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Bibliometric Analysis of Research Trends in Conceptual Understanding and Sustainability Awareness through Artificial Intelligence (AI) and Digital Learning Media

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ABSTRACT

This study conducts a bibliometric analysis to explore research trends in the conceptual understanding and sustainability awareness fostered through Artificial Intelligence (AI) and digital learning media. The growing integration of digital platforms in education has opened new avenues for enhancing students' comprehension of key concepts and their awareness of sustainability issues. By examining a decade of academic publications, this analysis identifies significant themes, influential authors, and emerging trends in the intersection of digital learning tools, conceptual understanding, and sustainability education. The results reveal notable growth in publication trends, with a sharp increase observed in the last three years. China and the United States are the leading contributors in terms of publication volume, followed by the United Kingdom, India, and Spain, reflecting global engagement in this research area. Affiliation analysis highlights the contributions of institutions such as Purdue University, King Abdulaziz University, and Nanyang Technological University, which have played significant roles in advancing this field.

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1. INTRODUCTION

In recent years, Artificial Intelligence (AI) and digital learning media have increasingly become central to educational practices, offering new opportunities to enhance conceptual understanding and foster sustainability awareness (Chen *et al*., 2020; Al-Khassawneh, 2023). The rapid development of technology, especially in AI, and the proliferation of digital devices and e-learning platforms to interactive applications, have transformed how students engage with content, enabling more dynamic and personalized learning experiences (Alam & Mohanty, 2023; Nursalim *et al*., 2022; Al Husaeni *et al*., 2024). Learning previously based on traditional approaches is now increasingly moving towards dynamic, personalized, and adaptive experiences, allowing students to learn at their own pace and learning style (Alimi *et al*., 2021).

Along with these changes, education systems around the world are faced with major challenges in addressing 21st-century issues, such as climate change, environmental degradation, and the need for better management of natural resources (Mohmmed, 2023; Ibrahim *et al*., 2024; Pablo *et al*., 2022). In this context, there is a growing push to integrate sustainability education into the curriculum, to equip students not only with knowledge about global environmental issues but also with practical skills to contribute to more sustainable solutions (Solihah *et al*., 2024; Namasivayam *et al*., 2023). Sustainability awareness, which includes an understanding of the importance of sustainable practices in everyday life, has emerged as a critical element in shaping the next generation of environmentally conscious learners (Nurramadhani *et al*., 2024; Ekamilasari & Pursitasari, 2021; Cruz *et al*., 2022).

In this regard, conceptual understanding, which refers to a deep understanding of key concepts and their interconnections, is a critical component of effective learning (Fiandini *et al.,* 2024; Fadjarajani *et al*., 2024). Digital learning media have proven effective in enhancing this understanding by providing engaging, interactive, and multimedia-rich environments that help students grasp complex ideas (Ghartey *et al*., 2024; Ariyanti & Nandiyanto, 2022). At the same time, sustainability awareness has emerged as a critical element in preparing students to engage with the pressing environmental challenges facing the world today. Digital platforms, through their global reach and diverse content, offer a unique way to promote sustainability awareness, ensuring that learners across contexts can access information and engage in conversations about sustainable practices. This study aims to explore research trends in the use of digital learning media to enhance conceptual understanding and sustainability awareness. Through a bibliometric analysis of key publications of a decade, the study identifies emerging themes, influential authors, and significant contributions to the field. These findings offer valuable insights into how digital learning media shape sustainability education and awareness, with implications for future research, curriculum design, and educational practice.

2. METHODS

This study uses a bibliometric analysis method to explore research trends related to conceptual understanding and sustainability awareness through Artificial Intelligence (AI) and digital learning media. Data for analysis were obtained using relevant keywords, namely "Artificial intelligence", OR "Conceptual understanding", OR "Digital learning media", OR "Sustainability awareness" OR “Education”, which were selected based on their relevance to the research topic. The search was conducted on the Scopus-recognized database with a focus on publications published between 2014 and 2024. This search was conducted using a combination of keywords in the TITLE-ABS-KEY column, which includes the title, abstract, and

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keywords of relevant articles. From this process, a total of 5.962 articles were identified, representing a comprehensive dataset of publications related to the chosen keywords. This extensive dataset highlights the growing academic interest and the rapid expansion of research in the fields of AI, digital learning media, conceptual understanding, and sustainability awareness. These articles form the foundation for the bibliometric analysis, ensuring that the study captures a wide range of perspectives, disciplines, and contributions.

After the data was collected, a bibliometric analysis was carried out to identify key trends-themes, influential authors, and relationships between related research topics, such as the relationship between AI and conceptual understanding or sustainability awareness. This analysis also includes mapping the collaboration network between authors, institutions, and countries to see the extent to which international collaboration has played a role in the development of this research.

VOSViewer, the software used for bibliometric analysis, allows for a visual mapping depicting keyword networks, leading authors, and clustering of emerging research themes. The tool also enables the analysis of keyword frequencies in publications, providing a clear picture of emerging or dominant topics in the literature related to conceptual understanding and sustainability awareness. The selected data were then analysed to identify key research trends and significant contributions to developments in the field.

Through this approach, the study not only provides deeper insights into how AI and digital media contribute to sustainability education and awareness development but also identifies possible future research directions. The large dataset of 157,865 articles ensures a robust analysis, offering valuable insights into global research efforts and highlighting areas of emerging significance. Detailed information regarding how to use and analyze using VOSviewer is reported elsewhere (Al Husaeni & Nandiyanto, 2022).

3. RESULTS AND DISCUSSION

3.1. Trend of Publications

Figure 1 shows the publication trend from 2014 to 2024, reflecting the increasing interest in research related to technologies such as artificial intelligence (AI) and digital learning media. In the early period, namely 2014 to 2018, the number of published documents was relatively small with slow growth, indicating that this topic was still in the early stages of exploration by the academic community. Starting in 2019, the number of publications showed a gradual increase, reflecting the increasing attention to digital technology in education, especially in supporting concept-based learning and sustainability awareness.

A significant spike occurred after 2020, with an exponential increase continuing until 2024, reaching more than 2,000 documents. This growth was influenced by the acceleration of technology adoption during the COVID-19 pandemic, which forced many educational institutions to adopt digital learning media and AI-based systems. In addition, the increasing urgency of global issues such as sustainability and educational transformation also drove research in this field. This trend reflects the global shift towards more innovative, adaptive, and relevant educational solutions to the challenges of the 21st century.

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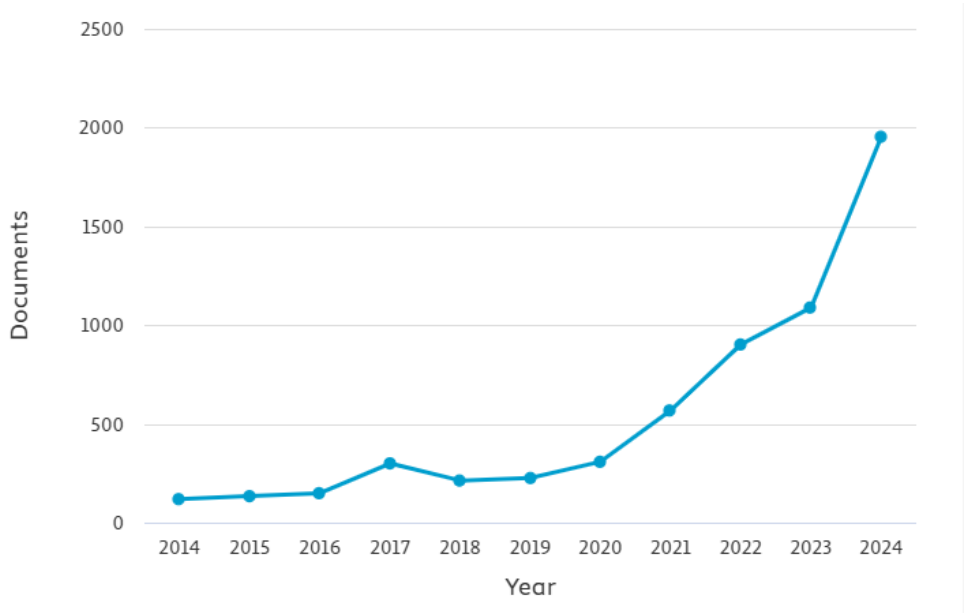

Figure 1. Development of publications over the last ten years.

3.2. Publication Contribution by Country and Affiliations

Figure 2 shows the contribution of publications by country. China is at the top with the highest number of publications, followed by the United States (US). The dominance of these two countries shows their significant role in leading global research, especially in the areas of technology, education, and sustainability. China, with its rapid advancement in artificial intelligence (AI) and digital technologies, shows a strong focus on innovation and international collaboration. Meanwhile, the US maintains its position as a global research hub with the support of top universities and large investments in technology and education. Countries such as the UK, India, and Spain also make significant contributions, reflecting their presence in global research relevant to technology-based education and sustainability. Australia, Germany, South Korea, Saudi Arabia, and Taiwan complete the list, showing the active participation of these countries in technology-based research despite their smaller scale compared to China and the US.

Figure 3 represents publication contributions by institutional affiliation. The first position is occupied by Purdue University. This signifies the important role of Purdue University in producing high-quality research relevant to education, technology, and sustainability. King Abdulaziz University of Saudi Arabia is in second place, reflecting the country's active efforts in building global research capacity through leading educational institutions. Nanyang Technological University in Singapore and The Education University of Hong Kong also make significant contributions, highlighting Asia's role in driving global innovation and research. Other institutions such as Arizona State University, Beijing Normal University, and University College London (UCL) make significant research contributions focused on educational transformation, digital technologies, and curiosity. The University of Michigan, Ann Arbor, and Tecnológico de Monterrey in Mexico round out the list with solid contributions, representing global collaborations involving institutions from North America, Latin America, Europe, and Asia.

Figures 2 and 3 illustrate the dynamics of global contributions to research involving different countries and institutions. The dominance of developed countries such as China and the US, supported by leading higher education institutions, indicates a strong focus on technological innovation and demand-driven education. In addition, the active participation

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of developing countries such as India, Saudi Arabia, and Taiwan demonstrates the trend of globalization in research, with contributions from different regions of the world increasing. This distribution highlights the importance of international collaboration in encouraging innovative research that can provide solutions to global challenges, especially in the fields of education, interest, and technology. With the presence of leading institutions from various countries, this research reflects not only the identity but also the great potential in the development of future-oriented science.

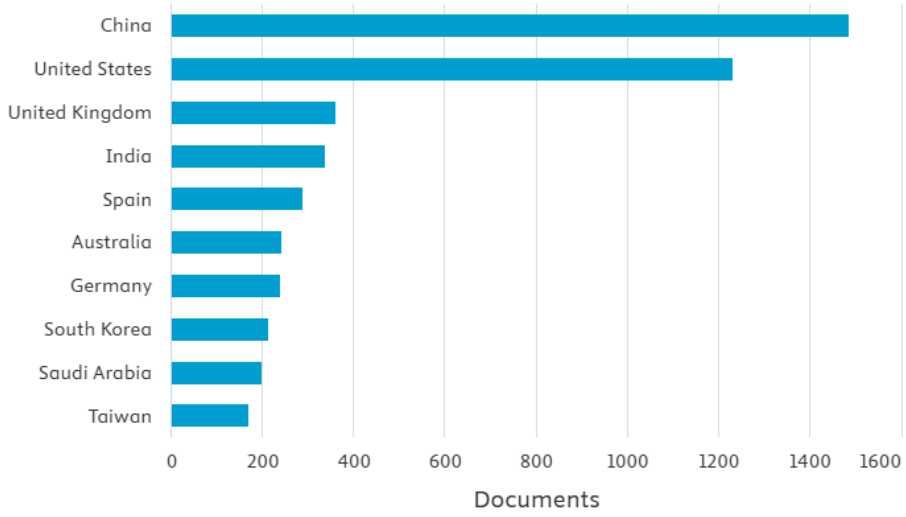

Figure 2. Top 10 Countries Contributing to Global Research Publications.

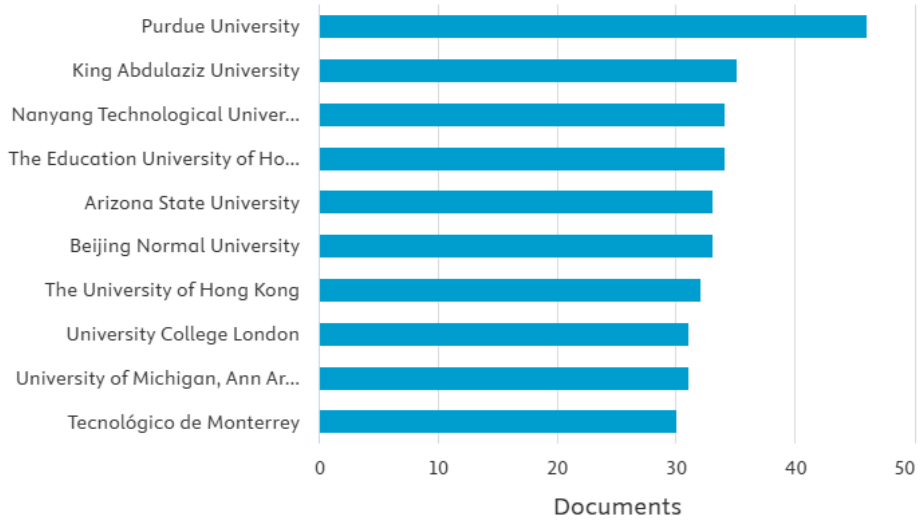

Figure 3. Top 10 Affiliations Contributing to Global Research Publications.

3.3. Visualization Mapping

Figure 4 visualizes the keyword network depicting the complex relationships between research topics focused on Artificial Intelligence (AI), Conceptual Understanding, Digital Learning Media, and Sustainability Awareness, grouped into clusters based on color. Each cluster reflects an interrelated research theme. The green cluster centers on technology and artificial intelligence, with key keywords such as “Artificial Intelligence,” “Deep Learning,” “Chatbot,” “Prediction,” and “Optimization,” indicating a focus on developing AI-based

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algorithms and technologies to support practical applications in education, big data analysis, and decision-making. The red cluster highlights the conceptual learning and skills aspects of education, including terms such as “Conceptual Understanding,” “Skill,” “Competency,” “Pedagogy,” and “Critical Thinking,” emphasizing the importance of in-depth understanding of complex concepts through innovative approaches such as active and inquiry-based learning.

The blue cluster focuses on educational innovation, encompassing keywords such as "Sustainable Education", "Engineering Education", "Online Education", and "Opportunity", which show the role of modern learning methods such as flipped classrooms and online education in supporting sustainability-based learning. In this cluster, Sustainability Awareness is one of the important elements, showing the integration of sustainability issues in education that aims to equip students with relevant skills to face global environmental challenges. The yellow cluster reflects digital transformation and technological innovation with keywords such as "Digital Transformation", "Innovation", and "Machine Learning Algorithm", which show how digital technology is increasingly influencing education and research. Meanwhile, the purple cluster includes aspects of interaction and supporting technologies such as "Virtual Reality", "Interaction", "Feedback", and "Emotion Recognition", which highlight the importance of improving user experience through cutting-edge technology.

The results of this visualization, provide in-depth insights into how AI-based technology and digital learning media support the development of Conceptual Understanding and promote Sustainability Awareness in the context of education. The relationships between clusters show that research in this area focuses not only on technological development but also on practical applications that can improve learning effectiveness and sustainability awareness. This visualization emphasizes the importance of integrating technological innovation and sustainability in education as a response to global challenges and the need to create a more adaptive, inclusive, and sustainable education system.

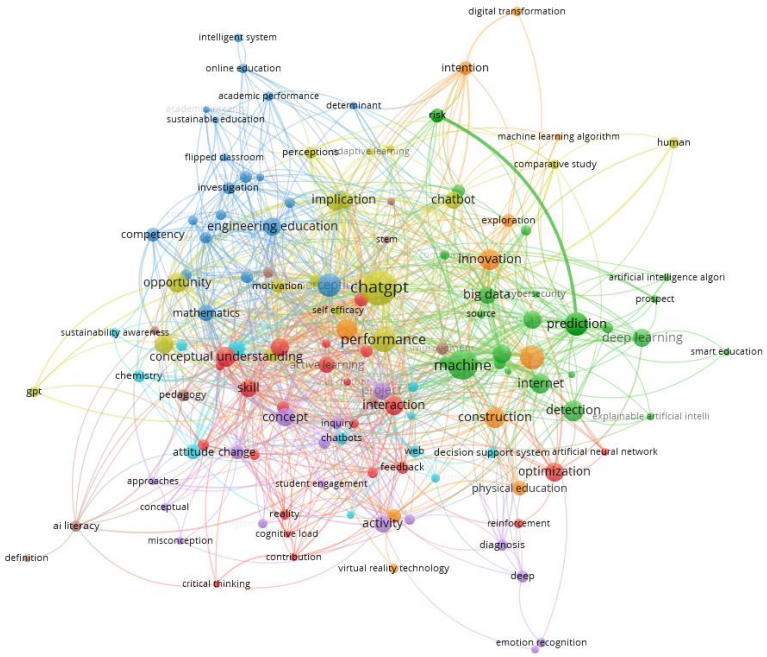

Figure 4. Network Visualization.

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Figure 5 illustrates the visualization of the keyword network overlay using VOSviewer, showing the relationship between research topics in the literature related to Artificial Intelligence (AI), Conceptual Understanding, Digital Learning Media, and Sustainability Awareness over some time. The colors in the visualization depict the temporal development of research, where darker colors (blue) represent earlier research (2020), while lighter colors (yellow) indicate newer and more relevant topics in 2023.

In the visualization of **Figure 5**, keywords such as “Artificial Intelligence”, “Deep Learning”, and “ChatGPT” dominate the network, indicating a significant increase in the relevance of AI technology in recent years. These topics are colored yellow, reflecting the very high growth in attention from 2022 to 2023. “ChatGPT”, for example, is at the center of the network with many connections to keywords such as “Interaction”, “Performance”, and “Machine Learning Algorithm”, reflecting the widespread adoption of AI chatbot technology in education and other technology-based applications.

Keywords such as “Conceptual Understanding” and “Skills”, located around the blue and green clusters, show consistent attention from 2020 to 2023 on developing conceptual understanding through digital learning media. This is closely related to keywords such as “Pedagogy”, “Critical Thinking”, and “Competence”, reflecting a focus on strengthening technology-based education to improve students’ skills. In addition, the keywords “Sustainability Awareness” and “Sustainability Education” are also closely related to terms such as “Engineering Education” and “Opportunities”, which are in the cluster with the color corrosion green. This shows that the desire for education has become a more relevant theme in recent years. Several keywords, such as “Digital Transformation”, “Innovation”, and “Big Data”, are located on the right side of the network with the dominant color yellow. This shows that digital transformation and technological innovation have become the main focus of research in the past two years. Meanwhile, keywords such as “Virtual Reality” and “Emotion Recognition”, which are related to interactive technologies, remain relevant but are in a more detached position from the center of the network, indicating that research in this area is growing but has not yet reached the same dominance as the main topics.

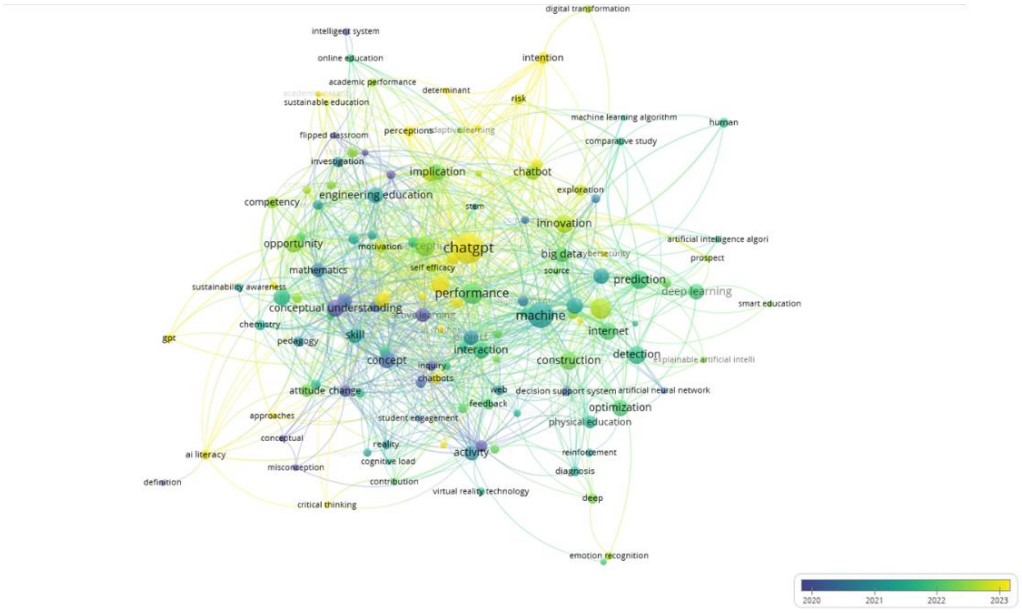

Figure 5. Overlay Visualization**.**

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The results of this study underscore the transformative potential of digital learning media in education, particularly in the context of sustainability awareness. By offering interactive, personalized, and immersive learning experiences, digital tools can deepen students' conceptual understanding and foster a greater sense of responsibility toward sustainability (Wamster, 2020). These tools can bridge geographical, cultural, and socioeconomic gaps, providing equitable access to sustainability education for learners worldwide. However, the integration of digital learning media also presents challenges, including the need for adequate teacher training and access to technology. In many regions, unequal access to digital tools and the lack of professional development opportunities for educators remain significant barriers to effective implementation. Addressing these challenges will be crucial to realizing the full potential of digital learning media in promoting conceptual understanding and sustainability awareness.

The findings highlight the significant role that digital learning media play in enhancing both conceptual understanding and sustainability awareness. The ability of digital platforms to engage students interactively and provide real-time, personalized learning experiences makes them powerful tools for fostering deeper learning and promoting sustainable practices. By integrating sustainability education into digital media, educators can cultivate a generation of learners who are not only knowledgeable but also motivated to contribute to environmental preservation and social responsibility.

As the field continues to evolve, future research should focus on exploring new technological innovations, such as AI and immersive technologies, to further enhance the educational experience. Additionally, addressing the challenges of equitable access to digital learning tools and ensuring proper teacher training will be critical in maximizing the impact of digital learning media on sustainability education.

4. CONCLUSION

This study provides a comprehensive bibliometric analysis of research trends in conceptual understanding and sustainability awareness through Artificial Intelligence (AI) and digital learning media. The findings reveal a significant growth in publications over the last decade, with a notable surge in the past three years, highlighting the increasing global interest in leveraging AI and digital platforms for education. The analysis identifies China and the United States as the leading contributors in terms of publication volume, followed by the United Kingdom, India, and Spain, demonstrating the international scope of this research area. Institutional contributions from Purdue University, King Abdulaziz University, and Nanyang Technological University further underscore the importance of collaborative efforts in advancing these fields. The study underscores the transformative potential of digital learning media and AI in fostering interactive, personalized learning experiences while promoting sustainability awareness. Key themes include interactivity, multimedia content, and personalized learning, which enhance educational outcomes and align with global sustainability goals. However, challenges like unequal access to technology and insufficient teacher training remain. Future research should focus on emerging technologies like AI and immersive media, equitable access, and curriculum integration to maximize the impact of digital tools. These advancements offer educators the opportunity to build a more sustainable future by equipping students with the knowledge and skills needed to tackle global challenges.

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5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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