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A comprehensive bibliometric analysis of information and communication technologies in science education

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Abstract

Using information and communication technologies (ICTs) in science education is presented in this article along with a comprehensive bibliometric analysis. Relevant articles are extracted using specific keywords related to ICT and science education from data in the Scopus Database. Data is then analyzed using various bibliometric markers such as publication citation and collaboration patterns. In this study you will find things like publication types, author keywords, author geography and journals. The bibliometric analysis aims to uncover the publishing pattern and trends at the intersection of science education and ICT. The results of this study show the growth of ICT-related research and innovation in science education during the previous ten years. The bibliometric examination uncovers a huge expansion in the quantity of distributions, showing a developing interest around here. In general, this article enhances our comprehension of the current state of ICT innovation and use in science education. The results can make it simpler for educators, researchers, and policymakers to grasp current trends and priority areas, making it simpler to develop effective ICT integration strategies for science education. Future research areas and their consequences for practice are also highlighted.

Keywords: information and communication technologies, innovation, science education, bibliometric analysis

INTRODUCTION

Information and communication technologies (ICTs) have revolutionized different segments, counting instruction. In recent years, there has been an expanding emphasis on integrating ICT into science education to improve understudy engagement, move forward learning results, and advance development (Jimoyiannis, 2010). This review points to a comprehensive bibliometric and clear investigation of the utilization of ICT and the coming advancement in science education.

The role of science education is integral to developing the scientific literacy and comprehension of individuals (Al Sultan et al., 2021; Niyazova et al., 2023). Nonetheless, conventional pedagogical methodologies may not sufficiently engage students in the contemporary digitally interconnected world. Hence, the integration of ICT tools and resources by educators can unlock technology's potential to deliver interactive and immersive learning experiences, boosting student motivation and promoting a more profound comprehension of scientific principles (Bayadilova-Altybayeva et al., 2023; Kamalova et al., 2022; Zeng et al., 2020). Interactive multimedia demonstrations and educational pastimes have been implemented to foster

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Contribution to the literature

- This article makes a distinctive contribution to the existing literature by meticulously charting the trajectory of ICT utilization within the realm of science education. Through an exhaustive bibliometric analysis, the study unveils the temporal evolution of this symbiotic relationship, revealing pivotal trends, seminal works, and emerging focal points. By discerning prominent scholars, institutions, and areas of research, this article furnishes a thorough comprehension of the academic terrain, competently directing educators, researchers, and policymakers.
- Moreover, the quantitative assessment of research productivity and impact enhances the discernment of influential contributions, fostering a deeper appreciation of the interdisciplinary nature of this field.
- Ultimately, this article's contribution lies in its ability to synthesize historical perspectives, emerging trends, and quantitative evaluations, offering a valuable resource that not only enriches scholarly dialogue but also informs effective pedagogical strategies and technological integration in science education.

interactive learning and student-oriented approaches (Zaw & Alpatova, 2023). Such methodologies have been substantiated to enhance learners' motivation, curiosity, and accomplishment in the domain of science education (Keller et al., 2017).

LITERATURE REVIEW

Research into the utilization of ICT in science education has essentially expanded during the most recent couple of years. According to Estriegana et al. (2019), a diverse set of ICT tools, including virtual labs, simulations, multimedia lectures, online cooperative platforms, and educational games, have been comprehensively examined. By utilizing these instruments, students benefit from immersive and investigative learning experiences, which enable them to study scientific phenomena in a secure and observable environment (Dunleavy et al., 2009).

The use of ICT in science education has been found to be advantageous according to numerous research (Herodotou, 2018; Hillmayr et al., 2020; Hu et al., 2018; Kalogiannakis et al., 2021; Rutten et al., 2012; Taconis et al., 2001; Webb, 2005). The use of virtual laboratories and simulations enables students to engage in experiments that may be hazardous or unfeasible in a conventional laboratory (Burkett & Smith, 2 016; Dyrberg et al., 2017; Gunawan et al., 2018; Ranjan, 2017; Tuysuz, 2010). According to Alkhabra et al. (2023), technological aids empower students to manipulate variables, observe outcomes in real-time, and foster critical thinking skills by analyzing and interpreting data.

Additionally, ICT technologies support active learning and student-centered methodologies, empowering students to create their own knowledge and participate in group problem-solving activities (Capone, 2022). For instance, online collaboration tools let students collaborate on scientific projects, share ideas, and receive comments from their peers, developing a sense of shared learning and improving communication abilities (Biasutti, 2011).

Furthermore, incorporating ICT into science education presents an opportunity to facilitate broader participation and foster inclusivity (Jeanpierre et al., 2005). Through digital platforms and resources, obstacles to access can be overcome, and distance learning can be made possible, creating opportunities for learners from varying socioeconomic backgrounds and geographic locations to engage with science education. This approach is essential in addressing historical boundaries to quality science education, including gender, socioeconomic, and geographical disparities (Hodson, 2003).

Despite several research into the advantages of the application of ICT in science education (Al-Rsa'i, 2013; Altin & Pedaste, 2013; Kennedy-Clark, 2011; Palomares-Ruiz et al., 2020), a detailed examination of the literature available is still lacking. This paper attempts to provide a comprehensive review of current research trends, influential authors and institutions, and the overall influence of ICT on science education by conducting bibliometric research. Furthermore, this paper aims to provide a bibliometric descriptive analysis of the various ICT tools and resources used, their effectiveness in enhancing learning outcomes, and difficulties encountered in their implementation.

In summary, it aims to offer insights into the state of research now, highlight the most important studies, and throw light on the potential of ICT in altering science education by reviewing the available literature and performing a bibliometric analysis. To improve the integration of ICT in science education, this analysis will ultimately support evidence-based practices, guide future research, and advise educational policies.

ICT has transformed modern education. ICT in science education enhances engagement, learning, and innovation (Akhmedova et al., 2023; Barak, 2014; Juuti et al., 2009; Watters & Diezmann, 2013; Wiseman & Anderson, 2012; Zourmpakis et al., 2022). This section reviews the literature on ICT in science education and its impact on learning outcomes. Numerous studies have explored the impact of ICT integration in science education. For instance, in a study by Fidan and Tuncel

(2019) the researchers investigated the effects of virtual reality (VR) on students' learning outcomes in a physics course. The results revealed that students who used VR technology demonstrated higher levels of engagement and improved conceptual understanding compared to those who used traditional teaching methods. Similarly, in a meta-analysis conducted by Higgins et al. (2020), the researchers examined the effectiveness of ICT tools, such as simulations and multimedia presentations, in science education. The findings indicated that the use of ICT positively influenced students' achievement, attitudes, and motivation towards learning science.

The literature offers a wide range of ICT tools and resources that have been applied in science education. Virtual laboratories and simulations are among the most used tools. A study by Smetana and Bell (2012) explored the impact of virtual laboratories on students' understanding of chemical concepts. The findings suggested that virtual laboratories facilitated student engagement, improved understanding of complex phenomena, and allowed for repeated practice without constraints of time and resources.

Science education frequently uses interactive multimedia presentations and educational games. The efficiency of an educational game in introducing physics principles was examined by Munoz et al. (2009). According to the findings, students who played the game had greater desire, a greater interest in physics, and enhanced learning results. In addition, Kara (2021) found that computer game was the most used game type in the systematic review of the use of serious games in science education.

Although ICT integration provides numerous benefits, it also has challenges and issues that must be solved. Ertmer (2005) cited several obstacles to efficient ICT integration, including a lack of technological resources, opposition to change, and a lack of teacher expertise and abilities. It was needed teacher professional development programs, sufficient infrastructure, and encouraging policies and actions to get over these obstacles. The research does, however, also highlight the difficulties and impediments to successful ICT integration (Bingimlas, 2009). Some of the most often encountered obstacles are a lack of access to digital resources, limited instructor understanding and proficiency with ICT tools, and opposition to change. To meet these issues, it is crucial to have enough infrastructure, supporting policies, and professional development programs for teachers (Wachira & Keengwe, 2011). Valuable insights into the research trends and impact of ICT integration in science education are provided by bibliometric studies. An analysis conducted by Aslan and Zhu (2017) on ICT-related articles in science education revealed a growing interest in ICT integration. The study indicated that a significant number of published articles focused on online learning platforms, simulations, and virtual reality.

Descriptive studies give in-depth examinations of various ICT technologies and their efficacy in science teaching. Lok and Hamzah, (2021) have out descriptive research on the utilization of mobile learning apps in chemistry teaching. The study discovered that mobile applications increased students' involvement, motivation, and comprehension of chemical ideas, demonstrating the use of such tools in scientific teaching. Finally, the review of research emphasizes the positive impact of ICT integration in science education, such as improved learning outcomes, higher student engagement, and improved conceptual comprehension.

After an extensive review of literature, it's clear that the incorporation of ICT into science education has the power to transform pedagogical practices, resulting in greater student involvement, heightened academic achievements, and the encouragement of inventive teaching methodologies (Smetana & Bell, 2012).

The findings of the bibliometric analysis highlighted the increasing research interest in ICT integration in science education, with a particular focus on virtual reality, simulations, and online learning platforms. This indicates the recognition of the transformative potential of these technologies in creating immersive and interactive learning experiences (King, 2002).

The descriptive bibliometric analysis revealed a variety of ICT tools and resources employed in science education, including virtual laboratories, educational games, multimedia presentations, and mobile applications (Heradio et al., 2016). These tools have demonstrated their effectiveness in promoting active learning, facilitating conceptual understanding, and fostering collaboration among students. Furthermore, they have shown promise in reaching a wider audience and promoting inclusivity by breaking down barriers to access.

However, the literature also identified challenges and barriers to effective ICT integration. Limited teacher knowledge and skills, inadequate access to technology resources, and resistance to change were identified as major obstacles. It is imperative for educators, policymakers, and researchers to address these challenges through professional development programs, investment in infrastructure, and the establishment of supportive policies and initiatives.

METHOD

The usage of ICTs and innovation in science education was examined in the current study using a mixed-methods approach that included bibliometric analysis and descriptive analysis. Data collection, data coding, and later analysis of the gathered data were all part of the methodology framework.

Data Collection

To conduct the bibliometric analysis, relevant articles were collected from academic Scopus Database. The search terms included variations of "ICT," "information communication technologies," "science education," and "innovation." The search was limited to peer-reviewed journal articles published within a specific time frame, e.g., the past decade.

For the descriptive analysis, a systematic literature review approach was employed. In addition to the articles collected for the bibliometric analysis, additional studies were gathered through snowball sampling and manual searching of relevant journals. The purpose was to obtain a comprehensive understanding of the use of ICT in science education and the resulting innovation.

Data Coding

For the bibliometric analysis, the collected articles were coded for various bibliographic data, including title, authors, publication year, journal, and citation count. Additional information, such as author affiliations and country of origin, was also coded to identify influential authors and institutions in the field of ICT use in science education. Bibliometric analysis software VOSviewer was used for data coding and analysis.

The data coding for the descriptive analysis focused on extracting information related to the use of ICT tools and resources in science education, including the types of ICT employed (e.g., virtual reality, simulations, educational games), the target audience (e.g., primary, secondary, or tertiary education), and the specific scientific disciplines addressed. Additional coding categories could include the learning outcomes, assessment methods, and reported benefits or challenges associated with ICT integration in science education.

Data Analysis

The bibliometric analysis involved analyzing the collected bibliographic data to identify trends, patterns, and the overall impact of ICT integration in science education. This could include generating visualizations, such as co-authorship networks or citation maps, to identify influential authors and research clusters. Statistical analyses could also be conducted to examine citation patterns and collaboration trends.

The descriptive analysis focused on synthesizing the data collected from the selected studies to provide an overview of the use of ICT in science education. This involved organizing and summarizing the coded data or emerging patterns, and discussing the reported benefits and challenges associated with ICT integration.

The methodological approach includes data gathering from academic databases, categorizing the collected data for different factors, and doing both bibliometric and descriptive analyses to acquire understanding of the use of ICT and innovation in science education. It is possible to examine the research trends, significant institutions, and authors, as well as the actual uses and effects of ICT integration in science education with the help of a mixed-methods approach.

Table 1. Number of the most frequent keywords used in articles

Keyword	n
Science education	93
Educational innovation	34
ICT	22
Education	18
Teaching	15
Computer science education	14
Responsible research and innovation	9

RESULTS AND DISCUSSION

Author Keywords and Their Network

The analysis type used was "co-occurrence," and the analysis unit chosen was "author keywords." Three times was chosen as the minimal number of repetitions for the keywords. 21 keywords have automatically been determined to be present. Science education (f=93), educational innovation (f=34), computer science education (f=14), responsible research and innovation (f=9) were the most frequently used keywords.

Table 1 shows the number of most frequent keywords in articles related to ICT use in science education and **Figure 1** displays the created map.

Annual Publication and Total Number of Citations

Articles related to the use of ICTs in science education published between 2008 and 2023 were identified using bibliometric analysis by the Scopus Database and relevant search phrases like "ICT," or "innovation," and "science education" to locate publications on the subject of ICT usage in science education between 2008 and 2023. The relevant publications were gathered using the inclusion and exclusion criteria. 325 publications on the subject were published overall throughout the 15-year period, according to the research. 1,394 citations or 11.06 citations per articles for these publications provide as more evidence of the importance of this field of study. As a conclusion, this study presents a useful summary of the studies done on the use of ICT in science education. The conclusions highlight the significance of this issue and provide insightful information on how it is doing right now.

Figure 2 displays the total yearly publications as well as the total cumulative citations of the research on the use of ICT in science education.

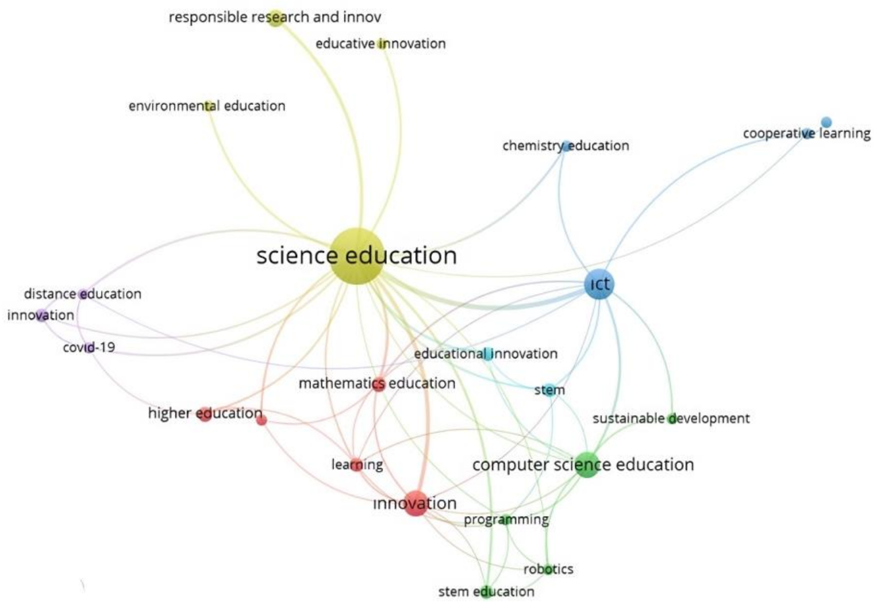

Figure 1. Author keywords and their networks (Source: Authors' own elaboration)

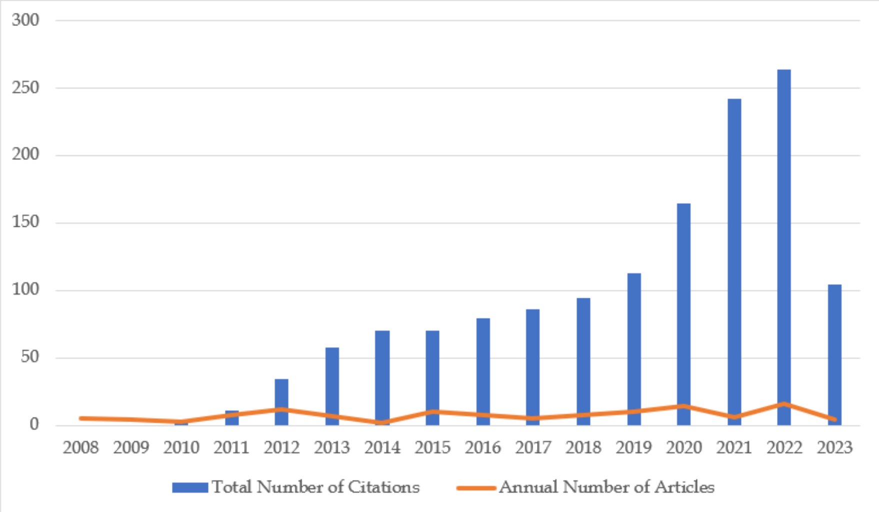

Figure 2. Total yearly articles as well as total cumulative citations of these articles (Source: Authors' own elaboration)

Networks of the Countries

Countries were chosen as the unit of analysis and "bibliographic coupling" as the analysis type. Five was chosen as the minimum number of articles for each country. 15 countries have automatically been determined to exist. USA (23 articles, 633 citations), Spain (19 articles, 232 citations), Germany (14 articles, 199 citations), China (five articles, 57 citations), Netherlands (five articles, 54 citations), Greece (five articles, 125 citations), and Taiwan (four articles, 41 citations) are the first seven countries publishing the most articles. The publications by authors from USA have the highest average number of citations, with 27.5 per publication, followed by Greece (25 per publication), Germany (14.2 per publication), and Spain (12.2 per publication), according to an assessment of the general quality of publications from the various countries based on the average number of citations. Thus, USA with the most publications in this area has the most total citations per article at the same time according to **Table 2**. This analysis yields significant perspective into which countries and networks lead the way in implementing ICT for innovation in science education.

Table 2. Countries with the highest number of articles & total citations

Country	Total articles	Total citations	Total citations/ total articles
USA	23	633	27.5
Spain	19	232	12.2
Germany	14	199	14.2
China	5	57	11.4
Netherlands	5	54	10.8
Greece	5	125	25.0
Taiwan	4	41	10.2
Total	54	1,341	24.8

Figure 3 shows the global network of countries working together to use ICT in science education.

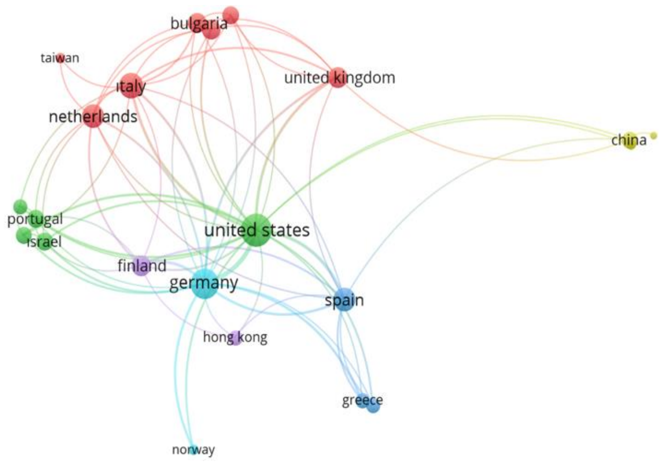

Figure 3. Networks of the countries (Source: Authors' own elaboration)

Countries that have collaborated for at least one publication with other countries make up the network. The size of each node is directly proportional to the number of articles produced, and the thickness of the links between nodes indicates the level of cooperation between countries. Clusters of like colors are used to make group countries frequently collaborating with one another. The most substantial collaboration is between USA and Israel, Germany and Greece, and United Kingdom and Bulgaria.

Journals and Their Networks

'Citation' was chosen as the kind of analysis and 'sources' as the unit of analysis. The minimal number of documents for a source (journal) and the minimum number of citations for a source (journal) were both chosen as five and twenty, respectively. The number of sources (journal) automatically came out to be eight sources. Sustainability, International Journal of Science Education, Journal of Research in Science Teaching, Science Education, Journal of Science Education and Technology, Journal of Research in Science Teaching, Educational Researcher, and Computers and Education were the most frequently cited journals.

Table 3 shows some journals published more articles about ICT use in science education. Research in Science Education, Eurasia Journal of Mathematics Science and Technology Education, and Sustainability were first three journals having most total citations per article respectively. Overall, the bibliometric analysis provides important information about the journals and networks that are most dedicated to the publication of scientific research regarding ICTs in science education (**Figure 4**).

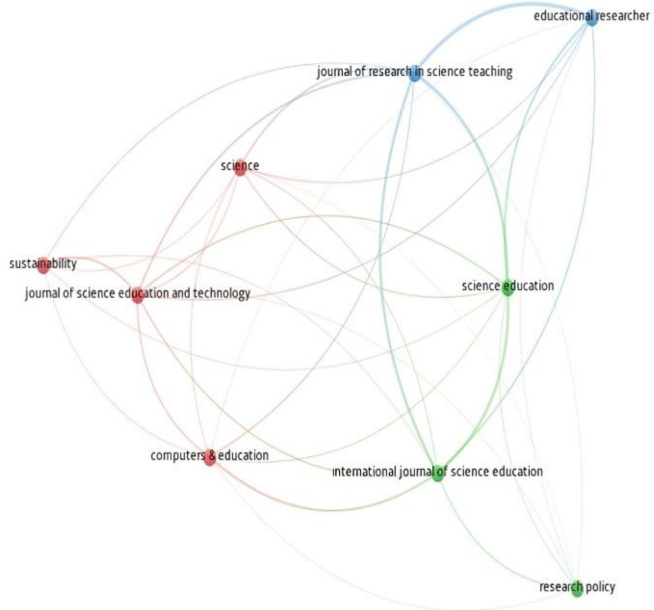

Figure 4. Journals & their networks (Source: Authors' own elaboration)

Organizations and Their Networks

In the domain of utilizing ICT in science education, a multitude of distinguished organizations and institutions have surfaced as crucial contributors, spearheading research, and progressions in this area. Notably, universities, research centers, and educational institutions have assumed a paramount role in delving into the potential of ICT to science education and foster efficacious learning experiences.

One of the main associations in this area is the Universitat de Barcelona to conduct research and reviews in science education and innovation. For example, their work centers around utilizing these advances to draw in understudies, advance dynamic learning, and work with active trial and error.

Universität Bremen is another notable establishment known for its distinguished standing in diverse fields of research, such as educational technology. Department of education has been actively investigating the effective

Table 3. Journals with the highest number of articles, total citations, & total citations per article

Journal	Total articles	Total citations	Total citations/ total articles
Sustainability	5	106	21.20
Journal of Science Education & Technology	4	57	14.25
EURASIA Journal of Mathematics Science & Technology Education	3	70	23.33
Research in Science Education	3	78	26.00
Journal of Baltic Science Education	3	9	3.00
Research in Science & Technological Education	2	9	4.50
Total	20	329	16.45

utilization of ICT to enhance science education. Their research predominantly highlights the implementation of online platforms, data analysis tools, and interactive multimedia resources to encourage inquiry-based learning and advance scientific thinking.

Arizona State University is a significant participant in the field of ICT and science education. One of its notable contributions is to conduct research on the application of ICT tools in science education. Their endeavors involve creating inventive applications, software, and digital resources that facilitate students' exploration of science concepts and phenomena in an immersive and interactive manner. National Science Foundation (NSF), a remarkable foundation in USA, gives significant financing to a huge number of examination projects relating to the use of ICT in science schooling. With the aid of various grant programs, NSF endorses researchers and educational establishments in their endeavors to construct and execute effective ICT strategies in science classrooms.

These endeavors frequently center around subjects such as web-based learning environments, data visualization, adaptive learning technologies, and computer simulations, all of which aim to augment scientific comprehension and captivate students in meaningful ways.

In summary, preeminent establishments of higher learning, investigative facilities, and instructional organizations such as Universitat de Barcelona, Universität Bremen, Arizona State University, and NSF have taken the lead in disseminating research concerning the application of ICT in science education (**Figure 5**).

Their combined efforts have made noteworthy contributions to the advancement of effective strategies, pioneering tools, and empirically based practices that use ICT to augment science pedagogy and scholarship, culminating in the preparation of students for a future that is heavily reliant on technology.

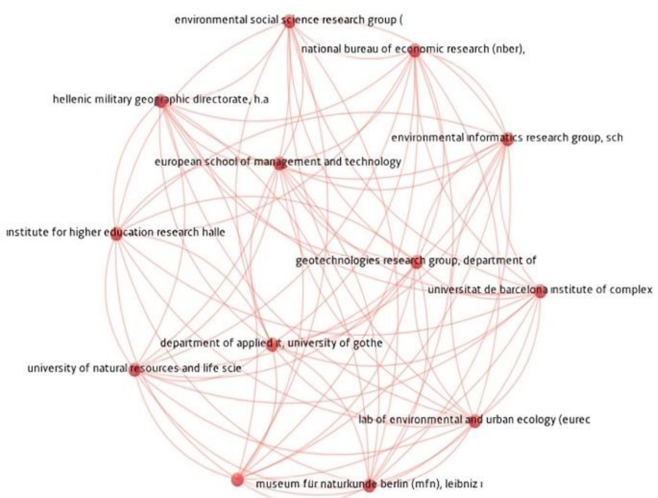

Figure 5. Organizations & their networks (Source: Authors' own elaboration)

Table 4. Most published articles & total citations by authors

Author	Institution/country	TA	TC
Bogner, F. X.	University of Arizona/USA	3	43
Huwer, J.	Universität Konstanz/ Germany	3	5
Eilks, I.	Universität Bremen/Germany	2	12
Fuzesi, Z.	University of Pécs/ Hungary	2	2
Imbenrnon, F.	Universitat de Barcelona/Spain	2	1

Note. TA: total articles & TC: Total citations

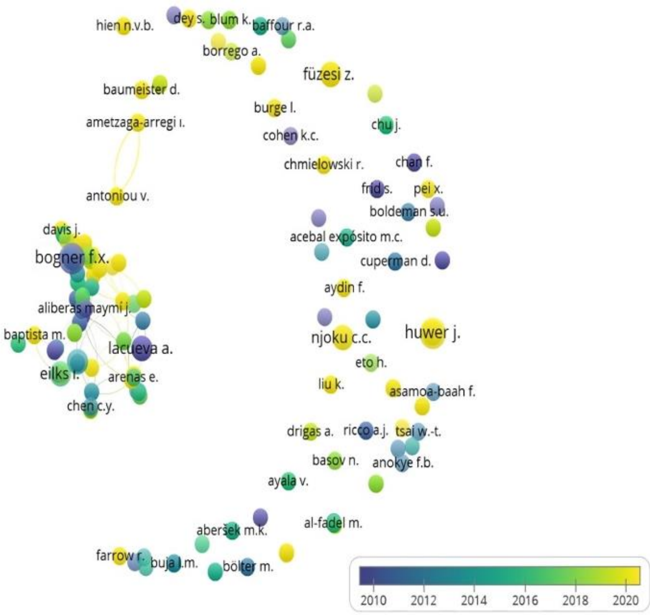

Figure 6. Authors' networks (Source: Authors' own elaboration)

Authors and Their Networks

Citation was chosen as the analysis type, and author was chosen as the analysis unit. The minimum number of papers for an author was chosen to be two, while the minimum number of citations for an author was chosen to be 20.

Six writers were automatically determined to be the total. Bogner, F. X. (three publications, 43 citations), Huwer, J. (three publications, five citations), Eilks, I. (two publications, 12 citations), Fuzesi, Z. (two publications, two citations), and Imbenrnon, F. (two publications, one citation) were the most productive writers (**Table 4**).

Figure 6 shows the network of research partnerships between authors on at least two articles that have been published. Most of the authors in this network are included in **Table 4**. Like the cooperation between countries, the network of author collaboration in this field of study is often weak and consists mostly of small-scale collaboration as shown in **Figure 6**.

CONCLUSIONS AND IMPLICATIONS

The objective of this study is to conduct a thorough bibliometric and descriptive examination of how ICTs are utilized in science education and their effects on innovation. The development, trends, and updates in the Scopus Database for articles on ICT use in science education were closely examined in this bibliometric review. Among the bibliometric factors looked at in this research are the overall number of publications, citations, and publishing trends over 15 years. 325 publications from Scopus-indexed journals satisfying the given criteria were systematically reviewed. The findings revealed that 126 of 325 publications were included in the study for assessment since the selection criteria of peer-reviewed articles. The findings also revealed that the first article addressing ICT use in science education was published in 1992, and most of the articles examined were published after 2008. The findings also revealed that many articles on ICT use in science education were undertaken in USA, Spain, and Germany.

The findings of this study have significant implications for science education practitioners, policymakers, and researchers. The integration of ICT in science education can offer transformative learning experiences that cater to the needs and interests of contemporary learners. The interactive and immersive nature of ICT tools can enhance student engagement, motivation, and conceptual understanding. Furthermore, the promotion of active learning and collaborative problem-solving through ICT integration aligns with the demands of the 21st-century workforce, where skills such as critical thinking, communication, and digital literacy are highly valued. Therefore, incorporating ICT in science education can help prepare students for future careers in science, technology, engineering, and mathematics fields. Additionally, the findings underscore the need for ongoing research and evaluation of ICT integration in science education. Continued investigation can provide insights into the most effective strategies, pedagogical approaches, and technologies maximizing learning outcomes. Moreover, longitudinal studies can examine the long-term impact of ICT integration on students' academic achievement, career aspirations, and scientific literacy.

The implications of this study extend beyond the classroom. Policymakers and educational institutions should prioritize investments in ICT infrastructure, ensuring equitable access to technology resources for all students. Professional development programs should be provided to teachers to enhance their technological competencies and pedagogical strategies in utilizing ICT effectively.

Furthermore, collaborations between researchers, practitioners, and technology developers are crucial for the design and implementation of innovative ICT tools and resources that address the specific needs of science education. Engaging in interdisciplinary partnerships can foster the development of cutting-edge technologies and pedagogical approaches that push the boundaries of science education. To sum up, this study's bibliometric and descriptive examination offers a thorough understanding of how ICT is utilized and innovation in science education. There is a possibility of bringing about a revolution in science education, increasing students' involvement, encouraging interactive learning, and cultivating innovative teaching methods by incorporating ICT. The discoveries made by this study provide useful observations for instructors, policymakers, and researchers to guide forthcoming attempts in exploiting the complete possibilities of ICT to revolutionize science education and equip students for the ever-changing technological landscape.

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Ethical statement: Authors stated that the study did not require ethical approval since it is based on existing literature.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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