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Review

Analysis of Knowledge Graph: Hotspots and Future Trends in Environmental Education Research

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Abstract: Currently, as human society develops, environmental issues have become one of the significant challenges faced by humanity. Consequently, environmental education has emerged in response to this need. Environmental education aims to cultivate citizens with knowledge about the environment, which is crucial in addressing global challenges, fostering human–nature sustainability knowledge, and cultivating resilient individuals and communities. A comprehensive analysis of the current state of environmental education and exploring how environmental education can enhance the sustainability of interactions between humans and nature is one of the focal points of contemporary research. This systematic review employs CiteSpace to visually analyze the advancements of environmental education research, aiming to uncover the current status, predominant themes, evolutionary trajectories, and emerging trends. The Web of Science core collection database was examined to retrieve environmental education research papers published from 2013 to 2022. A total of 1851 papers were included in the final analysis. CiteSpace was utilized for visualizing and analyzing environmental education researchers, keyword co-occurrences, and keyword clustering, and Timeview was employed to generate relevant maps. The analysis identified five major hotspots in environmental education research: environmental awareness and literacy, theories in environmental education, delivery modes and methods, developments and implementation of environmental education, and the intersection of climate change and environmental justice. Emerging research directions include environmental justice, climate change education, critical environmental education, and environmental citizenship education. The results show that environmental education is gradually transcending the natural realm currently and integrating into a holistic framework encompassing societal, economic, and political dimensions. Environmental citizenship education is increasingly attracting the attention of scholars. Solving environmental problems requires interdisciplinary dialogue.

Keywords: environmental education; CiteSpace; knowledge graph; visualization; bibliometric analysis

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1. Introduction

The survival and development of civilization are intricately linked to the environment. However, decades of excessive exploitation and uncontrolled utilization of natural resources have resulted in severe environmental damage (Miao et al., 2017) [1]. Although there were early calls to prioritize environmental balance in the 1970s, with proposals to provide every person with opportunities to acquire the knowledge, values, attitudes, commitments, and skills needed to protect and improve the environment (Potter, 2009) [2], it is only in the 21st century that environmental issues have gained widespread attention across all sectors of society.

Consequently, there has been a growing research emphasis on balancing economic development with ecological preservation. Simultaneously, education systems have been actively exploring more effective ways to incorporate environmental issues into curricula,

leading to the emergence of environmental education grounded in ideological transformation (Pirchio et al., 2021) [3].

Numerous studies argue that environmental education is crucial for addressing global change and enhancing knowledge of human–nature sustainability (Ardoin, 2020) [4]. Environmental education encompasses the development of appropriate attitudes, values, awareness, knowledge, and skills necessary to comprehend societal impacts on the environment and propose suitable actions (Monroe and Krasny, 2016) [5]. To foster environmentally knowledgeable citizens capable of addressing global environmental and resource sustainability challenges (Wheaton, Kannan, and Ardoin, 2018) [6], environmental education should be integrated into educational programs from infancy to old age (Leal Filho, Mifsud, and Pace, 2018) [7].

Significant strides have been made in recent years in systematic and analytical research within the field of environmental education. For instance, Rohayati, Safrina, and Purwanto (2021) [8] conducted a meta-analysis examining the levels of environmental education among primary-, middle-, and high-school students. Their study aimed to determine the extent to which environmental education influenced students' attitudes, revealing a moderate impact across all students, with a more pronounced effect observed among high-school students. Similarly, Van et al. (2022) [9] conducted a meta-analysis spanning five decades and 169 studies, analyzing the effectiveness of child and adolescent environmental education. Their findings indicated that environmental education significantly enhanced environmental knowledge, attitudes, intentions, and behaviors, offering insights into future research priorities in environmental education.

While past comprehensive research has yielded fruitful results in environmental education, the sheer volume of studies makes it challenging to apply subjective content interpretation and traditional literature analyses to objectively discern hotspots and development trends. However, employing bibliometric analyses based on knowledge graphs and visualization techniques offers an objective panoramic analysis of hotspots and development trends within the field (Kao et al., 2022) [10].

In light of this, this systematic review adopts a bibliometric analysis method and utilizes the visual bibliometric software program CiteSpace 6.1.R6 and CiteSpace 5.7.R5 (Gao et al., 2023) [11] to conduct a visual analysis of global environmental education research spanning from 2013 to 2022. This approach enables us to gain an in-depth understanding of the current status, hotspots, development trends, and evolutionary processes of environmental education research. It aims to reveal the overall trends in the development of environmental education, discuss comprehensive innovations in the environmental education content system, explore the innovation of educational methods in environmental education, and identify the direction for constructing diverse educational pathways.

The remainder of this paper is structured as follows: Section 2 outlines the research methods, including data sourcing, keyword selection, and bibliometric analysis techniques. The Section 3 comprehensively analyzes two contents, encompassing: (1) descriptive statistical analysis, charting the annual publication trends, to present a holistic view of the domain; (2) author co-occurrence network, with the purpose of investigating their collaborative ties. The Section 4 exhibits the outcomes of scientific mapping, encompassing: (1) identification of research hotspots and thematic trajectories related to environmental education research through keyword co-occurrence network analysis and clustering; (2) timeline and keyword burst analysis to track the evolution of research themes, reveal current frontiers and predict future trends. Finally, Section 5 synthesizes the principal contributions and limitations of this study and offers perspectives on future research.

2. Data Sources

2.1. Analytical Methods

CiteSpace is an information visualization and analysis software developed by Chaomei Chen, based on the Java programming language. It is utilized for detecting co-citation networks based on extensive bibliometric data (Chen, Hu, Liu, and Tseng, 2012) [12]. It generates knowledge graphs to visually present complex relationships such as interactions, evolution, and networks between knowledge units and clusters (Ellegaard and Wallin, 2015) [13]. It is capable of detecting and presenting the research hotspots, cutting-edge themes, and knowledge foundations within a specific field and elucidating the evolutionary relationship between the forefront of research and the knowledge base of a certain field. Additionally, it offers a visual analysis of the dynamic evolution trajectory of the knowledge foundation and the trend changes of frontier topics. By utilizing cluster analysis and Timezone, it can present hotspots, elucidating the key contours and inherent relationships of the knowledge units. Therefore, CiteSpace can effectively assist scholars in conducting systematic literature reviews in specific research fields, presenting the research's knowledge structure, evolutionary patterns, and future directions in graphs and charts that are easy to understand (Han and Liang, 2023) [14].

In this paper, CiteSpace 6.1.R6 and CiteSpace 5.7.R5 were used to visualize and analyze the literature data related to environmental education retrieved based on the Web of Science (WoS) core collection, and a systematic literature review was conducted on this basis, aiming to sort out the current research status, predominant themes, evolutionary trajectories, and emerging trends of environmental education.

2.2. Data Collection

The Web of Science (WoS) database, a core citation index database within the Institute for Scientific Information (ISI), comprises four independent databases: SCIE, SSCI, CPCI, and A&HCI (Han and Liang, 2023) [14]. It indexes high-quality journal articles with global impact that have undergone peer review by experts in the field and is widely recognized as an authoritative literature database (Tao and Tao, 2024) [15]. Web of Science indexes thousands of scholarly journals, conference proceedings, books, and other academic sources, facilitating literature reviews (Junjia, Alias, Haron, and Bakar, 2023) [16].

To uphold scientific rigor, the Web of Science (WoS) core collection database was chosen as the source of literature data to globally analyze research on environmental education. The search was conducted on 31 March 2023. To ensure comprehensive and reliable literature data, we initiated the search on the Web of Science (WoS) core collection database using the themes "TS = ("environmental education") OR TS = ("environmental and sustainability education")", the search range was limited to 2013–2022. The document type was specified as "article", and the language was restricted to "English." Subsequently, manual screening was conducted to save the retrieved results in plain text format. The acquired data included titles, authors, journals, abstracts, keywords, publication dates, references, and other relevant information. Following this, the data underwent rigorous preprocessing steps for filtering and deduplication. Ultimately, 1851 documents meeting the criteria were obtained for in-depth analysis. The data collection steps are shown in Figure 1.

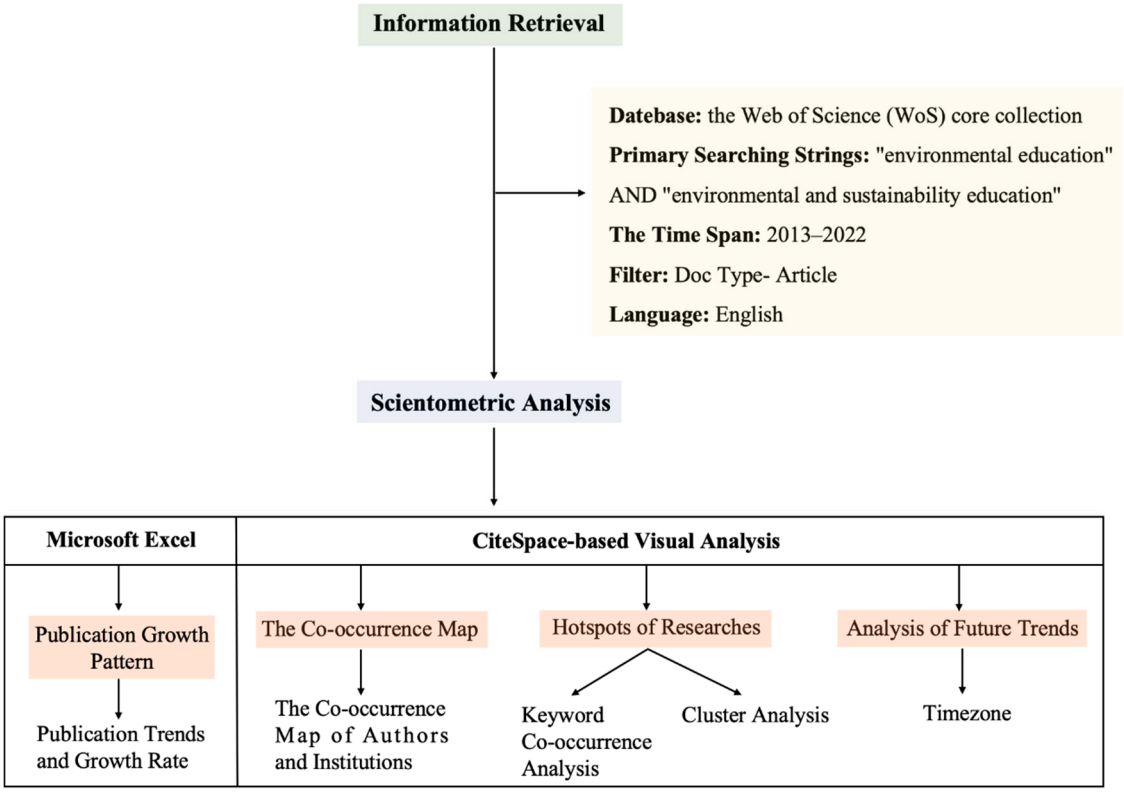


Figure 1. Research design.

3. Current Status of Environmental Education Research

3.1. Research Publication Trends

The annual publication counts on a specific topic and its temporal evolution serve as indicators of academic attention, offering a visual depiction of fluctuations in scholarly interest. A higher volume of publications in a given year reflects heightened research activity in that field and, to some extent, may predict potential future developments.

In this study, sample studies were analyzed using Excel to generate a statistical graph illustrating the number of environmental education publications from 2013 to 2022 (Figure 2). The graph reveals an active and increasing research interest in environmental education during this period, signifying heightened attention to environmental education issues. This trend implies that environmental problems continue to captivate research interest.

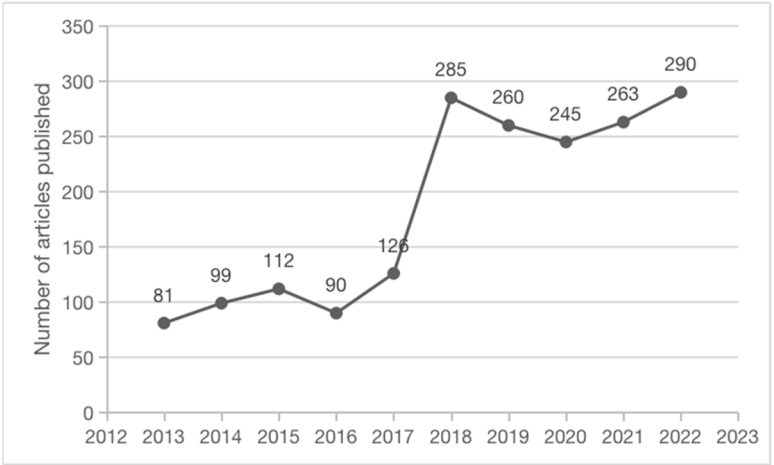


Figure 2. Annual publications concerning Environmental Education (EE) in the Web of Science (WOS^{TM}).

Environmental education research can be delineated into two primary stages: (1) the initial stage, spanning from 2013 to 2017, where the annual publication count remained relatively stable at around 101 with minor fluctuations; (2) the flourishing Stage, commencing in 2018, marked by a rapid surge in publications in core journals, reaching 285 in 2018. Despite some fluctuations from 2019 to 2023, an overall upward trend in environmental education research persists. This trend can be attributed to the amplified focus on sustainable socioeconomic and environmental development, driven by the imperative to address global environmental and resource sustainability challenges. Additionally, the increased research trend in environmental education may be linked to the United Nations summit on sustainable development in 2015, which introduced the 2030 Agenda for Sustainable Development, emphasizing the integration of sustainable development education at all educational levels (Cebrián, Junyent, and Mulà, 2020) [17]. Consequently, policy changes and real-world shifts have catalyzed a surge in environmental education research, with an emerging focus on bolstering civic environmental education as a recent trend.

3.2. Researcher Distributions

All research fields exhibit core authors, whose high productivity contributes significantly to sustained academic development. These core authors, often characterized by substantial output, wield considerable academic influence, shaping the trajectory of research in their respective fields. In contrast to other researchers and institutions, core authors typically possess a nuanced understanding of development trends, research hotspots, and directions, making an examination of their scientific contributions and affiliated research institutions crucial for a more precise comprehension of research directions.

To identify the core authors and institutions in the field of environmental education, CiteSpace was employed to generate author co-occurrence maps (Figure 3). The size of circles in Figure 3 corresponds to authors' influence, with larger circles denoting higher publication volumes and greater impact. The figure also delineates the collaborative network among different authors. The author co-occurrence map comprised 754 nodes and 945 links, yielding a network density of 0.0033. The author with the highest publication volume was Bogner, contributing 15 publications or 0.81% of the total sample, with a focus on environmental and sustainability education (ESE). Following closely were Kopnina with 11 publications and Johnson with 8 publications, constituting 0.59% and 0.43% of the total sample, respectively. Their primary research interests encompassed education sustainable development goals (ESDG) and outdoor environmental education. Other authors with substantial publication volumes included Krasny, Peterson, and Gericke. A detailed analysis of authors within the top 10% of publication volumes was conducted using Excel, and the results are presented in Table 1.

Table 1. High-volume authors (top 11) in the field of Environmental Education (EE) research.

Serial No.	Author's Name	Article Number	Percentage (%)	Institution
1	Bogner, Franz X	15	0.81	University of Bayreuth
2	Kopnina, Helen	11	0.59	Northumbria University
3	Johnson, Bruce	8	0.43	University of Arizona
4	Krasny, Marianne E	7	0.38	Cornell University
5	Peterson, M Nils	6	0.32	North Carolina State University
6	Gericke, Niklas	6	0.32	Karlstad University
7	Cincera, Jan	5	0.27	Masaryk University
8	Stern, Marc J	5	0.27	Virginia Polytechnic Institute and State University
9	Powell, Robert B	5	0.27	Clemson University
10	Van poeck, Katrien	5	0.27	Ghent University
11	Boeve-de pauw, Jelle	5	0.27	University of Antwerp

The formula proposed by the USA scholar Price for calculating core authors is represented: $M = 0.749\sqrt{Nmax}$, where M signifies the minimum number of publications required for an author to be considered core, and N_{max} denotes the maximum number of publications by any author in the field (Bian, Yu, and Zhang, 2020) [18]. Through statistical analysis, it was

determined that Bogner had the highest publication volume with 15 papers, resulting in an N_{max} of 15. Substituting these values into the formula yielded an M value of 2.9, establishing the prolific author threshold at 2.9. Consequently, authors who had published three or more papers on environmental education were categorized as prolific authors.

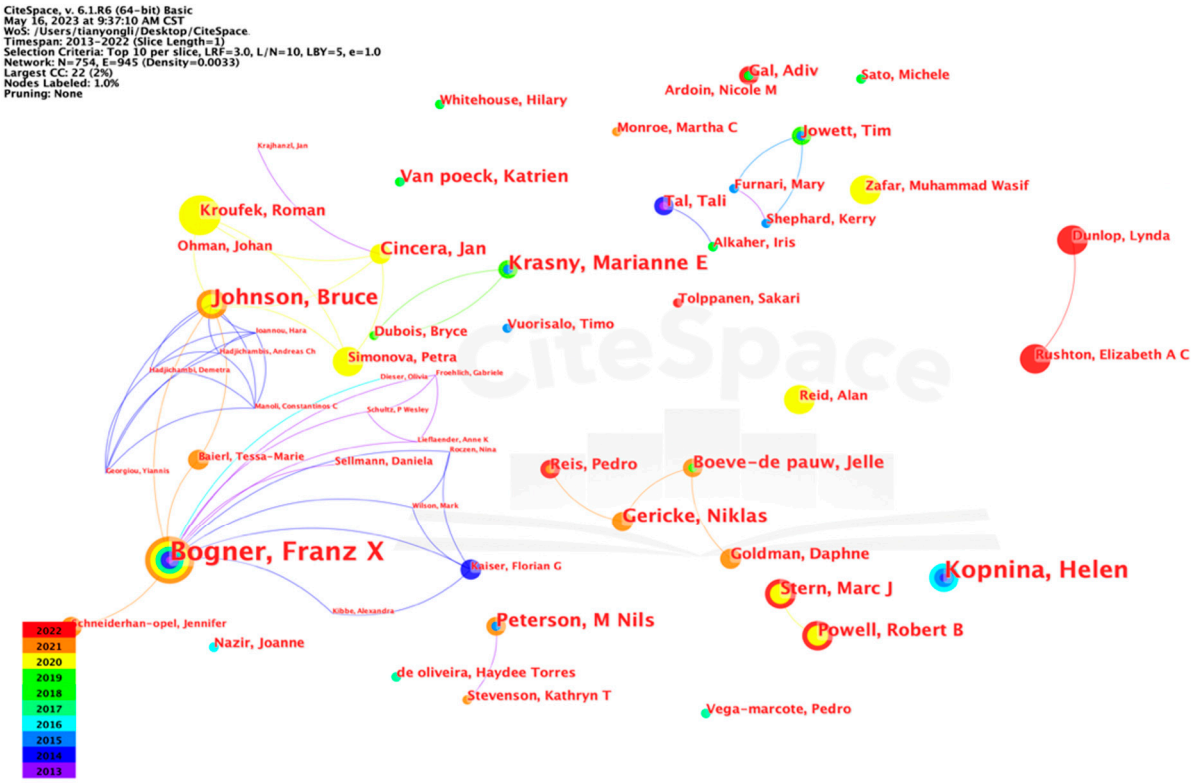


Figure 3. The co-occurrence map of research authors in the field of Environmental Education (EE) research.

The aggregate publication volume by prolific authors in the sample amounted to 166, constituting 8.97% of the total. This suggests that scientific collaboration among different environmental education authors was relatively weak, and their research institutions exhibited dispersion with relatively low publication volumes. Although a few core authors and research teams have been identified, the emergence of a cohesive group of prolific, highly influential core authors and research teams is yet to be realized.

4. Environmental Education Research Hotspots

4.1. Environmental Education Research Keyword Co-Occurrence Analysis

As keywords serve as condensed summaries of research topics, reflecting the primary focus of the main authors, frequently occurring keywords can serve as indicators of research hotspots. Consequently, keyword co-occurrence networks are valuable tools for researchers to identify prevalent research themes in a specific field (Li et al., 2023) [19].

In this study, the dataset of 1851 environmental education research publications was input into CiteSpace to generate the keyword co-occurrence network for environmental education research (Figure 4). This network comprised 477 keyword nodes, 2527 links, and had a network density of 0.0223. Utilizing Figure 4 and the CiteSpace network summary table function, a table (Table 2) was generated summarizing high-frequency keywords in environmental education research (≥40 appearances) from 2013 to 2022. Seventeen keywords appeared more than 50 times, with "environmental education" being the most frequent at 1046 occurrences, followed by "education" at 195 times. Given that these two keywords were crucial criteria for selecting literature samples, their frequent appearance

was expected. Other keywords such as "attitude", "knowledge", and "sustainable development" also featured prominently, indicating that these keywords represented core topics in environmental education research.

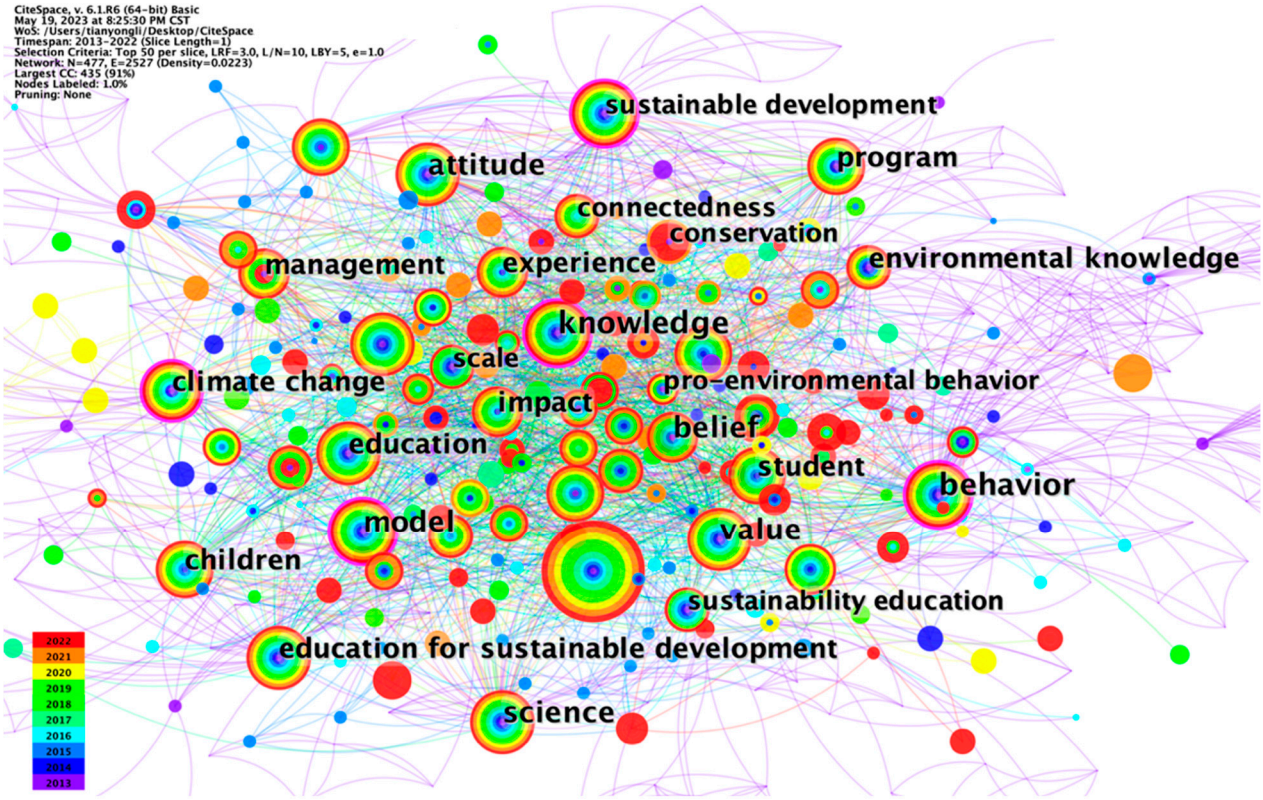


Figure 4. The knowledge map of keyword co-occurrence in the field of Environmental Education (EE) research.

Table 2. High frequency keywords in the field of Environmental Education (EE) research (frequency $\geq$ 40).

Serial No.	Keywords	Frequency	Year	Centrality
1	Environmental education	1046	2013	0.01
2	Education	195	2013	0.05
3	Attitude	178	2013	0.07
4	Knowledge	163	2013	0.12
5	Sustainable development	150	2013	0.10
6	Behavior	135	2013	0.18
7	Science	126	2013	0.08
8	Education for sustainable development	125	2013	0.07
9	Climate change	109	2013	0.11
10	Student	102	2013	0.06
11	Higher education	88	2013	0.04
12	Impact	86	2014	0.05
13	Experience	64	2013	0.05
14	Model	63	2013	0.13
15	Value	60	2013	0.05
16	Sustainability	60	2013	0.03
17	School	53	2013	0.02
18	Children	49	2013	0.07
19	Management	49	2013	0.08
20	Perception	49	2014	0.10
21	Education for sustainability	45	2013	0.04
22	Program	42	2013	0.05
23	Environmental awareness	41	2013	0.05
24	Place	41	2014	0.02

4.2. Environmental Education Research Keyword Cluster Analysis

To explore potential commonalities in environmental education research hotspots, the Logarithmic Likelihood Ratio (LLR) algorithm (Kao et al., 2022) [10] was applied to cluster keywords based on their similarity. Additionally, a change-point detection algorithm (Li et al., 2023) [19] was employed to identify keyword pairs exhibiting significant new trends or rapid changes within specific time ranges. This methodology led to the identification of 15 clusters of varying sizes, as illustrated in Figure 5.

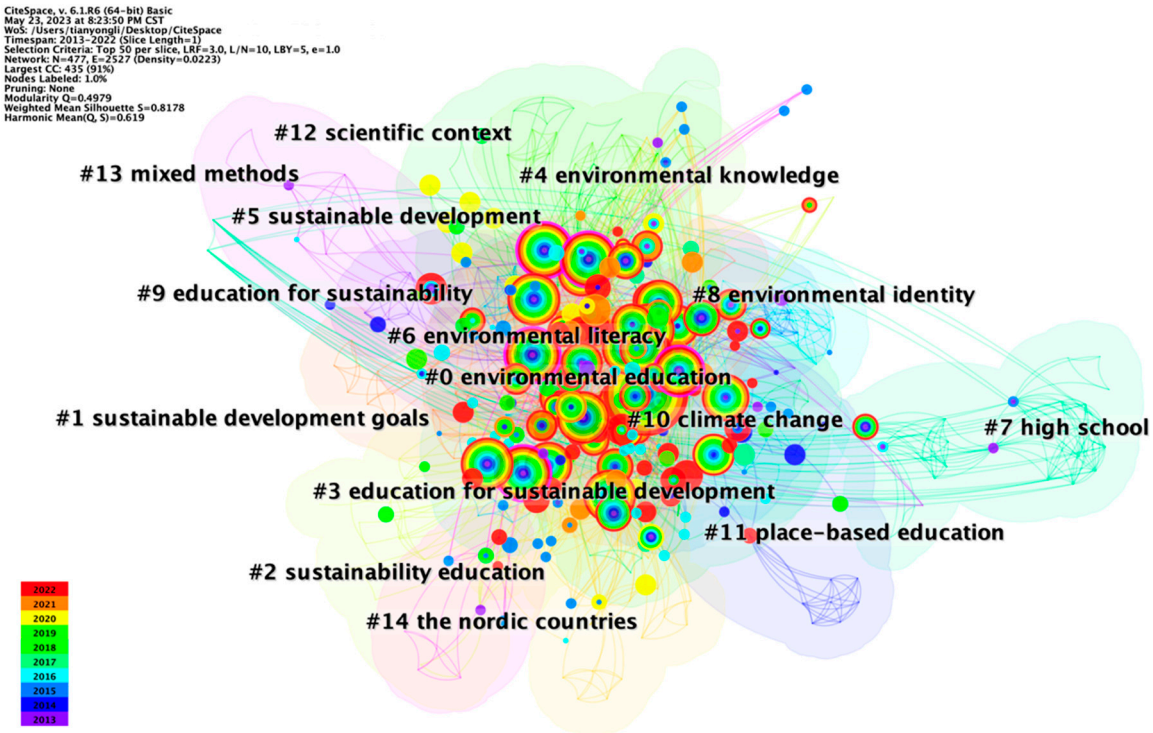


Figure 5. Keyword-based clustering view in the field of Environmental Education (EE) research.

The modularity cluster network value in Figure 5 was 0.4979 (>0.3), signifying a significant cluster structure (Shen et al., 2023) [20]. The Silhouette parameter, assessing keyword similarities within a cluster and ranging from −1 to 1, yielded an average value of 0.8178, surpassing 0.7, indicating convincing clustering results (Li et al., 2023) [19].

The 15 identified clusters were labeled as follows: #0 environmental education, #1 sustainable development goals, #2 sustainability education, #3 education for sustainable development, #4 environmental knowledge, #5 sustainable development, #6 environmental literacy, #7 high school, #8 environmental identity, #9 education for sustainability, #10 climate change, #11 place-based education, #12 scientific context, #13 mixed methods, and #14 the Nordic countries. These clusters represented the main topics in environmental education research, with cluster size indicating scale; larger clusters signifying more related keywords and higher attention to corresponding research topics.

The CiteSpace-generated clustering labels, along with other core keywords within each cluster, facilitated further exploration of related literature. Manual induction was employed to summarize the research topics of each cluster (Table 3), leading to the categorization of environmental education research into five main themes: environmental awareness and literacy, theories in environmental education, delivery modes and methods, developments and implementation of environmental education, and the intersection of climate change and environmental justice.

Table 3. The cluster keywords in the field of Environmental Education (EE) research.

Cluster No.	Cluster Name	The Number of Clusters	The Focus of Research
#0	Environmental education (environmental education)	67	The cultivation of environmental awareness and environmental literacy
#4	Environmental knowledge (environmental knowledge)	35	
#6	Environmental literacy (environmental literacy)	29	
#8	Environmental identity (environmental identity)	27	
#2	Sustainability education (sustainability education)	38	The ideas and theories of environmental education research
#3	Education for sustainable development (education for sustainable development)	35	
#9	Education for sustainability (education for sustainability)	25	
#1	Sustainable development goals (sustainable development goals)	44	The modes and methods of environmental education
#11	Place-based education (localized education)	18	
#12	Scientific context (scientific context)	13	
#13	Mixed methods (mixed methods)	11	
#7	High school (high school)	27	The development and implementation experience of environmental education
#14	The Nordic countries (Nordic countries)	10	
#10	Climate change (climate change)	21	Climate change and environmental justice

The Focus of Research	Related Keywords
The cultivation of environmental awareness and environmental literacy	environmental education, environmental knowledge, environmental literacy, scientific literacy, environmental identity, pro-environmental behavior, environmental behavior, environmental protection, environmental concern, critical thinking, science education, new materialisms, education policy, ecological literacy, educational leadership, content validity, elementary school, preadolescent students, teacher training gender, instruction, outcome, residue, field study
Thoughts and theories of environmental education research	education for sustainable development, education for sustainability, cultural historical activity theory, teacher development, teacher education, professional learning, complexity, early childhood education,
Mode and method of environmental education	place-based education, land education, indigenous education, participatory action research, participatory approach, technology, mixed methods, indigenous knowledge, settler colonialism, scientific context, environmental programme, moral reasoning, environmental impacts, satellite telemetry, public involvement, global trends, sustainable development goals
The development and implementation experience of environmental education	learner-centred pedagogy, quality assurance, curriculum reform, career and technical education, mobile learning communities, donor-funded projects, digital archives resource environmental education, ecological psychology, the Nordic countries, high school
Climate change and environmental justice	climate change, environmental justice, urban green space, recognition, natural environment

The first theme, 'environmental awareness and literacy', focused on relationships between environmental knowledge, attitudes, and behaviors. Keywords included literacy, environmental behavior, environmental protection, and environmental concerns. Environmental literacy was explored as encompassing awareness, sensitivity, understanding of solutions, values, motivations, skills, and abilities related to environmental protection, and a willingness to take environmental improvement actions (Roth, 1992) [21]. Studies, such as Chu et al. (2007) [22] and Činčera, Kroufek, and Bogner (2022) [23], revealed factors influenc-

ing environmental literacy, including gender, environmental information sources, parents' educational backgrounds, and correlations between environmental attitudes and behaviors.

Continued exploration of the remaining themes and related literature is presented in subsequent sections.

The second cluster delved into theories in environmental education, particularly emphasizing sustainability education, education for sustainable development, and education for sustainability. Key terms associated with this cluster included cultural-historical activity theory, teacher education, teacher development, and professional learning. The cluster shed light on the theoretical underpinnings guiding environmental education research.

Vare (2020) [24] contributed to this cluster by adopting a cultural-historical activity theoretical perspective, conceptualizing schools as activity systems for implementing environmental education. Through interviews with teachers and principals from 12 schools in England, the study identified 15 contradictions that could arise during the implementation of environmentally sustainable development education within schools. These contradictions were categorized into four levels: within an activity system element, between different activity elements, between the object of the dominant activity form and the object of more advanced cultural forms, and between the central activity and neighboring activities. The study also explored teachers' approaches to resolving these contradictions, highlighting instances where teachers may have higher expectations for school-based environmental education than the school leadership, resulting in frustration and a sense of powerlessness. Identifying these contradictions can empower teachers to provide students with meaningful and contextualized environmental education learning opportunities, fostering highly adaptable, resilient learners and improving teachers' self-esteem.

Cluster #3, 'Education for Sustainable Development', centered on the competencies that teachers and educators need to promote sustainability. Meanwhile, both Cluster #2, 'Sustainability Education', and Cluster #9, 'Education for Sustainability', underscored the importance of students acquiring cognitive, attitudinal, behavioral, practical, and value-related sustainable development skills and abilities through education.

The third thematic category delved into delivery modes and methods of environmental education, encompassing keywords such as place-based education, land education, indigenous education, and participatory action research. This category explored novel teaching modes and methods in environmental education. For instance, Albareda-Tiana et al. (2018, 2019) [25,26] proposed three sustainable development education strategies: problem-based learning (PBL), project-oriented learning (POL), and interdisciplinary seminars. Through experiments on pre-service teacher training students, the study found that project-oriented learning (POL) was particularly effective in cultivating sustainability thinking in higher education.

Moreover, localized education models were also examined within environmental education. Localized education, rooted in the local or community environment, links education and student learning to local environmental development requirements. It fosters interdisciplinary learning processes grounded in the local natural world, facilitating multifaceted learning (Vinlove, 2015) [27]. Ladachar, PooThawee, and Ladachart (2020) [28] investigated the understanding of smog-related issues among Thai students of various ages, using open questionnaires and semi-structured interviews to gather data for the development of localized smog education courses. Similarly, Herman, Zeidler, and Newton (2020) [29] conducted a qualitative study on college students in Yellowstone, after they received localized teaching on environmental and social science issues, revealing shifts in attitudes towards human and natural welfare.

The fourth category focused on developments and implementation of environmental education. From one perspective, it explored the role of environmental education and key issues for groups receiving it. Pauw et al. (2015) [30] found that sustainable development education in Sweden increased students' awareness of sustainable development. Glavič (2020) [31] identified twelve key issues in sustainable development education from environmental, societal, and economic perspectives. Another perspective focused on the im-

plementation of environmental education, particularly sustainable development education. For instance, Waltner et al. (2020) [32] investigated its implementation in German middle schools, revealing an increase in teachers' understanding of and views on sustainable development goals between 2007 and 2019. The study suggested frequent evaluation of teachers' knowledge and attitudes, increased teacher support through training, and further integration of sustainable development education with other teaching course structures.

The fifth category centered on the intersection of climate change and environmental justice. Studies have recommended that sustainable development education should encompass diverse disciplines, addressing issues like climate change and poverty reduction. For a comprehensive understanding of the past, present, and future impacts at local, regional, and global levels, sustainable development education must integrate aspects of the environment, society, the economy, their interrelationships, and temporal and spatial interactions. Given the conflicts of interest between individual, economic, social, and environmental goals, holistic sustainable development perspectives emphasize the importance of social and cultural factors in causing environmental problems. Education, transcending disciplines, should encompass both local and global perspectives and consider past, present, and future generations (Borg et al., 2014) [33].

Environmental education, grounded in the present and potential future impacts, should address conflicts of interest between individual, economic, social, and environmental goals. Valdez et al. (2017) [34] found that attention to climate change and discussions with family and friends about climate change could predict individual climate change behaviors. Students from cities with high socioeconomic status exhibited a higher likelihood of engaging in climate change behaviors compared to students from low socioeconomic status cities or rural schools. Therefore, giving more attention to climate change news and incorporating these discussions into environmental education could foster more positive behaviors toward climate change solutions and better address conflicts of interest.

Climate change is also incorporated into K-12 education in Western settings. Siegne and Stapert (2020) [35] studied a middle-school climate change course integrated into the comprehensive social studies and language arts framework, developed collaboratively by a private school, a non-profit climate education institution, and a government agency (NOAA). A year after the course implementation, students who had participated in the course showed significant improvements in climate literacy and overall engagement in climate-change-related activities. This underscores the effectiveness of interdisciplinary environmental education research, particularly in social-science-based climate change education.

4.3. Future Environmental Education Research Trends

The CiteSpace Timeview function facilitates the analysis of keywords over different periods, revealing the evolutionary research paths. This allows researchers to intuitively comprehend keyword distribution characteristics at various times and identify future research trends (Tao and Lin, 2023) [36]. Thus, CiteSpace Timeview was employed to analyze environmental education research keywords spanning 2013–2022, resulting in the development of a keywords timeline map (Figure 6). This keywords timeline map organizes keywords in chronological order, with circle nodes reflecting the frequency of corresponding keywords. The size of each node represents the magnitude of the keyword's occurrence within the dataset (Tao and Tao, 2024) [15]. Combining this analysis with high-frequency keywords from each stage, the evolution of research hotspots was observed to unfold in four stages.

The first stage (before 2013) primarily focused on cultivating environmental awareness and values. Figure 6 illustrates that international environmental education research was relatively mature before 2013. High-frequency vocabulary in this stage included education for sustainable development, environmental knowledge, environmental awareness, environmental concern, and teacher training. The primary focuses were: (1) environmental awareness—enhancing individual awareness and sensitivity to environmental issues;

(2) environmental knowledge—disseminating nature and ecological protection knowledge, transforming fragmentary individual knowledge into a systematic knowledge system, and cultivating a correct understanding of the relationship between humans and nature; (3) pro-environmental attitude—establishing environmental values and fostering subjective initiatives to engage in pro-environmental behaviors; and (4) pro-environmental skills—cultivating individual environmental protection skills and enhancing individual abilities to address environmental problems.

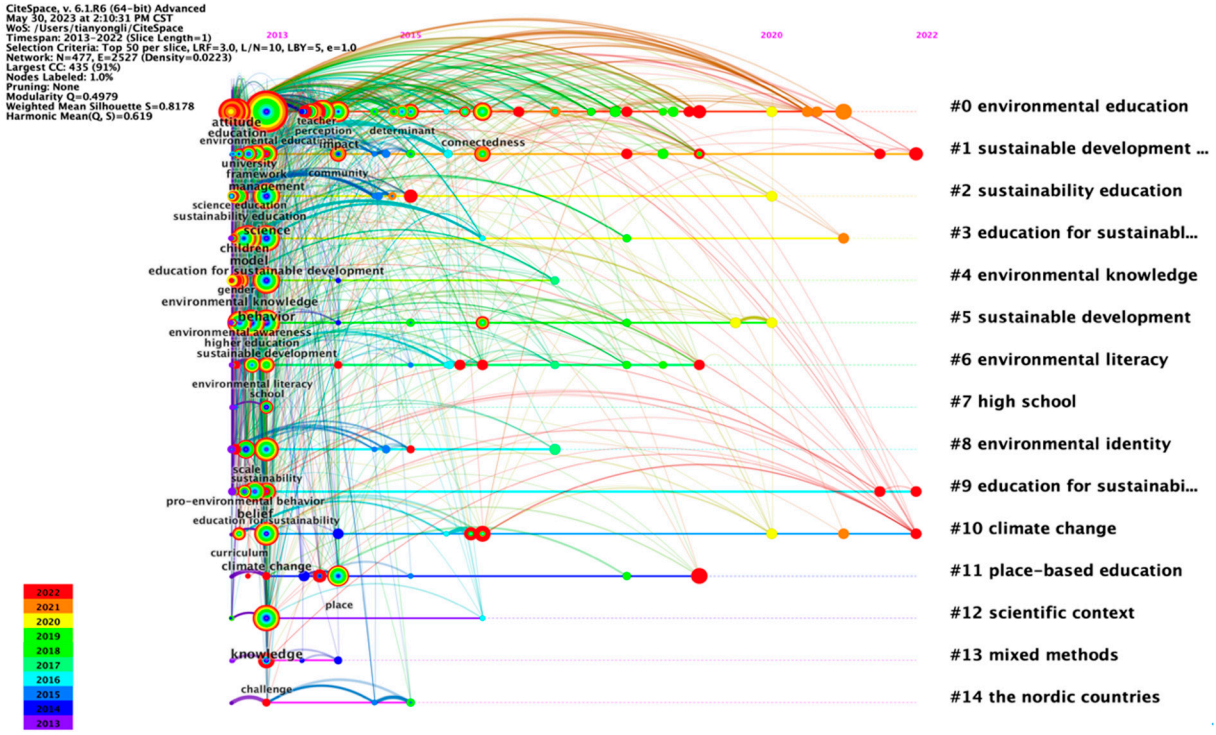


Figure 6. Keywords timeline map in the field of Environmental Education (EE) research.

In the second stage spanning from 2014 to 2018, high-frequency keywords included place-based education, ecological education, land education, environmental justice, case studies, program evaluation, planned behavior, competence, and strategy, with two primary research focuses. The first focus involved the gradual shift in environmental education from instrumental to values-based education, primarily oriented toward environmental issues. The aim was to enhance student knowledge and awareness of environmental science, protection technologies, and their ability to effectively address environmental problems. However, achieving this goal necessitated correcting environmental attitudes and values. Only through an awareness of nature could individuals develop conscious pro-environmental behaviors and actively participate in environmental protection activities.

During this stage, the purpose of environmental education gradually refocused on cultivating environmental values. Research began emphasizing the values and ethics associated with environmental education, giving greater attention to inner attitudes and beliefs. Topics such as place-based education, ecological education, and land education emerged, making localized education a more common mode in school-based environmental education. Community participation and local connections encouraged inquiry and perceptual learning. Environmental education increasingly focused on enabling individuals to rationally understand their local environments, with educational goals shifting towards sustainable local and individual development.

Simultaneously, local characteristics, including histories, culture, social politics, economics, and the natural environment, were integrated into the teaching process to enhance students' sense of belonging and improve their environmental responsibility. Educational

strategies in this stage emphasized the active use of local materials and resources, expanded the educational space, encouraged in-depth exploration of local events and phenomena, and promoted meaningful learning experiences through simulated or direct participation. For instance, Thomas, Teel, and Bruyere (2014) [37] found that localized cultural, social, and environmental education delivered to 12 students from Hawaiian rural communities enhanced their knowledge of nature, increased their knowledge, and deepened their understanding of their local environment.

In the second stage (2014 to 2018), the second main focus in environmental education research was interdisciplinary integration. Recognizing that social, economic, and environmental complexities cannot be resolved by a single academic discipline, there was a growing emphasis on integrating natural science, humanities, and social sciences to effectively address environmental challenges. Environmental teaching and learning required the fusion of these various disciplines to ensure comprehensive and impactful education. Scholars argued that environmental educators should possess knowledge in behavioral psychology, pedagogy, marketing, and sociology principles (Ardoin, Bowers, and Gaillard, 2020) [4]. For instance, Silbernagel et al. (2015) [38] developed a comprehensive, localized, classroom-based science education project integrating environmental humanities, technology, and aquatic science under a spatial background to enhance students' knowledge about estuary environments and culture.

The third stage (2019 to 2022) shifted focus to the integration of environmental education systems and new ideological trends. High-frequency vocabulary during this period included climate change education, transformative learning, citizen science, education for environmental citizenship, secondary education, emotion, ethics, and green. Two primary research directions emerged. (1) Shaping and cultivating environmental experiences, natural understanding, treatment methods, and ideology through systematic integration. This approach aimed to enable people to better address environmental problems by holistically incorporating social, political, and economic content into environmental education. Research attention increased towards environmental citizenship education, which raises public awareness of environmental problems from lifestyle, cultural, and systemic perspectives, promoting sustainable environmental development. Telešienė et al. (2021) [39] evaluated an educational intervention cultivating college student awareness of environmental citizenship, revealing positive changes. (2) Integrating social thought into environmental education to address global environmental governance challenges. Factors such as diplomacy, geopolitics, economic development, and system reform were recognized as intertwined with environmental issues. Environmental education systems incorporated new social developments in public science and the green economy to promote innovation and progress. Future directions involve exploring changes to traditional education methods, incorporating sociological, economic, and legal perspectives, and fostering dialogue between different disciplines. The focus will be on coordinating and balancing classroom environmental education with pro-environmental social and situational activities, cultivating sustainable development concepts, enhancing the sense of social responsibility and environmental literacy, developing pro-environment emotions, and motivating environmentally friendly behaviors. The experiential learning theory of environmental education proves its feasibility (Jose et al., 2017) [40]. Diverse environmental education paths are expected to develop, emphasizing macro contexts such as production globalization, the community of a shared future for mankind, and harmonious coexistence between people and nature.

To further observe the variations in a certain keyword across different years, this study employs the burst detection feature of CiteSpace to conduct a burst word detection on all keywords in the literature, yielding 30 words from 2013 to 2022 with the most significant burst, as shown in Table 4. "Strength" reflects the intensity of its burst and the "Begin" and "End" years indicate the span of its academic focus (Tao and Tao, 2024) [15]. The burst detection feature is capable of identifying keywords that have undergone significant changes in a short period, and it visually represents the trends of these abrupt changes in

keywords across different time intervals through varying shades of color. This method illustrates the changing characteristics of research hotspots and potential research turning points in certain years, indirectly supporting the keywords timeline map. The burstiness level of an emergent word reflects its value at the forefront of the field; a higher burstiness rate indicates a greater contribution to the forefront of the domain. The end year of emergence shows the latest progress in a research area.

Table 4. Top 30 keywords with the strongest citation bursts from 2013 to 2022 in the field of Environmental Education (EE) research.

No.	Keywords	Strength	Begin	End	2013–2022
1	Informal education	2.84	2013	2015	
2	Community	5.18	2014	2017	
3	Education for sustainability	4.64	2014	2015	
4	Conservation	3.72	2014	2018	
5	Business education	2.53	2014	2016	
6	Politics	4.43	2015	2018	
7	Ecological paradigm	4.26	2015	2017	
8	Policy	3.31	2015	2016	
9	Critical thinking	2.87	2015	2016	
10	Management	2.7	2015	2016	
11	Meta-analysis	2.47	2015	2017	
12	Context	4.1	2016	2019	
13	Self	3.57	2016	2017	
14	Ecology	3.39	2016	2017	
15	Environmental ethics	2.46	2016	2019	
16	Place-based education	4.17	2017	2018	
17	Consumption	3.47	2017	2018	
18	Teacher training	3.23	2017	2020	
19	Critical environmental education	4.45	2018	2019	
20	Ecological education	3.56	2018	2019	
21	Professional development	3.31	2018	2019	
22	Motivation	3.01	2018	2019	
23	Case study	2.67	2018	2019	
24	Challenge	5.17	2019	2020	
25	Engagement	4.18	2019	2020	
26	Climate change education	4.18	2019	2022	
27	Secondary education	3.72	2019	2020	
28	Green	3.21	2019	2022	
29	Environmental justice	3.34	2020	2022	
30	Health	2.87	2020	2022	

Table 4 reveals that the burst onset points for keywords began in 2013, with varying changes in burst intensity for different keywords. In terms of burst strength, "community" exhibits the highest intensity at 5.18, indicating it as a widely focused research frontier in the field of environmental education research. Regarding the timing of bursts, "informal education" appeared earliest, bursting in 2013 but fading from the field after three years. The burst start years for "community", "education for sustainability", and "conservation" were all in 2014, yet "conservation" had the longest burst duration, lasting five years. Keywords like "community", "politics", "context", "environmental ethics", "teacher training", "climate change education", and "green" all had burst durations of four years, reflecting prolonged scholarly attention in these research directions within the field of environmental education research.

The keywords "critical environmental education", "climate change education", and "environmental justice" sequentially marked their prominence in 2018, 2019, and 2020, respectively, indicating that scholars have been continuously expanding the depth and breadth of research in the field of environmental education research. Environmental

education is shifting towards teaching students to combine critical thinking with the capability to address social and environmental issues through pro-environmental actions. The prominence of these keywords also provides insights into the frontiers of environmental education research.

Furthermore, an integrated interpretation of the literature on environmental education research from 2018 to 2022 reveals that the emergence of keywords such as "ecological paradigm", "place-based education", and "case study" reflects the academic community's beneficial attempts in environmental education. These efforts provide references for the evaluation of environmental education and the exploration of new models.

5. Conclusions and Prospects for Foreign Environmental Education Research

5.1. Research Conclusion

This study utilized CiteSpace to create a visual knowledge map based on 1,851 environmental education research studies retrieved from the Web of Science core collection spanning from 2013 to 2022 and examined the overall status, research hotspots, and evolutionary trends of environmental education research. The objective results of the bibliometrics research are as follows:

(1) Temporal trends: The number of environmental education research studies exhibited fluctuations between 2013 and 2018, but a notable increase was observed after 2018.
(2) Research collaboration: Scientific collaboration among main research authors and other contributors was identified as relatively weak. The publication volumes of individual authors were modest, and there was a scarcity of core authors and research teams with high influence.
(3) Research hotspots: The research hotspots were categorized into five main areas: environmental awareness and literacy, theories in environmental education, delivery modes and methods, developments and implementation of environmental education, and the intersection of climate change and environmental justice. Key research keywords included education for sustainable development, ecological education, place-based education, environmental literacy, environmental identity, citizen science, behavior, models, knowledge, and climate change. Additionally, emerging research directions encompassed environmental justice, climate change education, critical environmental education, and environmental citizenship education.

The analysis revealed the following key findings:

(1) The overarching trend in the development of environmental education: Currently, environmental education is gradually transcending the natural realm and integrating into a holistic framework encompassing societal, economic, and political dimensions. Emerging societal trends such as public science and green economy are continuously being incorporated into the existing environmental education system, continually stimulating overall innovation in international environmental education research.
(2) Environmental citizenship education is increasingly attracting the attention of scholars: Future environmental education will place more emphasis on innovating educational methods that discuss the values, beliefs, and knowledge skills of the educated population. It will explore the organic coordination and balance between situational activities, social practice, and classroom education to promote the effective cultivation of sustainable development concepts and emotional construction in environmental education practice.
(3) Greater emphasis on interdisciplinary dialogue: In the future, environmental education will actively incorporate perspectives from disciplines such as law and economics to achieve objectives related to cultivating individual social responsibility and motivation for environmental protection. It will explore diverse educational pathways within the broader contexts of sustainable development, globalization, a shared human destiny, and ecological civilization. This will guide the public to reflect comprehensively on environmental issues from technology to lifestyle, from systems to culture, so as to seek a path that leads to a win–win situation for both the environment and development.

5.2. Research Limitations

(1) Limitations of data sources: The primary research methods of this study are bibliometrics and knowledge mapping, where the data sources used for bibliometric analysis are crucial for deriving accurate conclusions. Due to bibliometric software restrictions, only the Web of Science database was used. Future research could consider incorporating data from other databases into the analysis. Additionally, the output forms in current environmental education research are varied, including journal articles, monographs, dissertations, conference reports, and technical reports. This study only utilized journal articles as the data source for statistical analysis. Future studies could consider incorporating various forms of scientific outputs into the scope of study, thereby enhancing the accuracy of the analysis results.

(2) Limitations of research tools: Different knowledge-mapping tools can produce varied analysis outcomes from the same dataset due to their distinct core algorithms. This analysis solely employed CiteSpace, potentially limiting the comprehensiveness of the results. Future research opportunities could involve analyzing and comparing environmental education literature from diverse language databases and considering the integration of various knowledge mapping tools to provide a more comprehensive understanding of the global environmental education research knowledge structure.

(3) Limitations of the analysis scope: In conducting hotspot theme analysis with CiteSpace, the focus was only on keywords with high intermediary centrality. Future research could expand the analysis to include keywords with lower centrality but the potential for emergent significance, which may broaden the comprehensiveness of the analysis results.

5.3. Outlook

Environmental education has progressed from theoretical exploration to practical implementation, establishing a scientific and systematic system spanning early education to adulthood. Despite this progress, ongoing research efforts are crucial to address evolving global and social environments. Several recommendations for advancing environmental education research are outlined below:

(1) Methodological diversity: While there has been a notable increase in environmental education research, most studies rely on traditional methods like questionnaires and experiments, with limited use of qualitative approaches. Future research could benefit from a more diverse set of methods, including the application of case studies. Case methods offer a nuanced understanding of the complexity of environmental and sustainable development education, highlighting dynamic educational processes and revealing underlying mechanisms. Moreover, integrating traditional methods with emerging approaches like big data, artificial intelligence, virtual reality, and 5G could further enhance the scientific and applied aspects of environmental education research.

(2) Holistic and Hierarchical Perspectives: Environmental education research should adopt holistic and hierarchical approaches, considering multiple perspectives such as those of public groups, specific populations (e.g., in impoverished or underdeveloped areas), and special groups (e.g., individuals with disabilities). Future studies could propose targeted strategies and educational policies, conducting longitudinal intervention or follow-up research on diverse groups.

(3) Interdisciplinary collaboration: Keyword clustering and emergence analysis indicate that environmental education research has evolved in response to global environmental challenges. To provide more compelling evidence for environmental justice and foster environmental citizenship, researchers should expand the scope of environmental education by promoting interdisciplinary collaboration. Encouraging systematic multi-disciplinary research can enhance the understanding of environmental issues and their societal implications.

In conclusion, continuous and diversified research efforts in environmental education are essential to address contemporary challenges and foster a more sustainable and environmentally conscious society.

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