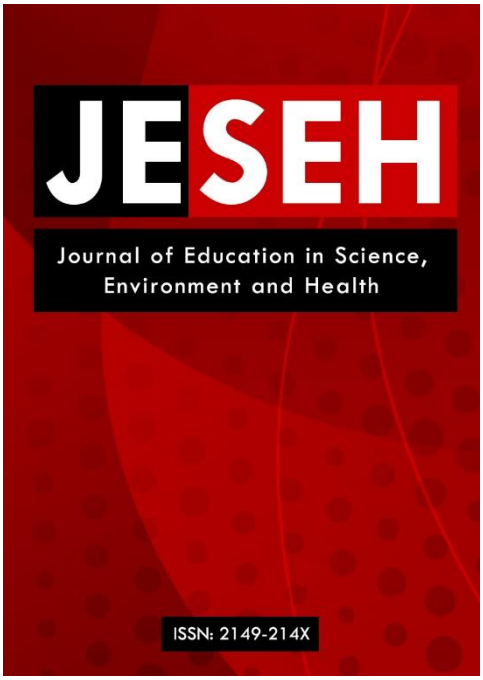

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Digitizing Early Childhood Environmental Education: A Bibliometric Study

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Digitizing Early Childhood Environmental Education: A Bibliometric Study

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Abstract

The integration of digital tools in education has gained attention for enhancing engagement and interactivity, particularly in fostering environmental awareness in early childhood. Early exposure to ecological concepts can nurture environmentally conscious individuals equipped to address climate challenges. This study analyzes research trends on digitizing environmental education in early childhood from 1968 to 2023. Using the Dimensions database, 443 relevant publications were identified from 9214 documents, and a bibliometric analysis was conducted via VOSviewer 1.6.20. Findings indicate that research in this field remains nascent. Although digital technology was first mentioned in 1968, significant scholarly interest only surged in 2023, with a record 1,503 publications. Vietnam, Thailand, and South Africa lead in publications, while top institutions include the University of Johannesburg, Mahidol University, and Ho Chi Minh University of Social Sciences and Humanities. The study also identifies key journals, prolific researchers, and highly cited works. Keyword co-occurrence analysis provides deeper research insights. These findings emphasize the rising role of digital tools in early childhood environmental education. Integrating technology enhances ecological understanding and fosters environmental responsibility. Additionally, this study offers a comprehensive literature overview, guiding future research on digitizing environmental education.

Introduction

The urgency of addressing global environmental challenges, such as the rise in global temperatures by approximately 1.2 degrees Celsius since pre-industrial times (Noor et al., 2021), has intensified the need for robust environmental education. Integrating such education into early childhood education (ECE) curricula is essential for fostering sustainable development and supporting the goals of quality education and climate action (Sanginova, 2024). This priority is reinforced by the academic community, which highlights the vital role of education in raising awareness and understanding of climate change (Priatna & Khan, 2024). In this context, the digitization of environmental education has emerged as a promising approach to enhance engagement, interactivity, and personalized learning among young learners (Pegrum, 2016).

To clarify this concept, “digitized environmental education in early childhood” refers to the intentional use of digital technologies to support environmental learning among young children (Mantilla & Edwards, 2019). This includes applications, videos, games, and interactive tools that teach concepts such as recycling, biodiversity, climate change, and sustainability in developmentally appropriate ways. Unlike general educational technology use, which may focus on literacy, numeracy, or entertainment, digitized environmental education specifically targets environmental awareness and action. It combines digital engagement with ecological themes to foster early environmental consciousness and responsibility (Hajj-Hassan et al., 2024).

Despite its potential, the implementation of digitized environmental education faces notable challenges. Only 38% of children worldwide have a fundamental understanding of climate change issues, indicating that environmental awareness among children remains shockingly low (Rulli et al., 2024; Biber et al., 2023). Digital technology is increasingly viewed as a key enabler for addressing this gap (Buchanan et al., 2018). However, significant infrastructural barriers persist, only about 53% of schools worldwide have internet access, which hampers the effective integration of digital tools into teaching and learning (Gupta & Hayath, 2022). This lack of connectivity poses a substantial obstacle to utilizing digital resources for environmental education in early childhood settings (Selwyn, 2011).

Consequently, the issue of digitizing environmental education in early childhood education is increasingly vital, and it has become a significant focus of educational innovation and policy development worldwide (Higgins et

al., 2012). Early childhood is a crucial period for shaping children's understanding and attitudes towards the environment (Madden & Liang, 2017). The use of digitizing tools in ECE can significantly enhance the learning experience and effectiveness of environmental education (Alper, 2016). Researchers from various fields have explored the impact of digital tools on young children's learning, demonstrating that high-quality digitizing tool integration can foster better engagement and comprehension of environmental concepts (Siraj-Blatchford & Siraj-Blatchford, 2006).

Moreover, from cognitive and developmental perspectives, digitizing tools have been found to support the development of essential skills such as critical thinking and problem-solving, which are vital for understanding environmental issues. There is evidence that the use of digital tools in teaching can bridge the gap in environmental knowledge among children from different socio-economic backgrounds, thereby promoting equity in educational outcomes (Erstad & Voogt, 2018). This is particularly relevant for disadvantaged children who might otherwise have limited access to quality environmental education. A child's cognitive and social-emotional skills can be significantly enriched through digitizing tool-enhanced environmental education. Consequently, it is logical to assume that digital tools can provide a feasible solution to compensate for deficiencies in environmental knowledge and skills that children might not acquire at home. Therefore, the effective use of digitizing tools in ECE can contribute to a country's overall human capital by fostering a generation that is more knowledgeable and conscious about environmental issues (Yetti, 2024).

At the same time, efforts have been made globally to integrate digital tools into the educational system, including early childhood education, to enhance learning experiences and outcomes (Johnson et al., 2020). Despite challenges such as limited access to digital resources and infrastructure, various initiatives by governments and non-governmental organizations have aimed to promote the use of digital tools in classrooms worldwide. For example, projects like BridgeIT, which uses mobile technology to deliver educational content, have shown promising results in improving teaching and learning processes, including environmental education in different parts of the world (Wennersten et al., 2015). These efforts underline the growing recognition of digital pedagogy as a vital component of inclusive and equitable education in the 21st century.

In light of this, environmental statistics emphasize the urgent need for effective environmental education. Recent research by Le Quere et al. (2021) indicates that atmospheric carbon dioxide (CO2) levels reached 413 parts per million (ppm) in 2021, a substantial increase from pre-industrial levels. Keenan et al. (2015) highlight alarming deforestation rates, estimating a loss of 10 million hectares of forest annually from 2015 to 2020. These findings emphasize the critical importance of integrating robust environmental education into early childhood education to address global environmental challenges effectively.

Accordingly, scholars advocate for the integration of digital tools in educational settings, particularly in ECE. This approach aligns with Sustainable Development Goal 4 (SDG 4), which emphasizes inclusive and equitable quality education (Elfert, 2019). However, disparities persist in global access to digital tools, especially impacting children in developing regions like sub-Saharan Africa (Selwyn, 2010). Efforts to bridge these gaps are essential to ensuring that all children benefit from innovative digital tools in their educational journey.

To this end, equitable access to digital tools in ECE is crucial, supporting high-quality environmental education that nurtures holistic child development. Ongoing research is vital to understand the evolving integration of digital tools in education. Voogt et al. (2013) stress the need for investigating the epistemology and intellectual structure of digitizing tools to fully comprehend their evolving impact. For instance, Pegrum (2016) discusses how educational software and interactive apps enhance the teaching and learning of environmental concepts in ECE, promoting engagement and critical thinking skills among young learners. Despite these advancements, there remains a gap in understanding how these tools specifically impact environmental education in ECE (Kim et al., 2023). This study addresses this gap by employing bibliometric analysis to investigate longitudinal trends in publications related to the digitization of environmental education within ECE. By examining the evolution and patterns of scholarly output, this study aims to identify key authors, primary sources, and influential academic affiliations contributing to this research domain (Donthu et al., 2021). Additionally, it seeks to uncover co-authorship dynamics and thematic associations through keyword co-occurrence analysis, thereby providing a comprehensive overview of collaborative networks and emerging trends in this field (Lozano et al., 2019).

Ultimately, understanding current publication trends, identifying prolific authors and institutions, and analyzing keyword co-occurrence are essential steps in advancing research on digitized environmental education in early childhood education (Van Eck & Waltman, 2010). The findings from this bibliometric study will shed light on the leading countries, institutions, and collaborative efforts driving this field (Moed, 2005). This comprehensive

overview will provide valuable insights into the global research contexts, offering a clearer picture of how digital tools are being integrated into ECE to enhance environmental education.

Therefore, this study fills a critical gap in the literature by specifically examining how digital tools impact environmental education in ECE through a bibliometric analysis. While previous research has focused broadly on digital tools in education (Kucirkova & Falloon, 2016; Edwards, 2013), few studies have investigated their application to environmental education in early childhood settings (Cutter-Mackenzie et al., 2014). By mapping longitudinal research trends, identifying key contributors, and analyzing collaborative networks, this study offers new insights into the role of digital tools in fostering environmental awareness among young learners. The findings will not only inform future research directions but also support educational strategies and policy development aimed at integrating digital innovations more effectively in environmental education, thereby enhancing learning outcomes and promoting sustainability from an early age. To achieve this aim, the study seeks to answer the following research questions:

1. What are the annual publication trends related to the digitization of environmental education in early childhood curriculum?
2. Which journals have made the most significant contributions to the field related to the digitization of environmental education in early childhood curriculum?
3. Which authors are most cited and influential in the study related to the digitization of environmental education in early childhood curriculum?
4. What are the leading organizations contributing to research related to the digitization of environmental education in early childhood curriculum?
5. Which countries are at the forefront of publishing research on digitization of environmental education in early childhood curriculum?
6. What is the key keywords co-occurrence within the field of digitization of environmental education in early childhood curriculum?

Methodology

This study employs bibliometric analysis to provide an analytical overview of the scholarly context surrounding the digitization of environmental education in early childhood curricula. Bibliometric analysis is a quantitative method that investigates publication patterns, authorship, citation networks, and thematic trends to evaluate the structure and development of scientific knowledge (Aria & Cuccurullo, 2017; Donthu et al., 2021). This approach is particularly effective for tracing the evolution of research domains, identifying influential works, and uncovering emerging topics. By applying bibliometric tools, this study aims to map the key contributors, thematic clusters, and intellectual structure of this interdisciplinary field, offering insights that guide future research and policy development.

Data Source

Publications related to the digitalization of environmental education in ECE were retrieved from the Dimensions database, covering the period from 1968 to 2023. The Dimensions database was selected for its extensive and integrated research coverage, particularly in education and social sciences. It offers a large volume of open-access content and detailed citation data without subscription barriers. Compared to traditional databases like Scopus and Web of Science, Dimensions is recognized for its broader disciplinary scope and more inclusive representation of global scholarship, especially from underrepresented regions and non-elite institutions (Herzog et al., 2020). Its selection aligns with the aim of the study that is to capture a comprehensive and globally inclusive perspective on digital environmental education in early childhood.

Despite its advantages, Dimensions also present certain limitations. While its coverage is extensive, it may not be as exhaustive as Scopus or Web of Science, potentially omitting some relevant literature. The inclusion or exclusion of grey literature and publications from lesser-known journals can influence the completeness and diversity of the dataset, which is particularly significant in interdisciplinary fields like environmental education in ECE (Herzog et al., 2020). Therefore, while the Dimensions database serves as a valuable source for this study, these limitations are acknowledged to avoid overgeneralizing findings and to support a balanced interpretation of the results.

Data Collection Period

An extensive search was conducted on Wednesday, October 9th, 2024, to collect relevant literature. The time frame for the data collection spanned from 1968 to 2023, allowing the study to capture a broad historical and longitudinal perspective on the integration of digital tools into environmental education in ECE (Green, 2015). The starting point, 1968, aligns with the global rise of environmental consciousness that gained momentum in the late 1960s. This period laid the foundation for modern environmental education frameworks. It was notably catalyzed by events such as the 1972 UN Conference on the Human Environment and early policy initiatives on sustainability (Handl, 2012). The end point, 2023, ensures inclusion of the most current research developments, reflecting the ongoing expansion of digital pedagogy and environmental literacy in early childhood contexts (Hook et al., 2018).

Inclusion and Exclusion Criteria

The inclusion criteria focused on peer-reviewed publications addressing the intersection of digital technology, environmental education, and early childhood education. Eligible sources included journal articles, book chapters, edited books, and conference proceedings published in English. To ensure thematic relevance, publications were screened through title and abstract review, with documents unrelated to the scope of study excluded. Grey literature and non-open-access materials were also excluded to maintain quality and analytical consistency (Langham-Putrow et al., 2021).

From the initial 9,214 documents retrieved, 2,124 duplicates were removed, and 6,647 records were screened for relevance. A total of 3,469 grey literature and 3,178 non-open-access publications were excluded during the selection process. After applying all exclusion parameters, a final sample of 443 documents was retained for analysis. These documents represented thematically appropriate and high-quality literature for bibliometric study. The step-by-step data cleaning and keyword selection process is summarized in Table 1.

Table 1. Data cleaning and keyword selection process

S/n	Steps	Description
1.	Initial retrieval	9214 articles identified using search string in Dimensions
2.	Duplicate removal	2124 duplicates removed
3.	Screening	Titles and abstracts screened for relevance to both “digital technology” “environmental education” and “early childhood education”
4.	Exclusion	3469 grey literature and 3178 non-open-access items excluded
5.	Final inclusion	443 documents retained based on peer-review, language, and thematic focus
6.	Keyword refinement	Synonyms consolidated “digital technology” “environmental education”, “early childhood education”

Search Strategy and Article Selection Process

The search was conducted on May 8th, 2024, using the Dimensions database, employing a comprehensive string of keywords related to digitalization, environmental education, and early childhood education. Search terms included “Digital Technology,” “Educational Technology,” “E-learning,” “Environmental Education,” “Sustainability Education,” and “Early Childhood Education,” among others. These keywords were strategically combined using Boolean operators and applied in the TITLE-ABS-KEY fields to ensure precision. Filters were also applied to limit the results to English-language publications from 1968 to 2023.

Following the database query, a total of 7,090 documents were initially retrieved. A systematic review process involving title and abstract screening, followed by exclusion based on relevance, accessibility, and publication type, was implemented. Articles that did not meet the thematic, linguistic, or accessibility criteria were excluded from the final sample. The resulting 443 documents were deemed relevant and were prepared for further bibliometric analysis. The full process of data selection and preparation for analysis is summarized in Figure 1.

While Figure 1 outlines the overall methodological workflow adopted in this bibliometric study from keyword selection to data visualization, the next step involves a more detailed breakdown of the publication screening and eligibility process. To ensure methodological transparency and replicability, the inclusion and exclusion stages

were systematically conducted following PRISMA guidelines (Page et al., 2021). Figure 2 illustrates this process, showing the progression from initial identification to the final selection of documents analyzed.

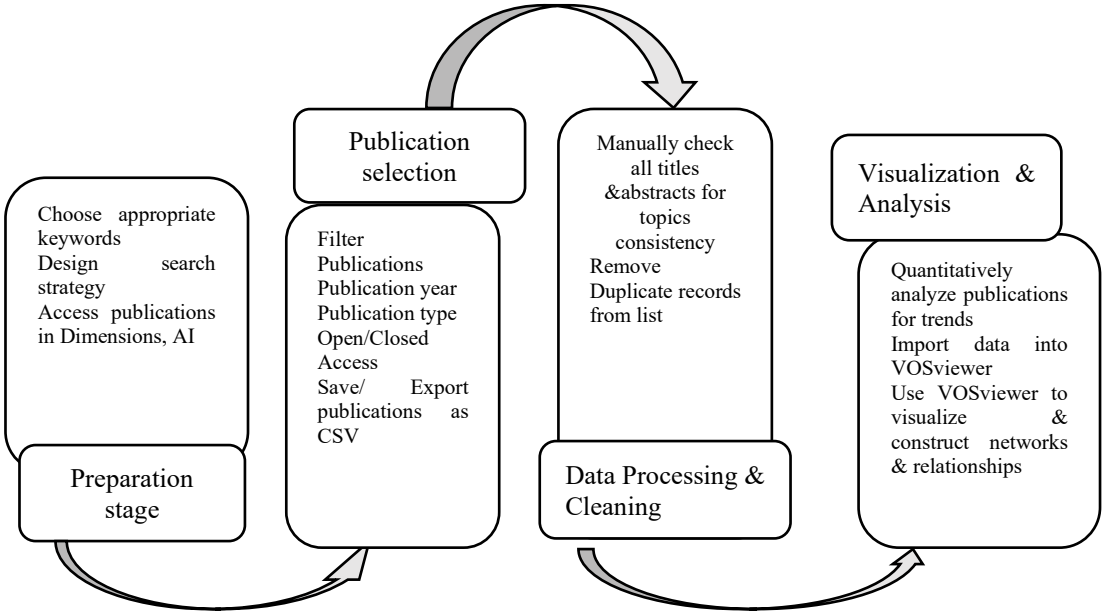

Figure 1. Bibliometric conceptual framework for the study. Adapted from Baako and Abroampa (2023)

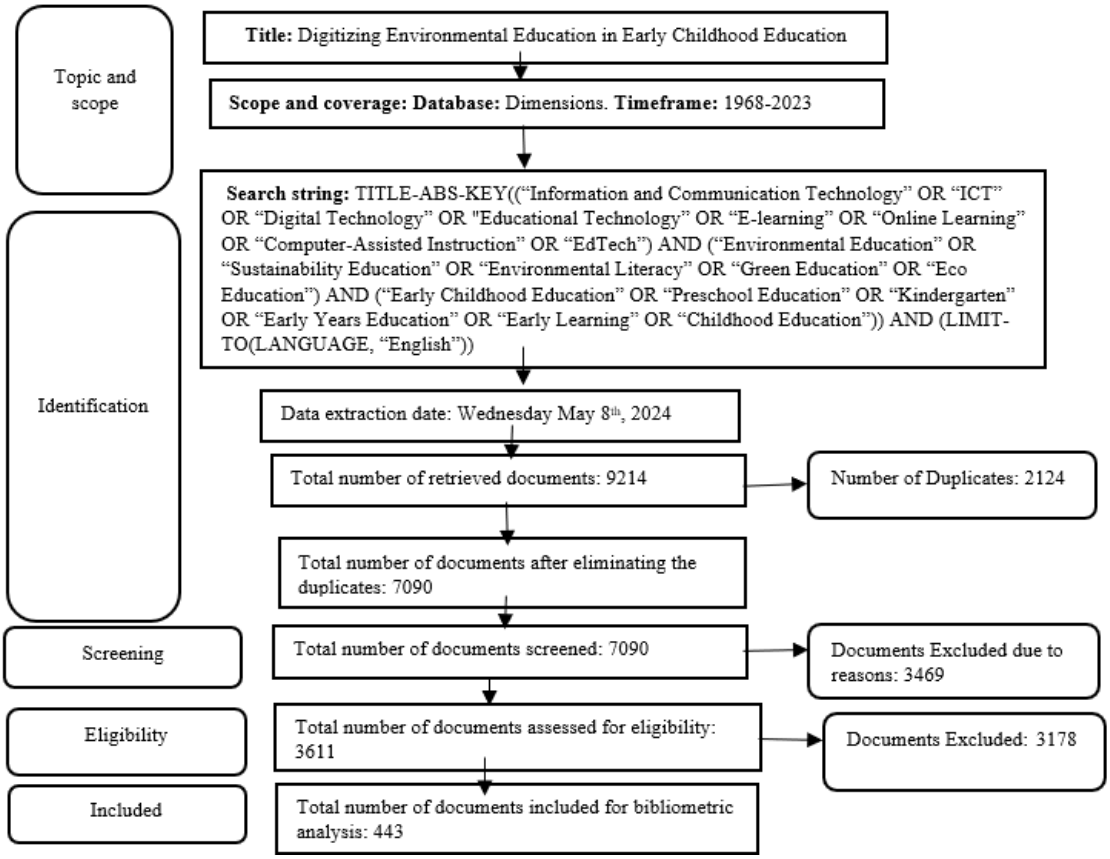

Figure 2. Flow chart illustrating the systematic review according to the PRISMA guidelines

Data Processing and Analysis

The selected documents were exported as a CSV file from the Dimensions database for processing and analysis. The data were cleaned to remove inconsistencies and ensure that only records directly related to the themes of the

study were retained. Keyword harmonization was performed to consolidate synonyms and enhance the clarity of co-occurrence analysis. This ensured a focused and accurate representation of the scholarly discourse in the dataset.

VOSviewer version 1.6.20 was used to conduct the bibliometric analysis, generating network and overlay visualizations. (Van Eck & Waltman, 2010). These visual tools identified patterns of co-authorship, country collaboration, institutional contributions, and keyword co-occurrences. The analysis revealed influential authors, thematic clusters, and emerging research areas in digital environmental education within early childhood contexts. This method provided a robust and visual overview of the intellectual structure of the field (Khodabandelou et al., 2018).

Results

This section presents the key findings from the bibliometric analysis of literature on digitizing environmental education in early childhood curricula. Drawing on data from 443 selected publications, the analysis explores publication trends, influential authors, core journals, collaborative networks, and thematic clusters. The results offer insights into the intellectual structure and emerging directions within this interdisciplinary field.

Publication Trends

Figure 3 presents a bar graph depicting the distribution of annual publications from 1968 to 2023 in the field of digitizing environmental education in early childhood education. The earliest publication recorded was in 1968, with only one publication. For five consecutive years from 1969 to 1973, there were no publications, indicating a period of inactivity. In 1974, a single publication was made, marking a minor resurgence of interest. A significant increase occurred in 1996, with 810 publications, highlighting a substantial growth in scholarly activity. The year 2020 saw the second-largest number of publications, totaling 1,293, likely influenced by the shift to remote learning during the COVID-19 pandemic. The peak year was 2023, with 1,503 publications, demonstrating a continued and growing interest in this research area.

The cumulative frequency graph illustrates the growth pattern of publications over the years. The curve is concave upwards, indicating an accelerating trend in publication activity. Before 1996, publication numbers were minimal, but post-1996, there was a noticeable increase. The slope became significantly steeper from 1996 onwards, particularly between 2019 and 2023, reflecting a rapid growth in research output. This trend underlines the mushrooming importance and recognition of integrating digital tools in environmental education for young children.

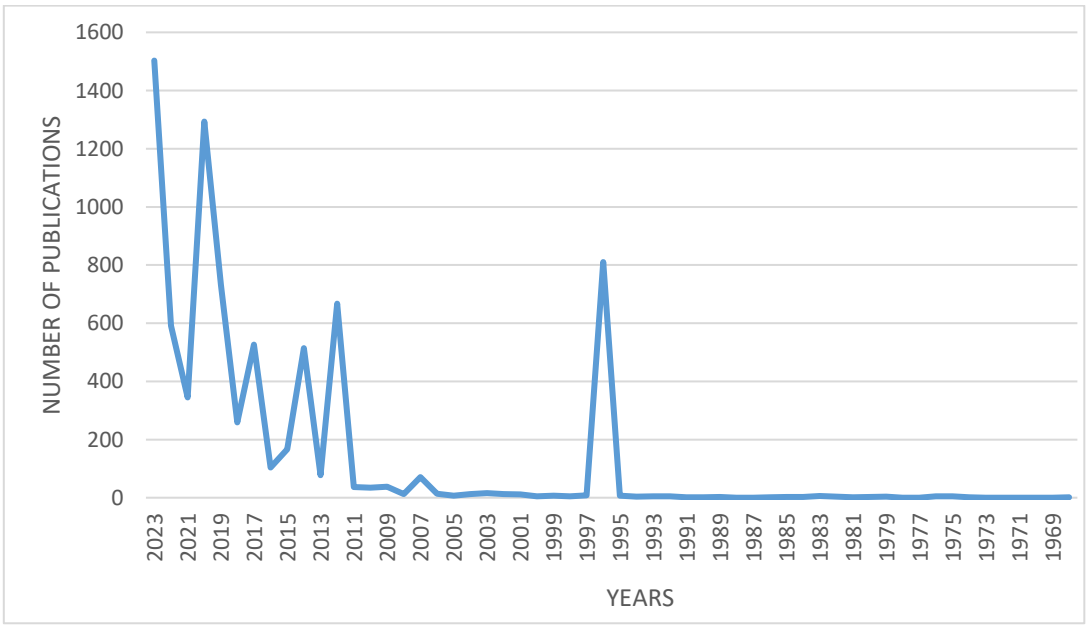

Figure 3. Distribution of publications by years

Most Productive Sources

The bibliometric analysis focused on identifying and visualizing sources that have contributed significantly to the literature on digitizing environmental education in early childhood education. Sources such as *Perspectives in Teacher Education and Development, Springer International Handbook of Education, Journal of Qualitative Research in Education* and *World Sustainability Series* appear prominently, reflecting strong productivity and frequent referencing by scholars. Figure 4 provides an overlay visualization of these sources, showing their relative productivity, influence, and temporal trends in publication. These findings suggest that these sources are highly influential in shaping research in this area. In contrast, sources like Perspectives on Teacher Education, although prolific in output, have received comparatively few citations.

This suggests that although "Perspectives on Teacher Education" produces many documents, they may not be widely cited, indicating potentially limited impact or relevance within the academic community. Therefore, it is reasonable to conclude that sources with higher citation scores tend to attract more manuscript submissions, solidifying their impact on advancing the digitization of environmental education in ECE. The citation network visualization stresses the importance of influential sources in shaping research directions and fostering academic discourse. Consequently, these highly cited sources play a crucial role in the ongoing development and dissemination of knowledge in this field.

The lack of interconnection between different sources in the figure may indicate that the cited sources are distinct and focused on specific aspects of the digitization of environmental education in early childhood education. This suggests that the research field might be diverse, with various studies contributing unique perspectives or findings rather than building directly on each other. It could also imply that these sources are influential within their specific subtopics, leading to isolated clusters of citations rather than a highly interconnected network. Figure 4 describes productive sources.

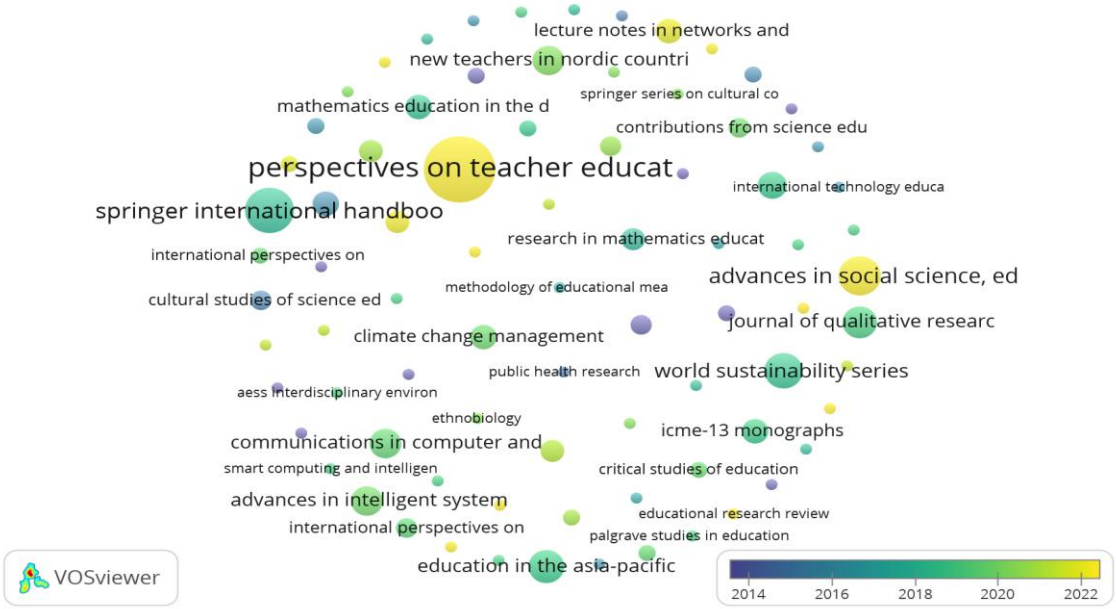

Figure 4. Overlay visualization of most productive sources

Productivity of Authors and Collaborations

Further bibliometric analysis was made to identify authors with the highest citations and collaborations with other authors in publishing in areas related to digitizing environmental education in early childhood education. Figure 5 indicates the patterns of most cited authors and collaboration with other authors in publishing in the area related to digitizing environmental education in early childhood education. Figure 5 indicates that Hallinger Philip, Nguyen-Vien-thong were the most cited authors in this area with 65 citations each. On the other hand, Avery Helen, Hallinger Philip, Nguyen-Vien-thong and Norden Birgitta were the authors with highest links in terms of collaboration. However, the total link strength among each of these scholars was only 2 which signify that the

level of collaboration is very minimal. One good thing about collaboration is that it has brought together scholars from three different continents, Africa, Asia and Europe.

Figure 5. Productivity of authors and collaborations

Most Productive Institutions

The bibliometric analysis also identified the most productive institutions in terms of citations and collaborations within the field of digital environmental education in ECE. Among the top institutions are the University of Johannesburg in South Africa, Mahidol University in Thailand, and Ho Chi Minh City University of Science and Humanities in Vietnam. These universities have made significant contributions to the research context, as indicated by their high citation counts. Their active involvement in this field highlights the global nature of research efforts, with key institutions from Africa, Asia, and Southeast Asia leading the way in advancing the digital integration of environmental education in ECE. When it comes to institutional collaborations, other universities such as the Malmo university, Lund university and Linnaeus university add up to the former institutions as illustrated in the figure 6.

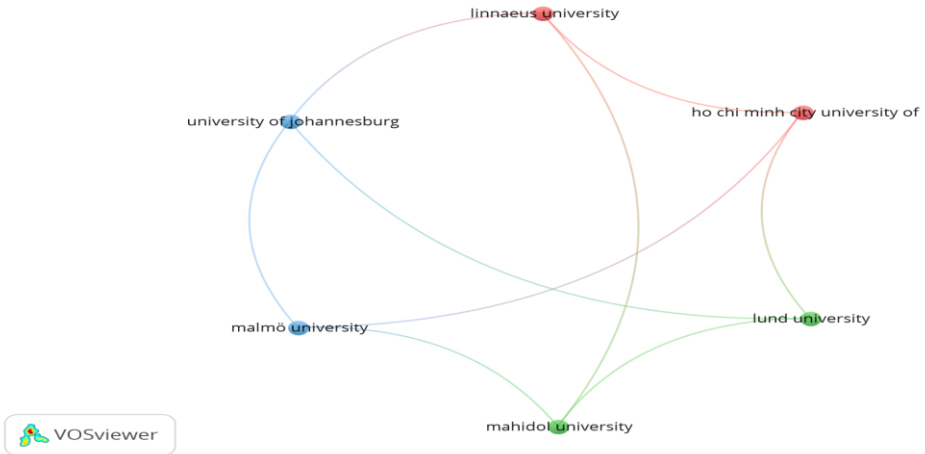

Figure 6. Most productive institutions

Author Co-citation

The co-citation analysis was conducted to identify authors who are commonly referenced in the field of digital environmental education in ECE. With a minimum threshold of two citations per author, the analysis revealed

that out of 4580 sources, 400 authors met the criteria. Among these, Rapleye Jeremy and Mohar David emerged as the leading co-cited authors. This highlights their significant influence and the regular referencing of their work alongside other prominent authors in the field. Interestingly, some authors had no co-citations, indicating either a niche focus or emerging research areas that have not yet established strong connections within the broader academic network. The strong presence of Rapleye Jeremy and Mohar David in co-citation networks highlights their key role in shaping research trends and contributing to the academic discourse on digital environmental education. See figure 7.

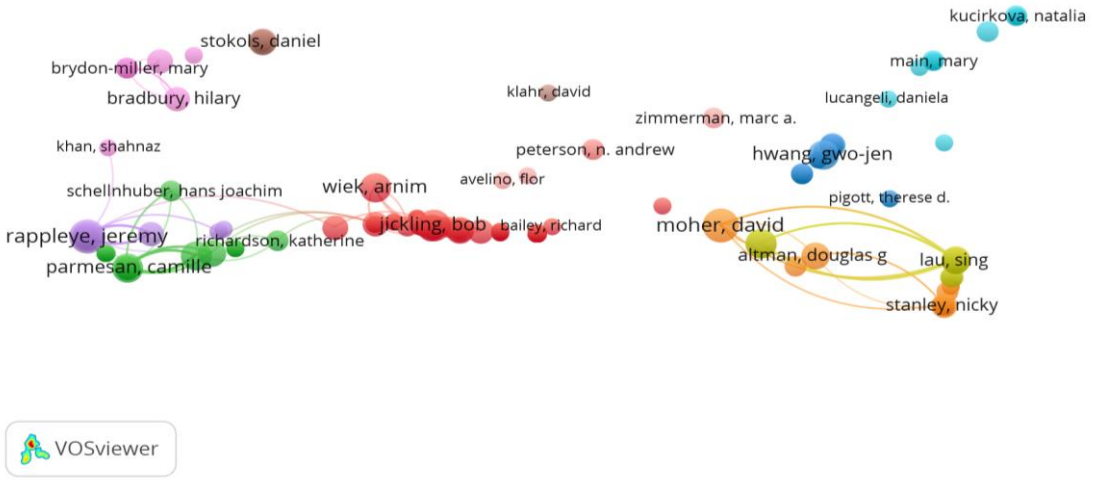

Figure 7. Author co-citation

Co-citation of Cited References

The co-citation analysis of cited references in the field of digital environmental education in ECE, with a minimum citation threshold of two, revealed that only 17 out of 1765 sources met this criterion. This indicates that a select group of references has significantly influenced the field. Among these, the works of Beit-hallahmi et al. (2014), Dezutter et al. (2006), Ivtzan et al. (2011), Hanley (2002), and Venter et al. (2010) stand out as the most co-cited references. Each of these studies has been cited eight times, with a total link strength of 32.

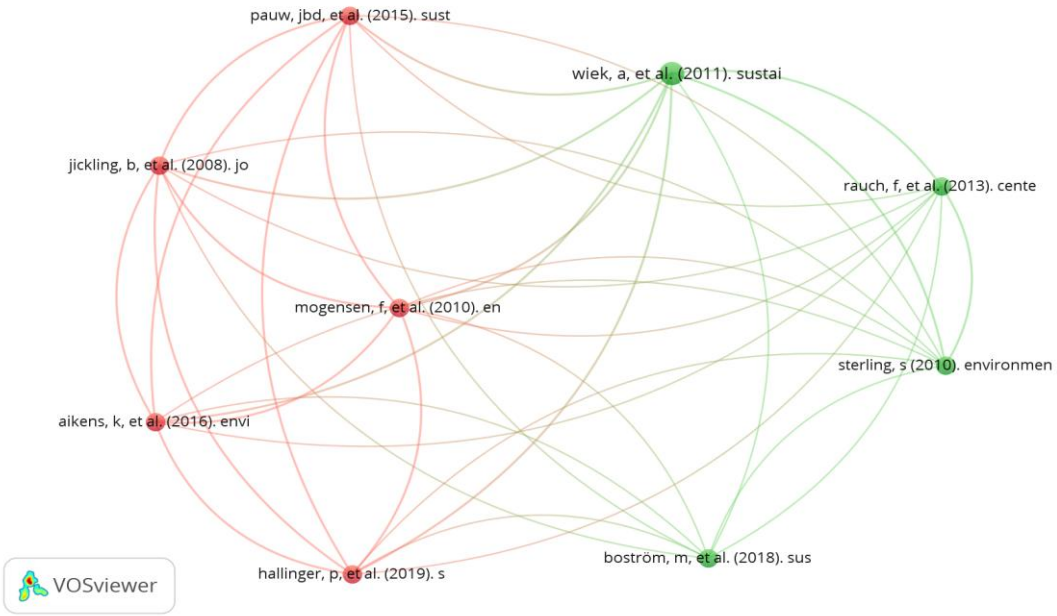

Figure 8. Co-citation of cited references

Interestingly, some of the 17 items were not connected to each other, with only 9 showing interconnections. This suggests that while a small number of references are highly influential, the field also contains isolated studies that

do not frequently co-cite other works. The high level of co-citation for the connected references emphasizes their pivotal role in providing essential frameworks or findings. These key studies are central to ongoing scholarly conversations and advancements in digital environmental education.

Bibliographic Coupling Analysis by Country

Figure 9 presents the bibliographic coupling analysis by country, illustrating the research connections and influence among nations contributing to digital environmental education in early childhood. The bibliographic coupling analysis, focusing on countries as the unit of analysis, revealed that South Africa, Vietnam, and Thailand are leading with 65 citations each and a total link strength of 148. This indicates a significant level of research activity and influence from these countries in the field of digital environmental education. The strong presence of South Africa underlines the continent's growing contributions to this research area. Vietnam and Thailand's prominence highlight the active role of Asian countries in advancing digital environmental education in early childhood education.

Interestingly, among the top ten countries, seven are from Europe, two from Asia, and one from Africa. This distribution suggests that Europe is a major hub for research in this field, contributing the majority of influential studies. The presence of multiple European countries in the top ten may reflect well-established research networks and funding opportunities that support extensive academic work. The inclusion of South Africa and two Asian countries (Vietnam and Thailand) in the top ranks demonstrates the global nature of research efforts and the increasing contributions from diverse regions, indicating a collaborative and widespread interest in the digitization of environmental education in ECE.

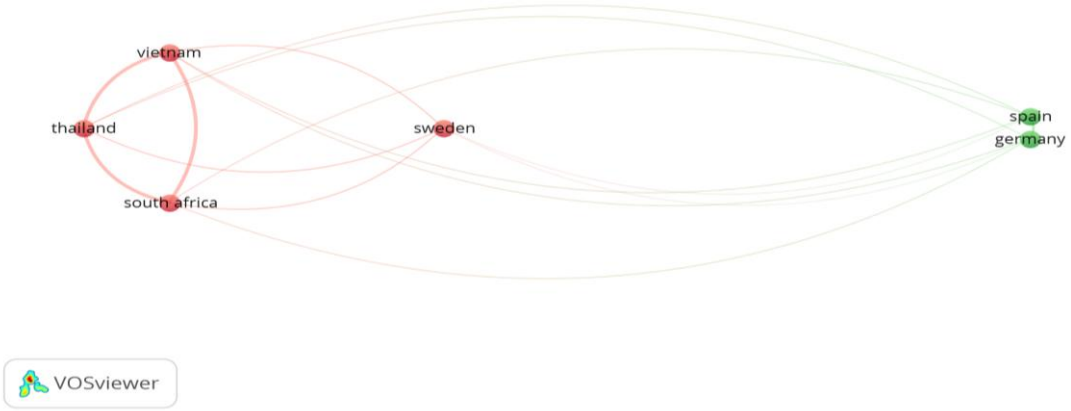

Figure 9. Bibliographic coupling analysis by country

Co-authorship

The co-authorship analysis, focusing on authors as the unit of analysis, offers a detailed understanding of collaborative relationships within the research field of digitizing environmental education in early childhood education. By examining the network of co-authors, this analysis identifies key researchers who play pivotal roles in facilitating and sustaining collaborative efforts. Figure 10 illustrates the co-authorship network among researchers, providing insights into the patterns and strength of collaboration within the field of digital environmental education in early childhood. The network visualization highlights that Jane Ellis is a central figure, frequently collaborating with other authors such as Bailey Sue, Farrelly Nicola, Downe Soo, and Stanley Nicky. This central positioning indicates Ellis's significant influence and leadership within the research community.

The analysis also reveals the presence of several interconnected subgroups, with varying strengths of collaborative ties. Authors like Hollinghurst Sandra, while connected to the main network, display fewer and weaker links, suggesting occasional or recent collaborations. The network's structure, with its mix of strong and peripheral connections, highlights opportunities for expanding collaborative efforts to include a broader range of contributors. This diversity of collaboration emphasizes the importance of key individuals in driving research forward and suggests potential for enhancing research productivity and innovation by fostering new collaborative relationships.

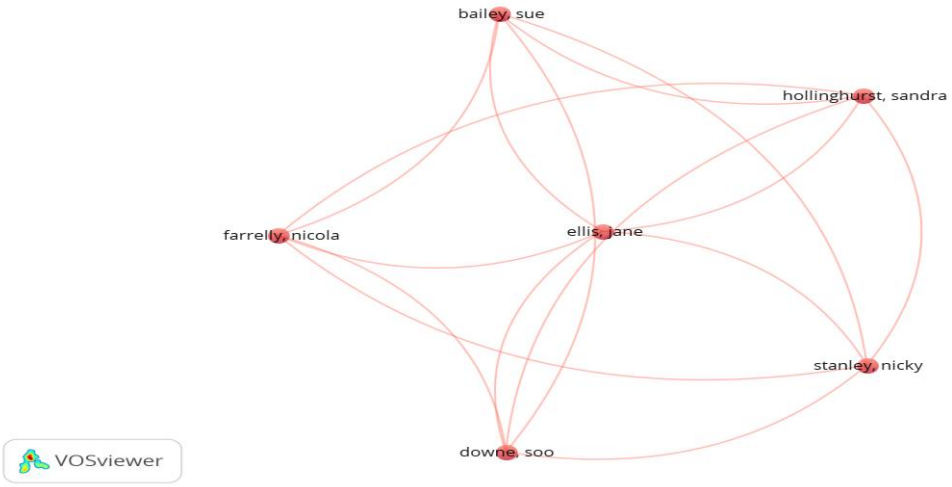

Figure 10. Co-authorship

Co-occurrence of Keywords in Digital Environmental Education in ECE

The co-occurrence analysis of keywords provides valuable insights into the thematic structure and research trends in digital environmental education within early childhood education. The visual map generated by VOSviewer reveals distinct clusters of keywords that highlight various focal areas of research. Each color represents a different cluster, indicating groups of related terms that frequently appear together in the literature. This clustering suggests the presence of interconnected subfields within the broader topic.

The red cluster prominently features terms like "theory," "teacher," "handbook," and "teacher education," indicating a strong emphasis on theoretical frameworks and educational methodologies related to digital environmental education. This cluster likely represents research focused on developing and evaluating educational practices and teacher training programs. These studies are crucial for advancing pedagogical strategies in digital environmental education. By examining these terms, researchers can gain insights into effective teaching methods and curriculum development.

The blue cluster includes keywords such as "climate change," "impact," "sustainable development," and "evidence." This suggests a focus on the outcomes and impacts of digital environmental education, particularly in relation to sustainability and climate change education. Researchers in this cluster are likely investigating the effectiveness of digital tools in fostering environmental literacy and sustainable behaviors among young children. This area of research is essential for understanding how early education can contribute to long-term environmental stewardship.

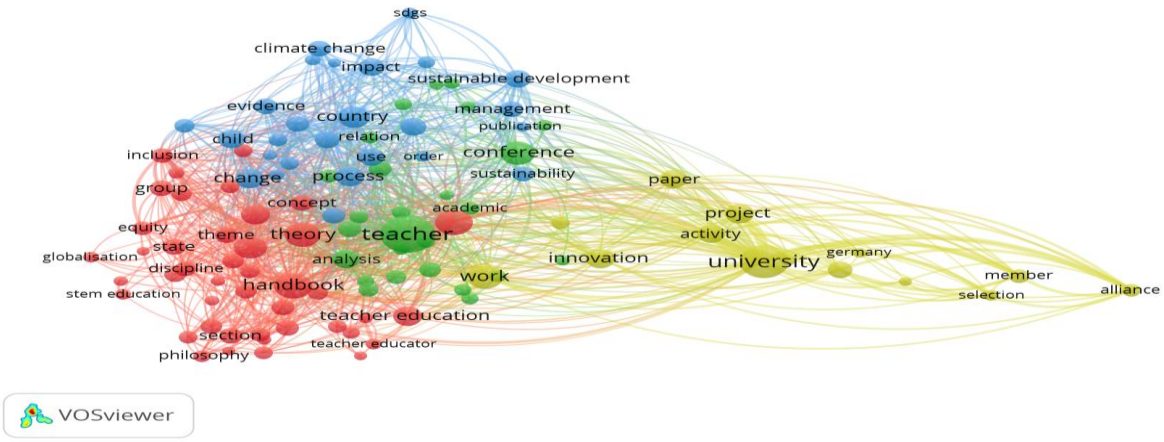

Figure 11. Co-occurrence of keywords in digital environmental education in ECE

The green cluster, with terms like "conference," "management," "publication," and "sustainability," appears to emphasize the dissemination and management of digital environmental education research. This cluster likely

includes studies on the role of academic conferences, publication practices, and the management of digital educational resources. These aspects are vital for the propagation of research findings and the continuous improvement of educational practices.

The yellow cluster features terms such as "university," "project," "innovation," and "activity," highlighting the involvement of higher education institutions and innovative projects in the field. This cluster suggests a focus on collaborative projects, institutional initiatives, and the development of new digital tools and activities to support environmental education in ECE. The involvement of universities in such projects indicates a strong research and development component, driving forward innovations in digital environmental education.

Beyond identifying clusters, the co-occurrence map (figure 11) also reveals the structural relationships and knowledge flows across the subfields. The central positioning of keywords such as "teacher," "work," and "theory" suggests their integrative role across multiple thematic domains, acting as conceptual bridges between research on practice, policy, and pedagogy. The proximity of the red and green clusters indicates a strong link between theoretical development and research dissemination, highlighting the role of academic publishing in shaping pedagogical approaches. Meanwhile, the spatial isolation of the yellow cluster particularly around terms like "university," "alliance," and "innovation" points to institution-led projects that may be less integrated into classroom-level pedagogical discourse, highlighting a potential gap between innovation development and practical application in early learning environments.

Discussion

The results of this bibliometric study point to a notable shift in the body of knowledge on early childhood education research on digitizing environmental education. The paucity of publications throughout the early years, 1968-1980s, indicates how digital technology integration with environmental education in ECE is still in its infancy. This early period's low production can be seen in the context of larger worldwide trends in digital education and environmental consciousness, which were just starting to gain momentum as areas of scholarly interest (Pegrum, 2016; Selwyn, 2011). The gradual rise from the 1980s to the 2000s is related to the increased global attention that environmental and sustainable issues are receiving, as well as the developments in digital technology that started to have an impact on educational practices. This pattern emphasizes the relationship between advancements in technology and the growing understanding of the role that environmental education plays in influencing young children's views toward sustainability.

In this regard, the emergence of digital technologies in early childhood education throughout this time span reflects both a wider movement in educational philosophies stressing experiential and interactive learning as well as technological improvements. Digital technology integration made environmental education more dynamic and enabled students to interact with the material in creative ways that complemented international educational reforms (Buchanan et al., 2018). Furthermore, the gradual increase in publications during this period of time reflects the increased awareness of environmental issues and the importance of early education in resolving them on a worldwide scale. This stage of development emphasizes how crucial digitization is to improving environmental education's efficacy and accessibility while also supporting global educational objectives and sustainability initiatives.

Significantly, the notable expansion that took place between the years 2000 and 2010 signifies a paradigm-shifting era in which digital technology was thoroughly integrated into early childhood environmental education methodologies. Global sustainability programs, like the UN Decade of Education for Sustainable Development (Huckle & Wals, 2015), and the growing accessibility of better digital tools during this time period also corresponded with an increase in publications. A change in pedagogical techniques was made possible by technological improvements, especially in the area of interactive and mobile learning technologies (Kim & Smith, 2017). This allowed teachers to include environmental content into digitally mediated learning experiences for young children (Haleem et al., 2022). Furthermore, as a result of these technical advancements and the demands of modern education, there has been a growth in publications since 1996, which indicates increased scholarly interest (Dhawan, 2020).

Subsequently, the period from the 2010's to 2023, the observed peak in publication rates signifies the maturation of the field. The stabilization in research output suggests that foundational studies have been established, and current research is increasingly focused on building upon existing knowledge. This pattern is common in emerging academic fields, where an initial phase of rapid growth is followed by a more sustained level of scholarly activity, characterized by deeper exploration and refinement of prior findings (Zawacki-Richter et al., 2020). As a result,

the field of digital environmental education in early childhood has entered a phase of consolidation, where new studies not only expand the existing literature but also address gaps in research, such as the underrepresentation of low-income and developing regions in the global discourse (Alò et al., 2020).

Nonetheless, given the crucial role early childhood education plays in fostering lifelong environmental attitudes, it is noteworthy that some regions are underrepresented in research on digital environmental education. Closing this gap is necessary for attaining the Sustainable Development Goals, particularly those related to inclusive and equitable education and urgent action on climate change (Ozturk, 2023). It is also critical for promoting greater equality in global research (Gupta & Vegelin, 2016). Digital tool accessibility is limited in many places, especially in low-income nations, which makes it difficult to incorporate technology-driven environmental education into ECE settings. Closing this gap will improve educational performance while simultaneously promoting early environmental literacy, giving the next generation the information and abilities they need to take on urgent global concerns (Biber et al, 2023).

Thus, to address the underrepresentation of research from developing countries, practical interventions are needed. These may include regional research funding initiatives that support local researchers, cross-national research partnerships between Global South and Global North institutions, and open-access publication incentives for low-resource settings (Sabzalieva et al., 2020). International organizations and education ministries can also develop policy frameworks that embed environmental education into early childhood curricula and teacher preparation programs (Leal - Filho et al., 2018). Such strategies can bridge epistemic gaps and enhance the global inclusivity of digital environmental education scholarship in early childhood contexts (Murcia et al., 2018).

Additionally, the way that digital environmental education is being integrated with more general global challenges like the fight against poverty, technological advancements, and the emergence of artificial intelligence (AI) emphasizes how important it is to use multidisciplinary approaches. Teachers can now connect environmental education with these changing global contexts in relevant and participatory ways due to the unique opportunities provided by digital technologies. Through integrating these resources into early childhood education, children could be given the tools they need to become change agents in their neighborhoods, encouraging environmentally friendly behaviors and building resilience in the face of rapidly changing technology (Kim & Smith, 2017). The potential of digital environmental education to promote critical thinking and environmental stewardship among young learners is vast, but it requires a concerted effort. Therefore, collaborative endeavors among researchers, policymakers, and educators are crucial to harnessing this potential and ensuring that digital tools in ECE contribute to a more inclusive, equitable, and sustainable future.

Equally important, key sources such as "*Perspectives in Teacher Education and Development",* "*Springer International Handbook of Education", "Journal of Qualitative Research in Education"* and *"World Sustainability Series"* have emerged as pivotal contributors to the discourse on digitizing environmental education in early childhood education. These sources play a crucial role in disseminating cutting-edge research, and their prominence within the field suggests a rigorous peer-review process and a broad readership, which likely contributed to their influential status. The high citation rates associated with these journals reflect their critical impact on shaping contemporary educational practices. This is consistent with Royle's et al. (2013) findings, which emphasize the role of leading journals in promoting innovative approaches to environmental education. The "World Sustainability Series", for instance, serves as a bridge between environmental science and educational theory, facilitating the integration of sustainability concepts into ECE curricula, a development highlighted in recent literature for its influence on educational innovation and research agendas (Waltman & Van Eck, 2012).

In terms of scholarly impact, citation analysis emphasizes an author's direct impact on the area by concentrating on how frequently their work is mentioned. Among the prominent contributors are authors like Philip Hallinger and Nguyen-Vien-Thong, whose studies on digital education and educational leadership, respectively, are often referenced. For example, Nguyen's (2018) investigation of digital learning tactics has been essential, demonstrating its broad suitability in early childhood education settings. These authors' high citation counts highlight both the fundamental nature of their work in promoting the integration of digital technology within ECE and their individual contributions. Their work has affected not just instructional strategies but also the way early childhood environmental education is framed.

Co-citation analysis, on the other hand, provides a broader perspective of scholarly effect by looking at the frequency with which two authors are referenced jointly in later works. Co-citation identifies important contributions such as David Mohar and Jeremy Rapleye, demonstrating their combined influence on the field's intellectual framework. Although the citation numbers of these authors may not be the greatest, their work is often mentioned in conjunction with other important studies, indicating that their research is valued as a key contributor

to the development of the discourse on digital environmental education. This indicates that Rapleye and Mohar's research shows how their work is connected to larger scholarly discourses by providing fundamental frameworks or notions that others build upon (Trujillo & Long, 2018).

Taken together, these citation patterns highlight different types of scholarly contribution. Citation analysis emphasizes individual leadership and direct scholarly contributions, while co-citation analysis reveals how the work of various authors collectively forms the conceptual backbone of the field. This interconnectedness, as illustrated by co-citation, reinforces the idea that progress in the digitization of environmental education in ECE is built on collaborative intellectual foundations rather than isolated scholarly efforts (Hota et al., 2020).

Regionally, the prominence of scholars from Asia, such as Nguyen, reflects a regional concentration of research activity, which points to geographical disparities in the field. Although there are emerging contributions from other regions, such as Africa, where institutions like the University of Johannesburg are becoming increasingly involved, there is still a noticeable imbalance. As Adams (2013) noted, increasing international collaboration among scholars could significantly enhance research quality and innovation. Strengthening collaboration would foster a more inclusive and interdisciplinary approach, leading to richer, more diverse perspectives in the field of digital environmental education.

Moreover, institutions such as the University of Johannesburg, Mahidol University, and Ho Chi Minh City University of Science and Humanities have been identified as leading research centers in the field of digitizing environmental education in early childhood education. Their significant contributions highlight the global nature of research efforts in this area, challenging the traditional dominance of Western institutions. This shift signifies a growing recognition of the valuable insights and context-specific knowledge that institutions from diverse geographical regions can offer. Teferra and Knight (2008) argue that including perspectives from non-Western institutions promotes a more comprehensive and inclusive approach to educational innovation. This inclusion is particularly important for addressing the unique challenges and opportunities presented by different cultural and environmental contexts, which are often underrepresented in research.

Thus, a move toward a more representative and balanced contribution to the field is also reflected in the growing significance of institutions outside of the traditional western world. This pattern emphasizes how important it is to promote global cooperation and communication in order to close the gap between various geographic areas (Wagner et al., 2015). Such initiatives are essential to guarantee that the digitization of environmental education in early childhood education is based on state-of-the-art research and customized to fit the unique requirements of diverse communities. Institutions from Asia and Africa support a more equal and productive global education system, which is essential for tackling common issues like sustainability and climate change. They also contribute to a more inclusive research environment. Moreover, the research findings indicate that when it comes to the dissemination of knowledge in digital environmental education for early childhood education, books, book chapters, and conference proceedings significantly outnumber journal articles. In contrast to traditional bibliometric analysis, which tend to focus mostly on journal articles, this study highlights the diversity of publication within the discipline. The popularity of books and related formats points to a more complex method of disseminating knowledge since they provide in-depth analysis, case studies, and theoretical frameworks that shorter journal articles would not be able to fully address (Monroe et al., 2019). This pattern may point to a preference for publishing in formats that allow for longer conversations, especially in fields where pedagogical and multidisciplinary ideas are critically important. As the field matures, however, a greater focus on peer-reviewed journal articles could reinforce its empirical and theoretical foundations. Doing so would also increase its integration into mainstream academic discourse. Expanding the prevalence of journal articles would raise the visibility and academic credibility of digital environmental education in ECE.

At the same time, the limited availability of open access sources further complicates the accessibility of research findings in digital environmental education for early childhood education. Open access publications play a pivotal role in widening knowledge dissemination, enhancing global collaboration, and ensuring equitable access to educational innovations (Nguyen, 2018; Leal -Filho et al., 2018). The scarcity of open access resources identified in this study suggests potential barriers to knowledge sharing and collaborative research efforts, which may hinder the field's progress toward evidence-based practices and informed policy developments. This situation emphasizes the critical need for strategies that promote open access publishing initiatives, strengthen support for open science practices, and foster inclusive approaches that recognize the value of diverse publication formats while upholding rigorous scholarly standards.

Therefore, addressing these challenges is essential not only for advancing research but also for ensuring that findings are accessible to a broader audience, including practitioners, policymakers, teachers and researchers in

resource-constrained settings. By facilitating access to high-quality research, the field can enhance its impact and relevance, ultimately contributing to the sustainable development goals related to education and environmental stewardship. Moreover, fostering a culture of openness in research will empower educators and stakeholders to implement innovative practices that address pressing environmental challenges, ensuring that future generations are equipped with the knowledge and skills necessary for a sustainable future.

Conclusion

The findings of this study offer significant insights into the evolution of digitizing environmental education in early childhood education from 1968 to 2023. The bibliometric analysis identified a substantial increase in academic interest, particularly notable in 2023 with a record 1503 publications. This rise underlines the growing recognition of digital tools' potential to enhance engagement and personalized learning in ECE environmental education (Haleem et al., 2022). By establishing a comprehensive baseline, the study marks key milestones and trends, providing a foundation for future research focused on the critical developmental phase of early childhood, where foundational attitudes and environmental knowledge are formed.

Hence, this study emphasizes the importance of global research efforts and collaborations, highlighting significant contributions from diverse geographical regions. It emphasizes the need for context-specific research and addresses critical gaps, such as the underrepresentation of research from developing countries. Future research should prioritize inclusivity and diversity to foster a more effective and equitable educational context. This aligns with global goals such as the Sustainable Development Goals (SDGs) related to quality education and climate action, recognizing the unique influence of early childhood education in fostering long-term environmental awareness (Mliless et al., 2024).

Overall, this study lays a strong foundation for future research and innovation in digitizing environmental education in ECE. By mapping existing literature and trends, it provides a valuable resource for researchers and policymakers aiming to advance this field. The findings emphasize the importance of interdisciplinary approaches and international collaboration, especially in the wake of challenges like the COVID-19 pandemic, which has accelerated the adoption of digital tools in education. Addressing identified gaps and leveraging global research efforts will be crucial in integrating digital technologies into early childhood environmental education, ultimately contributing to a more sustainable and technologically advanced educational framework. This ensures that early education stages foster a generation that is both environmentally literate and digitally proficient.

Recommendations

To enhance the integration of digital technologies in environmental education within early childhood education settings, specific recommendations for educators, policymakers, and researchers are essential.

For Teachers

Teachers should actively incorporate interactive and experiential digital tools into environmental education curricula, as these tools enhance young learners' engagement and understanding of sustainability issues. Utilizing platforms that combine digital storytelling, simulations, and virtual experiences can provide children with hands-on learning that fosters environmental awareness from an early age (Buchanan et al., 2018; Murcia et al., 2018; Haleem et al., 2022). Moreover, professional development programs are crucial for equipping teachers with the skills needed to effectively integrate these technologies into their classrooms. Continuous teacher training in emerging digital technologies and their educational applications should be prioritized to keep pace with technological advancements (Selwyn, 2011). Teachers should also be encouraged to share best practices through professional networks to build a collective knowledge base for digital environmental education.

For Policymakers

Policymakers must ensure that national education policies prioritize the integration of digital technologies in environmental education, particularly in early childhood settings. This could include the development of funding programs that support the acquisition of digital learning tools in low-income and underrepresented regions,

thereby addressing disparities in digital access and promoting inclusivity (Alò et al., 2020). Governments should foster collaborations between educational institutions, technology providers, and environmental agencies. This aligns with the Sustainable Development Goals, particularly Goal 4 on inclusive education and Goal 13 on climate action (Gupta & Vegelin, 2016). Additionally, legislative frameworks should encourage schools to adopt evidence-based digital practices that promote environmental responsibility from early childhood. Public-private partnerships may also be leveraged to support long-term investment in digital learning infrastructures.

For Researchers

Researchers should continue to investigate the long-term impacts of digital environmental education in ECE settings, focusing on how digital tools can foster environmental stewardship among young learners. Further research is needed to explore the effectiveness of various digital platforms and how these tools influence children's cognitive and emotional responses to environmental issues (Zawacki-Richter et al., 2020). Additionally, comparative studies that examine the accessibility and effectiveness of digital environmental education across different socio-economic contexts would provide valuable insights for both global and local implementation strategies (Hajj-Hassan et al., 2024). Collaborative research efforts between institutions in high-income and low-income regions could bridge existing knowledge gaps and contribute to the development of more equitable digital education systems.

For Ministries of Education

Ministries of education should establish national strategies that institutionalize digital environmental education in early learning systems. These strategies should ensure curriculum alignment, teacher capacity-building, infrastructure development, and monitoring mechanisms. Ministries can play a key role in creating centralized repositories of digital learning materials and guiding schools on their effective use. Policies should also promote equitable access to digital tools and internet connectivity, particularly in underserved regions, to reduce disparities. By investing in structured implementation plans, ministries can scale up digital environmental education and contribute meaningfully to national and global sustainability agendas (ElMassah & Mohieldin, 2020).

For Donors and Development Partners

Donors and international development partners have a key role to play in supporting digital environmental education initiatives, especially in resource-constrained settings. They can fund pilot projects that test scalable digital interventions for teaching sustainability concepts in ECE. Investment in open-source digital tools and teacher training initiatives can ensure broader access and long-term sustainability. Donors should also support research collaborations that include scholars from developing countries to promote more inclusive and context-sensitive innovations. Finally, donor funding should align with national education priorities and sustainability frameworks to ensure long-term impact and systemic integration.

Scientific Ethics Declaration

* The author declares that the scientific, ethical, and legal responsibility of this article published in JESEH journal belongs to the author.

Conflict of Interest

* The author declares that he has no conflict of interest

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