Exploring Youth Understanding of Climate Change and Optimizing Educational Approaches in China

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Climate change education plays a crucial role in addressing the escalating risks of climate change. This study aims to comprehensively assess the level of youth knowledge on climate change, their risk perception, and their response measures. Based on an analysis of relevant articles from major Chinese and English literature databases between 2014 and 2023, a youth cognition survey scale was developed, encompassing three target variables, seven dimensions, and 62 items. A questionnaire survey was also conducted among students aged 15-20 from two high schools and four universities in Zhengzhou. The results of the literature analysis on keywords related to climate change indicate the primary keywords included “Human Activity” “Carbon Cycle” “Ecosystem” “Global Warming”. Statistical analysis revealed that the scores for all seven dimensions and 62 items exceeded 4, demonstrating a good overall understanding among the youth in terms of climate change knowledge, risk perception, and response measures. The Network and SEM analysis findings indicate that knowledge of climate change enhances both risk awareness and response measures, with risk perception directly fostering proactive strategies. Based on these findings, the study proposes three specific recommendations: integrating climate change education with core subjects, adopting innovative teaching methods, promoting practical engagement and community projects, and policy implications and collaboration with stakeholders. These strategies aim to effectively enhance youth’s climate change awareness and translate it into practical actions.

Introduction

The global community today faces the unprecedented challenge of climate change. The 2023 Emissions Gap Report, titled "Record-breaking Temperatures Set New Records, but the World Fails to Reduce Emissions (Again),"highlights that the continuous increase in greenhouse gas emissions has led to rising temperatures and significantly intensified climate impacts[1]. Unless countries escalate their actions and exceed their current commitments, the world will face a temperature increase far greater than the target set by the Paris Agreement[2]. The effects of global warming are evident, with extreme climate events such as heatwaves, heavy rainfall, floods, droughts, and rapidly intensifying tropical cyclones occurring frequently and causing increasingly severe damage[3].

Climate change is a complex and urgent global issue that demands sustained, coordinated efforts across multiple sectors[4]. Recognizing this, the Organization for Economic Cooperation and Development (OECD) has called for greater attention to the critical role young people play in climate change governance, emphasizing the importance of education in fostering environmental awareness among youth[5]. Research increasingly highlights the influence of factors such as education, socioeconomic background, and media exposure on young people’s climate knowledge and engagement[6], demonstrating that targeted educational programs can significantly enhance climate literacy and inspire action[7].

Climate change education enhances students’ climate literacy by imparting knowledge, cultivating interdisciplinary thinking and adaptability, and guiding them to effectively respond to climate change and environmental damage. Youth engagement in climate issues involves progressing from awareness to understanding climate science and taking pro-environmental actions, which are essential for nurturing environmental stewardship and informing future policy development8[8].

This study, therefore, centers on examining climate change cognition among youth by developing a climate awareness scale and conducting research in selected high schools and universities in Zhengzhou City, Henan Province, China. The study, using online and offline questionnaires and structured interviews, aimed to assess young people’s climate knowledge and risk awareness, analyze variable correlations in climate cognition, and suggest ways to enhance climate education. The ultimate goal is to provide a reference for cultivating young people’s knowledge, sense of responsibility, and practical abilities in coping with climate change.

Literature review

Climate Change Cognition

Climate change cognition refers to the mental processes by which individuals understand the multifaceted issues surrounding climate change, including knowledge, risk perception and response measures. Central to this is knowledge, which encompasses factual and conceptual insights into greenhouse gases, carbon footprints, and global warming mechanisms[9]. Risk perception is also a critical component in climate change cognition, showing strong correlations with climate action[10]. Response measures, defined as youth engagement in mitigation or adaptation practices (e.g., energy conservation, recycling), reflect the connection between climate knowledge and tangible actions[11].

Understanding the psychological foundations of climate change cognition helps to identify the drivers and barriers to climate-conscious behaviors. Several theoretical frameworks inform this research, including the Theory of Planned Behavior (TPB)[12], Social Cognitive Theory (SCT)[13], Protection Motivation Theory (PMT)[14], and the Value-Belief-Norm Theory (VBN)[15]. These frameworks reveal how youth process climate information and the psychological drivers behind pro-environmental actions. Through these theoretical frameworks, researchers have built an understanding of how people process information about climate change and the factors that drive or hinder pro-environmental actions[16]. Addressing the cognitive, social, and emotional components of climate change cognition can foster more effective educational and policy interventions, ultimately promoting a more informed, engaged public capable of contributing to sustainable solutions.

Youth Engagement in Climate Change Education

Youth Engagement in Climate Change Education Understanding how youth perceive and engage with climate change is crucial for shaping effective educational strategies and fostering future environmental stewardship. Research shows that youth engagement in climate issues varies according to factors like education, cultural context, and socio-economic status. For instance, in a survey of American teenagers, only 25% displayed high climate literacy levels[17]. Empirical evidence suggests that government policies promoting climate education, community-driven environmental initiatives, and individual empowerment approaches collectively contribute to heightened youth awareness and pro-environmental actions[18]. For example, community-led clean-up events and recycling initiatives were linked to higher environmental awareness among local youth[19].

Some studies also have developed evaluation systems for college students' awareness of climate change[20], covering aspects such as "climate change knowledge,""awareness of the correlation between agriculture and climate change,"and "participation in coping with climate change."Other scholars have examined young people's knowledge of climate change, their behavioral measures, and their willingness to cope with climate change[21]. One significant aspect of study focuses on the cognitive and emotional responses of young individuals to climate change information. Studies were carried out to explore how cultural cognition influences perceptions of environmental risks, shedding light on the diverse ways youth interpret and respond to climate-related messages[22]. Moreover, research highlights that hope and optimism motivate youth to engage with environmental issues, showing that fostering a hopeful outlook enhances their environmental participation, emphasizing the need for positive narratives in climate education.[23]. Additionally, there is growing interest in examining the effectiveness of educational interventions aimed at enhancing climate literacy among youth[24]. These interventions often integrate scientific knowledge with practical actions, aiming to empower young individuals to contribute meaningfully to climate mitigation and adaptation efforts. Despite advances, most studies on climate cognition focus primarily on university students, with fewer addressing younger age groups[25]. Research has also shown that fostering hope and optimism through positive narratives significantly increases youth engagement with climate issues, demonstrating the importance of emotionally resonant education[26].

Developing Inclusive and Action-Oriented Climate Education for Youth

Current research on youth understanding of climate change underscores the complexity of cognitive, emotional, and socio-economic factors influencing their perceptions and responses. Moving forward, addressing these insights will be crucial for developing inclusive and effective educational strategies that empower young people to become informed and proactive agents of environmental change. Research increasingly supports experiential learning methods like project-based activities, community involvement, and interactive digital platforms as effective ways to engage youth and enhance long-term climate literacy26. These approaches are particularly relevant in China, where traditional lecture-based formats may hinder critical thinking and student engagement[27]. Chinese students often show high awareness of environmental issues but lack the depth of understanding needed for effective climate action[28].

Comprehensive climate education must integrate knowledge dissemination, emotional engagement, and practical action to cultivate a generation of environmentally conscious and active individuals ready to tackle the challenges of climate change. However, these studies often focus on risk awareness related to climate change, overlooking young people's understanding of climate knowledge and failing to analyze coping strategies at policy, community, and individual levels. Therefore, it is necessary to deepen the investigation and research on young people's cognition of climate change, building on the results of international climate change studies.

Methods

Knowledge graph analysis

CNKI (China National Knowledge Infrastructure) is the world's largest continuously updated database of Chinese academic journals[29]. We utilized from the CNKI newspaper database, the Chinese Science and Technology Core Journal Database, and the Web of Science Core Collection, which is the world's leading citation database. Using the keyword "climate change", we retrieved 2,451, 7,036, and 297,534 documents from each source, respectively, covering a time span from 2014 to 2023. All documents were analyzed using CiteSpace[30].

Questionnaire Development

The questionnaire was developed based on existing theories of climate change cognition and education[31], as well as frameworks and indicator systems from similar studies on climate change awareness[32]. It covers three dimensions: Knowledge of Climate Change (A), Awareness of Climate Change Risks (B), and Awareness of Measures to Address Climate Change (C).

1. **Knowledge of Climate Change** (A) refers to the cognitive understanding of fundamental climate change concepts, causes, and phenomena. It includes understanding:
   - Knowledge of climate change related vocabulary (A1)
   - Understanding of climate change events (A2)
   - Understanding the causes of climate change (A3)
2. **Awareness of Climate Change Risks (B)** refers to the recognition and perception of the potential negative impacts of climate change on both a global and local scale. It includes understanding:
   - Understanding the impact of climate change on plants and animals (B1)
   - Understanding the impact of climate change on animal and human health (B2)
   - Perception of climate change risks (B3)
3. **Awareness of Measures to Address Climate Change (C)** refers to the knowledge and understanding of strategies and actions that can mitigate or adapt to the effects of climate change. It includes understanding:
   - Macro-level countermeasures (C1)
   - Community-level response measures (C2)
   - Individual-level response measures (C3)

The items included in each dimension are detailed in Table 1. For each item, a higher score indicates a greater alignment with the relevant knowledge design.

Reliability and Validity Testing of Questionnaire

The questionnaire underwent pilot testing with a sample of 30 students (not included in the final study sample) to check for clarity, relevance, and reliability of items. Experts in climate education reviewed the content to ensure its representativeness and relevance to the field. The experts assigned a Content Validity Index (CVI) score of 0.89, indicating a high level of agreement regarding the questionnaire's relevance to the subject matter33.Based on feedback, minor revisions were made to improve readability and reduce ambiguity. Cronbach's alpha was calculated for each section to evaluate the reliability and validity, with values above 0.70 indicating acceptable reliability[33].

Data Collection of Questionnaire

A stratified sampling method was applied to a combination of offline paper questionnaire interviews and online surveys (via QR code on Wenjuanxing)[34] among 15-20 age group. As individuals in this group are in a critical developmental phase where they form lasting beliefs, values, and environmental attitudes, making them particularly receptive to climate education[32]. Stratification was based on academic level (high school versus university) to account for variations in climate education exposure[35]. In selecting specific schools, two high schools and four universities in Zhengzhou were chosen based on their accessibility and willingness to participate. This sample size was also selected to achieve a reliable estimate of responses within the target population where a minimum of 300 respondents is generally considered adequate for generating statistically significant findings in a large population[33].

A total of 312 valid questionnaires were collected, comprising 82 paper questionnaires and 230 online questionnaires Among the respondents, 128 (41%) were male and 184 (59%) were female. The age distribution was as follows: 37 respondents were 15 years old (12%), 72 were 16 years old (23%), 69 were 17 years old (22%), 69 were 18 years old (22%), 34 were 19 years old (11%), and 31 were 20 years old (10%). This distribution aligns closely with the age range of the target research subjects.

Data Analysis

SPSS 28.0 was used for the initial descriptive and correlation analyses. JASP 0.18.3 was utilized to conduct network analysis[36], while plspm package[37] in R4.4.2 was introduced to conduct structural equation modeling (SEM) analysis, evaluating

Table 1 Adolescents' Climate Change Cognition Survey Scale and Its Descriptive Statistics

Dimensions	Question item	Average ±Standard Deviation	Dimensions	Question item	Average ±Standard Deviation
A1	Global Warming	6.81±1.06	B2	Very Big	6.01±1.39
	Greenhouse Effect	6.67±1.35		Larger	5.21±1.66
	Renewable Energy	4.89±2.87		General	3.61±1.74
	Paris Agreement	2.67±2.69		Smaller	2.79±1.74
	Fossil fuels	4.59±2.94		Very small	2.45±1.87
	Greenhouse Gases	5.96±2.27	B3	Extreme weather events increased by	6.05±1.12
	Carbon Emissions	5.71±2.46		Ocean acidification and its impact on fisheries	5.47±1.56
	Sea level rise	5.38±2.66		Glacier and Permafrost Melting	5.72±1.41
	Biodiversity	5.58±2.55		Increased frequency and intensity of forest fires	5.75±1.31
	Ecosystem	5.25±2.73		Species extinction caused by ecosystem imbalance	5.85±1.33
	Sustainable Development	5.58±2.55		Reduced crop yields and rising food prices	5.7±1.39
	Carbon Neutral	5.49±2.60	C1	Reduce fossil energy consumption	5.79±1.27
	Human Activities	4.62±2.94		Use new technologies to control greenhouse gas emissions	6.03±1.21
	Carbon Footprint	3.08±2.86		Planting trees to increase carbon dioxide absorption	5.85±1.32
	Extreme Weather	5.66±2.50		Recycling of waste	5.31±1.63
A2	Tsunami	3.74±1.84	C2	Save water	5.89±1.31
	Hurricane	3.74±1.73		Save electricity	6.02±1.12
	The Great Flood	5.75±1.32		Recycling and sorting waste	5.32±1.64
	Forest Fire	5.42±1.56		Reduce the use of disposable plastic products	5.53±1.53
	Extremely high temperature	5.77±1.46		Use public transportation or ride a bicycle more often	5.91±1.30
	Winter Storm	4.03±1.82		Purchase and use environmentally friendly products	5.66±1.46
A3	Fossil Fuel Combustion	5.65±1.226		Reduce meat consumption and increase plant-based diet	4.88±1.91
	Deforestation A3-2	5.53±1.22		Plant trees or participate in tree planting activities	5.60±1.50
	Industrial waste gas emissions A3-3	5.64±1.20		Participate in volunteer activities or organizations related to environmental protection	5.50±1.61
	Automobile exhaust	5.39±1.30	C3	Raise awareness and education on climate change	6.16±1.20
	Changes in Solar Activity	4.87±1.50		Promoting the adoption of renewable energy in schools and communities	6.05±1.27
B1	Very big	6.05±1.25		Participate in and support environmental policies and movements	5.98±1.27
	Larger	5.05±1.72		Choose sustainable consumption patterns	5.89±1.35
	General	3.62±1.80		Encourage family and friends to adopt environmentally friendly practices	5.94±1.29
	Smaller	2.92±1.83		Support and participate in the activities of environmental protection organizations	5.90±1.37
	Very small	2.50±1.89		Use energy-saving products and technologies	6.03±1.24

the hypothesized structural relationships between different dimensions related to climate change cognition.

• **Network analysis** Network analysis is a relatively new and promising method for modeling interactions between large numbers of variables. Unlike latent variable modeling, which aims to reduce the structure of variables to their shared information, network analysis estimates the relations between all variables directly. In this analysis, nodes are positioned using the Fruchterman-Reingold algorithm, which organizes the network based on the strength of connections between nodes. This algorithm employs pseudo-random numbers to determine node placement within the network structure[38].

The network analysis results were interpreted through three key metrics. Network density measured the overall connectivity among keywords, providing an overview of how interlinked the network elements were. Centrality identified the most influential keywords, representing the core themes within the network. This metric comprised three measures: Betweenness, which quantified the number of shortest paths passing through a node; Closeness, defined as the inverse of the total distance from a node to all other nodes, indicating its accessibility; and Strength, calculated as the sum of a node's absolute input weights. Cluster analysis revealed thematic groupings, facilitating a deeper examination of keyword relationships and underlying thematic structures. Key clusters were highlighted to explore the interconnections and focal points within climate change research.

• **Structural equation modelingSEManalysis**

Structural equation modeling (SEM) is beneficial for analyzing complex dependency relationships, combining factor analysis and path analysis to evaluate both observed and latent variables. PLS-SEM was chosen due to its predictive accuracy, offering more tolerance compared to Covariance-Based SEM (CB-SEM)[39]. Using PLS-SEM, we iterated the model 1,000 times to compute external loadings, weights, and path coefficients[40]. Variables with a Variance Inflation Factor (VIF) exceeding 4.0 were removed to avoid multicollinearity. We hypothesized relationships: Knowledge of Climate Change (A) impacts Awareness of Climate Change Risks (B), Knowledge of Climate Change (A) impacts Awareness of Measures to Address Climate Change (C), and Awareness of Climate Change Risks (B) impacts Awareness of Measures to Address Climate Change (C).

Path coefficients were estimated with the PLS algorithm, and their significance was assessed using bootstrapping with 1,000 samples[40]. Paths were deemed significant at $P<0.05$. To assess model fit, we evaluated indices including Goodness of Fit (GOF), Normed Fit Index (NFI), and Standardized Root Mean Square Residual (SRMR). A good model fit is indicated by a GOF above 0.36, NFI above 0.9, and SRMR below 0.1.

Results

Climate Change Knowledge Graph Analysis

The analysis of the climate change knowledge graph was conducted using CiteSpace to organize and analyze all keywords related to climate change. The network density of the CNKI Chinese Newspaper Database, Chinese Science and Technology Core Journal Database, and Web of Science Core Collection Database are 0.3841, 0.4221 and 0.5825, reflecting a more interconnected and established knowledge structure in climate change research. Keywords with frequencies 30 was analyzed for the CNKI Chinese Newspaper Database (Table 2). Keywords with over 100 mentions included "Paris Agreement" "United Nations" "global warming" "carbon neutrality", which are easily understood by the public.

The 10 most frequently appearing keywords related to climate change are listed as shown in Table 3. It can be seen that the number of related literatures in the Web of Science Core Collection Database is much higher than that in the Chinese Science and Technology Core Journal Database. Keywords include terms like "Human Activity" "Carbon Cycle" "Ecosystem" "Global Warming" with notable variations in publication volume across the two databases. For example, key words carbon cycle shows a high count in Web of Science (5335) compared to the Chinese database (85), whereas spatiotemporal changes have a more balanced presence across both (1693 in Web of Science and 571 in the Chinese database).

By examining the number of documents related to climate change from 2014 to 2023 (Fig. 1), it is clear that there has been a steady annual increase in climate-related research publications. Notably, there was a marked surge in document numbers between 2021 and 2023. In the Web of Science Core Collection Database and the Science and Technology Core Journal Database, document counts grew from 3,715 and 1,749 in 2014 to 9,861 and 2,242 in 2023, respectively.

The primary keywords associated with climate research have shifted from 2014 to 2023 (Fig.2). There was a notable increase in publications related to keywords like "Carbon Cycle" "Global Warming" "Environmental Monitoring" "Spatiotemporal Changes" in the English-language database. Meanwhile, in the Chinese database, document numbers associated with "Human Activity" "Spatiotemporal Changes" "Vegetation" saw significant growth. This trend reflects a heightened awareness of the environmental impact of human activities and an increasing exploration of strategies such as vegetation restoration and environmental management to address climate change.

Scale test of questionnaire survey

The overall Cronbach's α coefficient for the questionnaire is 0.938, with the subscales for knowledge of climate change,

Table 2 Keywords related to climate change in the CNKI Chinese Newspaper Database

Key words	Number of Literature	Key words	Number of Literature
Paris Agreement	191	Global Climate Governance	42
United Nations	168	Contracting Parties	42
global warming	158	Paris Climate Conference	37
Carbon neutral	139	Climate risks	34
Meteorological Bureau	88	Extreme weather and climate events	33
World Meteorological Organization	80	Renewable Energy	33
extreme weather	66	Global Climate	31
Climate system	53	Biodiversity	31
Extreme heat	46	Extreme events	30
Qinghai-Tibet Plateau	44	Sea-level rise	30

Table 3 Keywords related to climate change in scientific and technological journals database from 2014 to 2023

Key words	Number of Literature		Key words	Number of Literature	
	Web of Science Core Collection Database	Chinese Science and Technology Core Journal Database		Web of Science Core Collection Database	Chinese Science and Technology Core Journal Database
Human Activity	2302	626	Annual Precipitation	1243	99
Carbon Cycle	5335	85	Vegetation	1006	338
Ecosystem	1752	115	Global Warming	5231	224
Spatiotemporal Changes	1693	571	Land Use Change	1884	163
Run Off	3267	193	Environmental Monitoring	7497	71

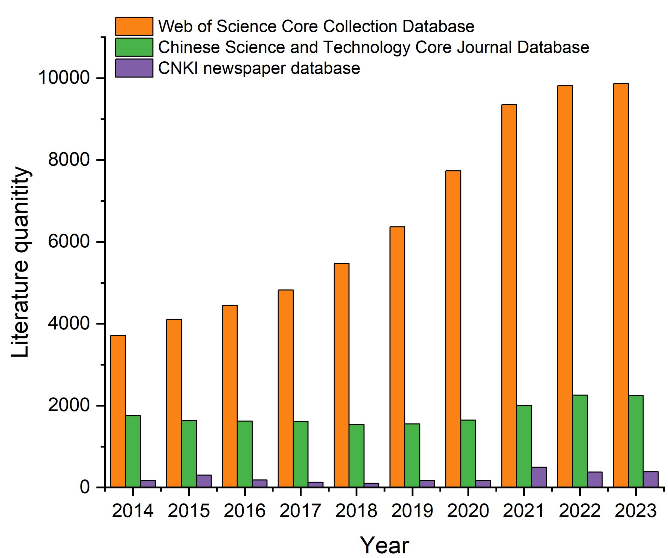

Fig. 1 Literature quantities related to climate change from 2014 to 2023

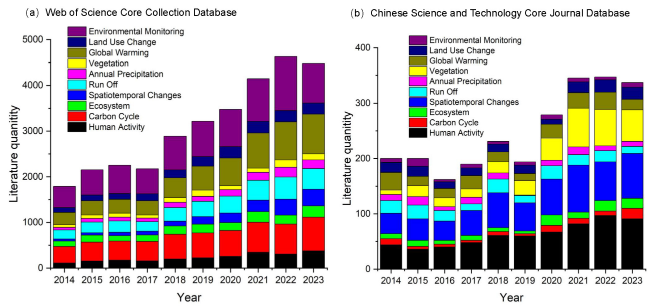

Fig. 2 Literature quantities of keywords related to climate change from 2014 to 2023

awareness of climate change risks, and awareness of climate change response measures scoring 0.859, 0.845, and 0.965 respectively (Table 4). These coefficients, all exceeding 0.7, demonstrate good internal consistency across variables and dimensions, confirming that the sample data passes the reliability test. Furthermore, the construct validity test shows a Kaiser-Meyer-Olkin (KMO) measure of 0.867, and Bartlett's test of sphericity yields a significant P value <0.001, indicating high validity of the questionnaire.

Results of questionnaire survey

1. **Analysis of climate change knowledge:** Based on Tables 1 and 4, it is evident that knowledge about the causes of climate change receives the highest overall score. This trend remains consistent across different genders and educational levels. Specifically, respondents show a clear understanding of causes such as fossil fuel combustion and industrial waste gas emissions, reflecting their awareness of these significant contributors to climate change. This aligns well with current environmental realities. Respondents were most familiar with extreme heat and floods, but had less knowledge of events such as tsunamis and hurricanes. This discrepancy may be attributed to the respondents' geographic location in inland areas, suggesting limited exposure to international climate change events through media sources. Scores for climate change-related vocabulary are notably high, with an overall score of 4.88. Key terms that respondents are familiar with, scoring above 5 on the scale, include global warming, greenhouse effect, greenhouse gases, carbon emissions, extreme weather, biodiversity, sustainable development, carbon neutrality, sea level rise, and ecosystems. These terms are widely recognized among the respondents. However, more specialized terms like carbon footprint and less commonly discussed terms such as the Paris Agreement receive lower scores of 3.08 and 2.67, respectively.

2. **Analysis of Climate Change Risk Awareness:** Young people demonstrate a heightened sensitivity to climate change risks, with overall scores averaging 5.76. Specifically, the highest awareness scores were 6.05 for the increase in extreme weather events (such as typhoons, floods, and droughts), 5.85 for species extinction caused by ecosystem imbalance, and 5.75 for the rise in the frequency and intensity of forest fires (Table 4).Moreover, respondents recognize the significant impact of climate change on both animals and plants, with 65% of respondents rating the impact as very large (6.05) or relatively large (5.05). Similarly, 74% of respondents believe that climate change will greatly (6.01) or relatively significantly (5.21) affect human health.

3. **Analysis of measures to address climate change:** The study explored adolescents' perceptions of climate change mitigation measures at macro, community, and individual levels. As shown in Table 4, the overall score for individual awareness is 5.99, surpassing scores of 5.75 at the macro level and 5.59 at the community level, indicating deeper personal engagement and certainty in individual cognition. Adolescents mainly support adopting new technologies to cut greenhouse gas emissions, followed by afforestation and reducing fossil fuel use, while recycling was the least favored. These preferences reflect adolescents' expectations for effective climate change solutions, emphasizing the pivotal role of technology in addressing the issue. At the community level, measures such as electricity conservation (6.02), using public transport or cycling (5.91), water conservation (5.89), purchasing and using environmentally friendly products (5.66), and tree planting or participating in reforestation activities (5.60) received higher scores (Table 1). Notably, raising awareness and education about climate change scored the highest at 6.16, underscoring its priority in personal responses to climate change.

Correlation analysis of questionnaire survey

Pearson correlation coefficients were computed using SPSS28.0 software to analyze relationships between different dimensions

Table 4 Cronbach's α coefficients of variables and dimensions and their scale scores (Average±Standard Deviation)

Variables and Cronbach's α coefficient	Dimensions and Cronbach's α coefficient	Overall	Gender		Education	
			Male	Female	High School Students	College Students
Knowledge of climate	Relevant vocabulary recognition 0.888	4.88±1.14	4.57±1.59	5.02±1.403	4.75±1.44	4.92±1.48
change 0 .859	Knowledge of relevant events 0 .755	4.75±1.07	4.79±1.14	4.74±1.039	4.76±1.03	4.75±1.08
	Knowledge of the causes of climate change 0 .867	5.42±1.02	5.45±1.11	5.41±0.985	5.37±0.74	5.44±1.10
Perception of climate	Impact on plants and animals 0.726	4.02±1.18	4.29±1.22	3.90±1.156	3.96±1.22	4.04±1.17
change risks 0 .845	Impact on human health 0.849	4.01±1.02	4.15±1.05	3.94±1.152	3.97±1.07	4.02±1.14
	Perception of climate change risk 0 .920	5.76±1.10	5.62±1.09	5.82±1.163	5.82±0.79	5.74±1.23
Perception of measures	Macro level 0.825	5.75±1.00	5.73±1.12	5.75±1.087	5.63±0.90	5.78±1.14
to address climate	Community level 0.942	5.59±1.02	5.64±1.16	5.57±1.277	5.5601.16	5.60±1.26
change 0 .965	Individual level 0.966	5.99±1.10	5.84±1.13	6.06±1.194	6.06±0.84	5.97±1.26

of the scale (see Table 5). The results show significant positive correlations between the three dimensions of climate change response measures, indicating that greater risk awareness aligns with a stronger grasp of response strategies. For example, correlation coefficients between the perception dimension of climate change risk and the macro, community, and individual dimensions of climate change response measures were 0.831, 0.680, and 0.782, respectively, all reaching extremely significant levels.

Furthermore, correlations among the macro, community, and individual levels of climate change response measures were all above 0.70 and also reached extremely significant levels. These findings underscore a cohesive relationship between heightened risk awareness and mature response strategies across different scales. Conversely, as shown in Table 5, there is no significant correlation between knowledge of climate change-related vocabulary and understanding of the impacts on animals, plants, and human health. This suggests a need for more targeted education to deepen young people's understanding of climate change effects on biodiversity and human health.

Social network analysis of questionnaire survey

The analysis of social network structures (Fig. 3) within the climate change scale reveals the interconnectedness of various dimensions. Strong positive correlations were identified among specific factors, such as the impact of climate change on plants and animals (B1) and its impact on animal and human health (B2). These relationships underscore the importance of considering interconnected influences in climate change research.

Centrality measures highlight the significance of certain nodes in the climate change awareness network. The betweenness and closeness values for nodes like understanding climate change events (A2), understanding the impact on plants and animals (B1), perception of climate change risks (B3), and community-level response measures (C2) were relatively high compared to others. This indicated that these nodes served as critical conduits for the shortest paths and were more accessible within the network. Generally, a higher centrality measure indicates that the node is more central to the network. From the graph, it can be seen that the dimension item with the highest centrality in Knowledge of climate change (A) is Understanding the causes of climate change (A3). In Awareness of climate change risks (B), the highest centrality dimension item is Understanding the impact of climate change on plants and animals (B1). For Awareness of measures to address climate change (C), the highest centrality dimension item is Macro-level countermeasures (C1). Across all dimensions, the dimension item with the highest centrality is Macro-level countermeasures (C1). This suggests that policy-level climate measures are closely linked to improving adolescents' knowledge, crisis awareness, and personal preparedness.

Structural Equation Modeling (SEM) analysis of questionnaire survey

The PLS-SEM model fit indices confirmed the model's suitability (Fig. 5). Specifically, the GOF score was 0.530, exceeding the threshold of 0.36 and indicating strong fit. The NFI was 0.92, surpassing the 0.9 benchmark, which shows a good model fit relative to a null model. The SRMR was 0.07, within the acceptable range of <0.1, suggesting minimal residuals between observed and predicted covariance matrices.

Table 5 Correlation coefficients of each dimension

Dimensions	A1	A2	A3	B1	B2	B3	C1	C2
A2	0.13	1						
A3	0.08	0.469 **	1					
B1	0.124	0.427 **	0.201 **	1				
B2	0.072	0.382 **	0.204 **	0.875 **	1			
B3	0.227 **	0.410 **	0.651 **	0.193 **	0.217 **	1		
C1	0.189 **	0.430 **	0.665 **	0.195 **	0.214 **	0.831 **	1	
C2	0.174 **	0.449 **	0.540 **	0.253 **	0.241 **	0.680 **	0.719 **	1
C3	0.216 **	0.317 **	0.563 *	0.136 *	0.148 *	0.782 **	0.773 **	0.738 **

Note: When the correlation coefficient is significant, ∗ represents significant test $P < 0.05$; ∗∗ represents $P < 0.01$.

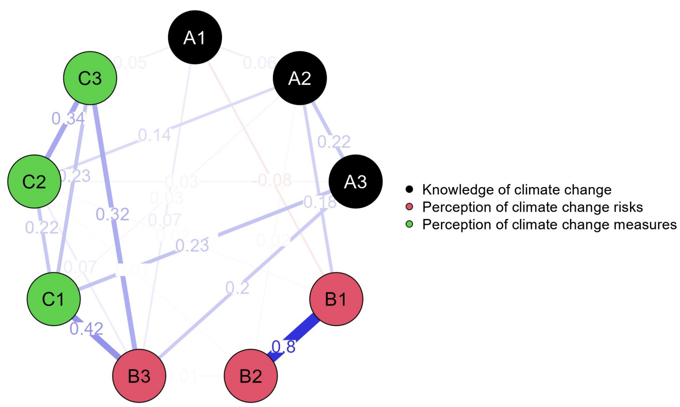

Fig.3 Network analysis of each dimensional items

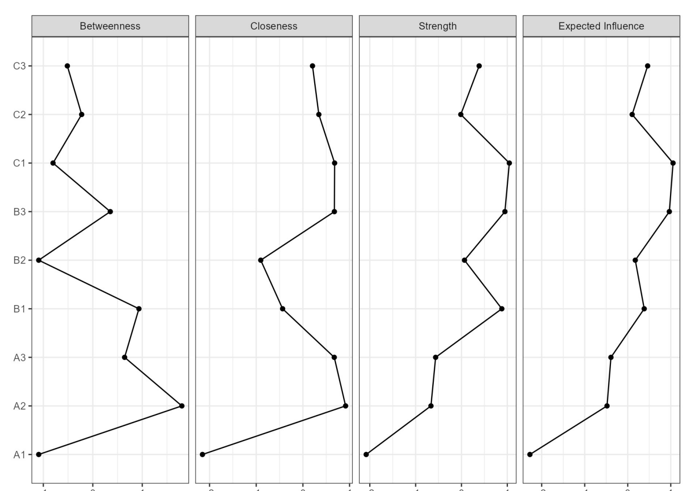

Fig.4 Centrality analysis of each dimensional items

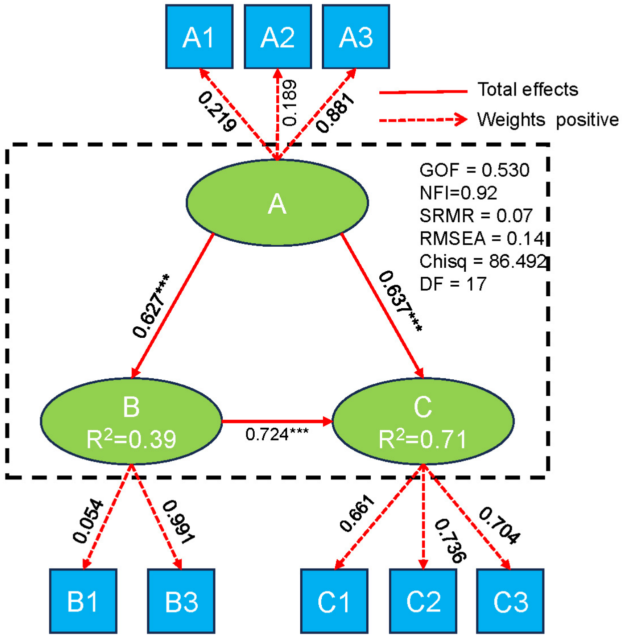

Fig.5 Structural equation modeling (SEM) analysis of each dimensional items

Direct effects and path coefficients indicated significant positive effects from A to both B and C, with coefficients of 0.627 and 0.637, respectively ($P < 0.01$). The path from B to C also had a strong positive effect, with a coefficient of 0.724 ($P < 0.01$). The R^2 value for B and C were 0.39 and 0.71, indicating 39% and 71% of the variance in these constructs were explained by Knowledge of Climate Change (A), respectively. These results affirm that Knowledge of Climate Change (A) positively influences both Awareness of Climate Change Risks (B) and Awareness of Measures to Address Climate Change (C), while B further contributes positively to C, supporting the hypothesized relationships among constructs.

Discussion

Implications and Significance Rising scholarly interest and interdisciplinary focus are evident in climate change literature. The analysis of climate change-related literature from 2014 to 2023 reveals a significant upward trend in publications, reflecting growing scholarly interest in this critical area. The trend reflects an evolving research landscape where interdisciplinary approaches and international collaboration are increasingly vital to developing comprehensive solutions to the climate crisis[41]. The heightened interest in keywords such as "Vegetation"and "Spatiotemporal Changes"in China may indicate an effort to explore adaptive solutions, including vegetation restoration and environmental monitoring, as methods to mitigate climate impacts[42]. The increased frequency of "Environmental Monitoring"and "Global Warming"keywords in English-language research further aligns with international initiatives aiming to track and assess environmental changes on a global scale, supporting informed policy and decision-making to counteract adverse climate effects.

Early climate change education fosters environmental stewardship among youth. Introducing climate change education during adolescence is crucial for nurturing environmental awareness and responsibility among students[43]. Understanding how youth perceive and engage with climate change is pivotal for developing effective educational strategies and fostering environmental stewardship among future generations. Research indicates that youth awareness and concern about climate change vary widely across different demographic and socio-economic backgrounds[13]. Factors such as education level, geographic location, and access to information significantly influence the depth of understanding and engagement among young individuals[44]. For instance, urban youth often exhibit higher levels of climate change awareness compared to their rural counterparts due to greater exposure to media and educational initiatives[45].

Climate knowledge is foundational for motivating youth to take action. These results emphasize the critical role of climate change knowledge in shaping awareness of risks and responses. The strong path coefficient between Knowledge of Climate Change (A) and Awareness of Measures to Address Climate Change (C) (0.78) indicates that education focusing on climate science can directly enhance youth engagement in climate action. These findings align with previous research that highlights knowledge as a driver of environmental behavior and risk perception[7]. The significant path from Awareness of Climate Change Risks (B) to Awareness of Measures to Address Climate Change (C) supports the notion that risk perception can motivate individuals to seek out and adopt protective actions[10]. This suggests that curricula incorporating real-world climate impacts could not only raise awareness but also empower youth to actively participate in mitigation efforts.

Existing climate education is often limited by fragmented and superficial understanding. Despite some awareness of climate impacts, many students lack a systematic understanding of underlying causes, complex impacts, and potential solutions. This limitation can lead to skepticism or confusion, particularly in the face of conflicting information from media and public discourse[17]. Addressing these challenges requires innovative communication strategies that promote transparency, clarity, and engagement, tailored to the diverse needs and learning styles of young individuals. Moreover, the study highlights the imperative to enhance adolescents' understanding of climate change's deeper causes and community-level response measures.

Suggestions for Improving Climate Change Education

To address these gaps, the following recommendations are proposed:

- **Integrating Climate Change Education with Core Subjects:** Climate change education should be integrated into geography, chemistry, biology, and other relevant courses to provide a holistic understanding. Strengthening the depth and breadth of climate change content within these subjects can enhance students' comprehension of its ecological and scientific implications. This interdisciplinary approach encourages students to explore ecological restoration solutions within the context of climate change. For instance, within a biology course, educators could include modules on ecosystems and biodiversity loss, while chemistry courses might address the chemical processes behind greenhouse gas emissions[46]. To implement this, schools should establish climate-focused curricula aligned with national education standards, and teacher training programs should be introduced to equip educators with climate science expertise and effective teaching strategies.

- **Adopting Innovative Teaching Methods:** Moving beyond traditional lecture-based approaches, interactive, discussion-oriented, and experiential learning strategies can foster a more profound engagement with climate issues. For instance, educators might incorporate role-playing simulations on carbon reduction policies or facilitate debate sessions on international cooperation[47]. Additionally, situational teaching methods—such as case studies on local climate impacts or community problem-solving exercises—could enhance critical thinking and deepen understanding[41].

- **Promoting Practical Engagement and Community Projects:** Bridging the gap between knowledge and action is crucial. Educators should emphasize practical activities related to climate change, such as establishing climate change clubs, conducting extracurricular research, and engaging in community-based environmental projects. Collaborations with universities, research institutions, and environmental organizations can provide valuable resources for outdoor research and social welfare activities centered on climate change. Additionally, situational teaching methods—such as case studies on local climate impacts or community problem-solving exercises—could enhance critical thinking and deepen understanding[48]. These initiatives not only enhance climate literacy but also cultivate a sense of responsibility and active participation among students in addressing climate challenges.

- **Policy Implications and Collaboration with Stakeholders:** Expanding climate change education requires robust policy support at various levels. Policymakers should work to mandate climate education as a core component of the national curriculum, providing funding for curriculum development, teacher training, and learning resources[42]. Additionally, research on policy effectiveness, including evaluating regional and national education programs, could inform and improve strategies to foster climate knowledge among youth. Collaborative efforts among policymakers, educators, and community organizations can ensure that climate literacy initiatives receive the sustained support needed to make a meaningful impact on youth awareness and action.

Limitations of the Current Study

Despite the significant insights offered, this study presents several limitations that may affect the interpretation and broader applicability of its findings.

- Age-Based Bias: This study focuses on 15-20-year-old students, which may introduce an age-based bias. Adolescents in this range are in a formative phase for developing environmental values and are particularly responsive to climate education[32]. However, this focus may limit generalizability, as young adults aged 21-30, who have more life experience and diverse educational or work environments, may exhibit different climate-related perceptions and motivations[49].

- Sampling and Survey Limitations: Methodological limitations in sampling and survey design may introduce potential biases. Although a stratified sampling method was used, the sample size and selection criteria may not fully represent the heterogeneity of the youth population. For instance, factors like socioeconomic status and access to climate information were not fully controlled, which may impact climate awareness results[50].
- Community, Personal, and Policy Factors: Additionally, this study does not assess community, personal, and policy factors affecting adolescent climate cognition, overlooking dimensions crucial for understanding climate awareness comprehensively[51].

Directions for Future Research

Future research could enhance this study by incorporating a broader age range, particularly young adults aged 21-30, to investigate how climate cognition evolves with age, life experiences, and varying educational or professional backgrounds. Additionally, it would be valuable to explore the influence of community and policy factors on youth climate awareness, as this could help identify effective local interventions and inform policy frameworks[42]. Innovative climate change education methods tailored to youth engagement—such as experiential learning, project-based approaches, and digital platforms—should also be examined.

Conclusion

Climate change education stands as a pivotal tool in addressing the escalating risks posed by climate change by equipping youth with essential knowledge and empowering them to take proactive steps. This study comprehensively assessed youth's knowledge of climate change, their perceptions of associated risks, and their responses. The analysis underscored a growing global focus on issues such as "Human Activity" "Carbon Cycle" "Ecosystem" "Global Warming". The study revealed that knowledge of climate change enhances both risk awareness and response measures, with risk perception directly fostering proactive strategies, highlighting the foundational role of climate change education in motivating youth toward proactive environmental stewardship. In conclusion, by embedding robust climate change education strategies within educational frameworks and communities, we can empower today's youth to become informed advocates and catalysts for sustainable change. The research effectively met its goal of developing a comprehensive understanding of youth cognition regarding climate change knowledge, risk perception, and response readiness. Although the objectives were largely fulfilled, however, enhancing youth understanding of climate change requires multifaceted approaches that address cognitive, emotional, and socio-economic factors influencing their perceptions and behaviors. By fostering climate literacy, promoting positive emotions, and leveraging educational innovations, society can empower young people to become informed and proactive agents of environmental change.

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