmen (39.286%), 167 were sophomores (20.567%), 195 were juniors (24.015%), and 131 were seniors (16.133%). As for majors, 479 students (58.990%) were from science-related fields, while 333 students (41.010%) were from humanities. Overall, the sample distribution reflects the general demographic characteristics of university students in southwestern Guangxi.

Table 1. Statistics of sample distribution.

Variable	Category	Number	Percentage (%)
Gender	Male	228	28.079
	Female	584	71.921
Academic year	Freshman	319	39.286
	Sophomore	167	20.567
	Junior	195	24.015
	Senior	131	16.133
Major	Science	479	58.990
	Humanities	333	41.010

4.2. Reliability and validity analysis of variables

Based on the questionnaire data, the reliability and validity analyses were conducted to evaluate the reliability of the scales and the construct validity of the model. As shown in **Table 2**, the Cronbach's α for the scales measuring environmental knowledge, environmental risk perception, environmental attitude, and pro-environmental behavior were 0.766, 0.927, 0.834, and 0.845, respectively, all exceeding the recommended threshold of 0.700. This indicates that the scales possess good stability and internal consistency. The values of composite reliability (CR) for the four constructs ranged from 0.864 to 0.978, all above the standard value of 0.6. The average variance extracted (AVE) ranged from 0.502 to 0.755, all above the accepted minimum of 0.500 (Khan et al., 2021), suggesting that the constructs exhibit strong convergent validity.

The overall fit indices of the model were as follows: $\chi^2/df = 3.608$; GFI = 0.915; RMR = 0.039; SRMR = 0.073; RMSEA = 0.057. Incremental fit indices were RFI = 0.869, CFI = 0.917, NFI = 0.889, IFI = 0.918, and TLI = 0.902. These results indicate that the model fits the data well, and the alignment between the theoretical model and the observed data is acceptable

Table 2. Reliability and validity analysis of variables.

Construct	Cronbach's α (>0.7)	CR (>0.6)	AVE (>0.5)
Environmental knowledge	0.766	0.917	0.502
Environmental risk perception	0.927	0.976	0.755
Environmental attitude	0.834	0.978	0.747
Pro-environmental behavior	0.845	0.864	0.519

4.3. Correlation analysis of variables

The results of the correlation analysis are presented in **Table 3**. A significant positive correlation was observed between environmental knowledge and environmental risk perception ($r = 0.246$, $p < 0.001$). A significant positive correlation also exists between environmental knowledge and pro-environmental behavior ($r = 0.084$, $p < 0.05$). Environmental risk perception is significantly positively correlated with environmental attitude ($r = 0.420$, $p < 0.001$). There is a significant positive correlation between environmental risk perception and pro-environmental behavior ($r = 0.525$, $p < 0.001$). Additionally, environmental attitude is significantly positively correlated with pro-environmental behavior ($r = 0.571$, $p < 0.001$). The correlation coefficients among environmental knowledge, environmental risk perception, environmental attitude, and pro-environmental behavior range from 0.032 to 0.571, indicating moderate to low correlations. Therefore, no issues of multicollinearity were identified.

Table 3. Correlation analysis of variables.

Variable	Environmental knowledge	Environmental risk perception	Environmental attitude	Pro-environmental behavior
Environmental knowledge	1			
Environmental risk perception	0.246***	1		
Environmental attitude	-0.032	0.420***	1	
Pro-environmental behavior	0.084*	0.525***	0.571***	1

4.4. Regression analysis

In Model 1, with environmental knowledge as the independent variable and pro-environmental behavior as the dependent variable, a linear relationship between variables was appropriate ($F = 5.816$, $p < 0.05$), and environmental knowledge had a significant positive effect on pro-environmental behavior ($\beta = 0.084$, $p < 0.05$). In Model 2, where environmental knowledge was the independent variable and environmental risk perception the dependent variable, the linear model was also appropriate ($F = 52.348$, $p < 0.001$), showing a significant positive effect of environmental knowledge on environmental risk perception ($\beta = 0.246$, $p < 0.001$). Model 3, with environmental knowledge and environmental risk perception as independent variables and environmental attitude as the dependent variable, also supported a linear relationship ($F = 98.795$, $p < 0.001$), showing that environmental knowledge had a significant negative effect on environmental attitude ($\beta = -0.144$, $p < 0.001$), while environmental risk perception had a significant positive effect ($\beta = 0.456$, $p < 0.001$). In Model 4, where environmental knowledge, environmental risk perception, and environmental attitude were the independent variables and pro-environmental behavior the dependent variable, the linear model remained appropriate ($F = 198.835$, $p < 0.001$). In this model, environmental knowledge no longer had a significant effect on pro-environmental behavior ($\beta = 0.014$, $p > 0.05$), whereas both environmental risk perception ($\beta = 0.341$, $p < 0.001$) and environmental attitude ($\beta = 0.428$, $p < 0.001$) continued to exhibit significant positive effects.

Table 4. Hierarchical regression.

Variable	Model 1 Pro-environmental behavior	Model 2 Environmental risk perception	Model 3 Environmental attitude	Model 4 Pro-environmental behavior
Environmental knowledge	0.084*	0.246***	-0.144***	0.014
Environmental risk perception			0.456***	0.341***

Variable	Model 1 Pro-environmental behavior	Model 2 Environmental risk perception	Model 3 Environmental attitude	Model 4 Pro-environmental behavior
Environmental attitude				0.428***
F value	5.816*	52.348***	98.795***	198.835***
R^2	0.007	0.061	0.196	0.425
Adj-R^2	0.006	0.060	0.194	0.423

Table 2. (*Continued*)

**p <0.050; ***p <0.001.*

4.5. Mediation analysis

As shown in Tab. 5, the total effect of environmental knowledge on pro-environmental behavior was 0.085, with a 95% confidence interval of [0.016, 0.153], indicating a significant total effect. The direct effect was 0.014, with a 95% confidence interval of [-0.041, 0.069], which includes zero, indicating that the direct effect was not significant. The mediating effect of environmental risk perception was 0.084, with a 95% confidence interval of [0.056, 0.115], indicating a significant mediating effect and supporting Hypothesis H1. The mediating effect of environmental attitude was 0.062, with a 95% confidence interval of [-0.090, -0.033], indicating a significant mediating effect and supporting Hypothesis H2. The chain-mediation effect through environmental risk perception and environmental attitude was 0.048, with a 95% confidence interval of [0.032, 0.067], indicating a significant chain mediation effect and supporting Hypothesis H3. These results suggest that environmental knowledge can influence pro-environmental behavior through environmental risk perception and/or environmental attitude and that environmental risk perception can shape the influence of environmental attitude on pro-environmental behavior.

Table 5. Analysis of direct and indirect effects.

Type of effect	Effect estimate	SE	95% CI
Environmental knowledge→environmental risk perception→pro-environmental behavior	0.084	0.015	[0.056, 0.115]
Environmental knowledge→environmental attitude→pro-environmental behavior	-0.062	0.015	[-0.090, -0.033]
Environmental knowledge→environmental risk perception→environmental attitude→pro-environmental behavior	0.048	0.009	[0.032, 0.067]
Environmental knowledge→pro-environmental behavior	0.014	0.028	[-0.041, 0.069]
Total effect	0.085	0.035	[0.016, 0.153]

5. Discussion and conclusion

5.1. Discussion

Environmental knowledge facilitates translating individuals' concerns about environmental issues into concrete actions to protect the environment. The higher the level of environmental knowledge, the more likely individuals are to engage in pro-environmental behaviors[39]. Such knowledge deepens understanding of environmental problems, which in turn shapes emotional responses and attitudes toward the environment, ultimately motivating pro-environmental actions. It fosters greater awareness, more positive attitudes, and a stronger sense of responsibility[33]. Generally, individuals with limited knowledge of environmental issues are less likely to care about the environment or adopt environmentally friendly behaviors. Environmental knowledge is considered one of the most effective predictors of pro-environmental behavior[40]. According to

PMT, changes in attitude are driven by the level of protective motivation elicited through cognitive appraisal. However, Liu et al. (2020) found that environmental knowledge does not directly affect pro-environmental behavior, but instead, it serves as an important distal factor whose influence is fully mediated by environmental attitudes and behavioral intentions[52]. This study finds that among university students in Southwest Guangxi, China, environmental knowledge has a significant positive impact on pro-environmental behavior. Moreover, this effect is fully mediated by environmental risk perception and environmental attitude, aligning with existing research. In other words, higher levels of environmental knowledge among university students are associated with more significant pro-environmental behaviors.

Individuals' understanding of environmental issues is reflected in their environmental knowledge. Those with greater environmental knowledge tend to exhibit more pro-environmental attitudes. Attitudes are built upon cognition, i.e., only with sufficient understanding can individuals make informed evaluations that lead to the formation of positive attitudes. Students who are more informed about environmental issues generally possess richer environmental knowledge and stronger environmental attitudes. Environmental knowledge and attitude together constitute essential components of students' environmental literacy. Enhancing students' environmental attitudes to improve their environmental behavior cannot be achieved without proper environmental education. Within the framework of PMT, environmental knowledge influences individuals' risk perception, shapes their expectations of protection, and affects how they judge the effectiveness of coping responses, thereby influencing their intentions to protective behavior. Moreover, Choe et al. (2019) indicate a significant positive correlation between students' environmental knowledge and their environmental attitudes[36]. Students with higher levels of environmental knowledge tend to demonstrate more positive attitudes and a greater degree of concern for environmental issues. However, findings from this study reveal a significant negative association between environmental knowledge and environmental attitude among university students in Southwest Guangxi, China. In contrast to existing research, the results suggest that the higher the students' environmental knowledge, the less evident their environmental attitudes. This indicates that environmental knowledge alone does not determine environmental attitudes.

The impact of risk perception on behavioral change is primarily based on individuals' willingness or attitudes. According to PMT, the components of risk and individuals' evaluation of those risks generate protective motivation, which subsequently shapes protective attitudes. People with a positive attitude are more likely to believe that environmental improvement results from their own pro-environmental behaviors. In addition, Chu (2020) found that environmental risk perception can influence pro-environmental behavior indirectly through the mediating role of environmental attitude[46]. The findings reveal that among university students in Southwest Guangxi, China, environmental risk perception has a significant positive effect on environmental attitude. This result is consistent with existing research, suggesting that the more accurately students perceive and assess environmental risks, the stronger their concern for environmental issues and their commitment to environmental protection.

Environmental risk perception among university students serves as a full mediator between environmental knowledge and pro-environmental behavior, consistent with the findings of Dong et al.[41], which also demonstrated the mediating role of risk perception. This indicates that increased environmental knowledge enhances students' ability to perceive environmental risks, thus promoting pro-environmental behaviors. Likewise, environmental attitude also acts as a full mediator in this relationship, as supported by Liu et al.[42] found that environmental attitude plays a mediating role. The mediation effects in this study suggest that while university students may possess extensive environmental knowledge, without a corresponding attitude toward environmental protection, they may not necessarily engage in pro-environmental behaviors. This finding further supports the conclusion of Torsney and Matewos[2] that

individuals may have broad environmental knowledge, but without the intention to protect the environment, such knowledge does not automatically translate into action.

5.1. Conclusion

Furthermore, this study reveals a significant chain-mediating effect in which environmental risk perception and environmental attitude sequentially mediate the relationship between environmental knowledge and pro-environmental behavior. The positive chain-mediating effect suggests that enhanced environmental knowledge, when coupled with the ability to perceive environmental risks, can strengthen environmental attitudes and ultimately lead to more pro-environmental behavior—an important and interesting finding. These results reinforce the idea that improving environmental knowledge enhances students' capacity to evaluate and respond to environmental risks[18], fosters positive environmental attitudes, and stimulates the motivation to engage in environmentally responsible behavior[28]. This pathway, from knowledge to risk perception, to attitude, and to behavior, offers an effective framework for environmental behavior interventions among university students. It also presents a low-cost strategy to support the implementation of SDG 13 in China. Universities in Guangxi can design contextualized curricula based on local ecological issues to enhance the students' perception of risk and trigger environmentally responsible actions. This finding may also serve as a valuable reference for some of the developing countries in Southeast Asia facing similar situations.

The results of this study further confirm that both environmental risk perception and environmental attitude significantly influence students' environmental behavior. Therefore, in addition to fostering environmental knowledge, universities and environmental protection agencies must focus on enhancing students' ability to perceive environmental risks[10]. Without improving students' capacity to assess the risks associated with environmental issues or fostering positive environmental attitudes, environmental knowledge alone may raise awareness of existing problems but will not necessarily inspire a commitment to environmental protection, thereby failing to lead to pro-environmental behaviors. Environmental attitudes and pro-environmental behavior also exhibit a cross-lagged effect[11], meaning that improving students' risk assessment abilities and helping them understand the potential harm of environmental issues is essential to triggering positive environmental attitudes and a willingness to act, ultimately leading to pro-environmental actions. The model in this study also reveals that environmental risk perception plays a crucial role in shaping pro-environmental behavior, acting not only as a full mediator between environmental knowledge and behavior but also as a key factor driving the formation of a positive environmental attitude.

Based on the research findings, we recommend that Chinese universities enhance their environmental education by developing localized teaching modules that address regional environmental issues and strengthen risk perception abilities among students. In addition, establishing a behavior feedback system of "green campus" (such as a waste sorting point system) can help convert environmental attitudes into habitual actions. These cost-effective measures can also be applied in other resource-constrained developing regions, supporting the achievement of SDG 12.8 across the globe.

6. Limitations of the study

This study has several limitations. First, the sample is drawn exclusively from university students in Southwest Guangxi, China, which may limit the generalizability of the findings to other cultural backgrounds or rural populations. Second, the data on pro-environmental behavior are based on self-reported measures. Although validated scales were used, the results may still be affected by self-reporting bias. Future

research should consider incorporating more diverse samples, objective behavioral indicators, and longitudinal tracking to more accurately capture the internalization of environmental knowledge over time.

7. Future research directions

Future longitudinal studies should overcome regional limitations by selecting 3 to 5 representative cities for comparative analysis. From a contextual perspective, future research could explore how knowledge enhancement moderates the relationship between environmental knowledge and behavior, as well as examine the influence of family socioeconomic status on the formation of pro-environmental behavior.

Author contributions

Data curation, writing-original draft preparation, Honglan Yang; Supervision, Yuan-cheng Chang; Project administration, Kexuan Zhu. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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