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Mapping the Landscape of Technology-Enhanced Misconception Research in Science Education: Trends, Impact, and Future Directions.

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ABSTRACT

This study uses a quantitative bibliometric approach to map trends, collaborations, and research directions in the field of technology-based misconception remediation in science education. Data were extracted from the Scopus database using keyword searches related to misconceptions, educational technology, and science learning from 2000 to 2024. After filtering, 280 documents were analyzed using VOSviewer to explore publication patterns, author collaboration networks, and conceptual connections through co-authorship, co-word, and co-citation analysis. Network map visualizations provide an overview of key actors, popular topics, and emerging thematic clusters. The study results indicate significant growth in publications and international collaboration, while also identifying potential research gaps. These findings are expected to serve as a strategic reference for researchers and policymakers in directing technology-based pedagogical research and innovation to address misconceptions in science education.

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I. Introduction

Misconceptions in science education are common and persistent, affecting students at all levels of education, even prospective teachers [1]. Misconceptions can significantly hinder scientific understanding. Misconceptions can arise from everyday experiences, inadequate teaching methods, content that is disconnected from context, and inadequate research skills [2], [3]. Misconceptions are prevalent across all science disciplines, with physics and biology being the most studied fields, but chemistry also exhibits high levels, particularly among prospective teachers and students of all ages [4]–[10]. Even science teachers and university professors can have misconceptions, which can hinder their ability to teach correct concepts [6], [11], [12].

In physics, topics such as force, motion, thermodynamics, and mechanics often give rise to misconceptions. For example, over 80% of undergraduate students in STEM fields misunderstand the direction of force in basic physics problems [2], [13]. In biology, misconceptions are commonly found in topics such as membrane physiology and cell biology, and often persist despite instruction, particularly due to the interdisciplinary nature of the topics [3], [5], [7]. Meanwhile, in chemistry, science teacher candidates and students often share the same misconceptions about basic chemical concepts, with studies showing that 40–80% of teacher candidates hold the same misconceptions as children [5], [6], [12].

Technology-based misconception remediation learning has become very important because it has been proven effective in improving students' conceptual understanding. The hybrid model, which combines online and face-to-face learning, shows a success rate of up to 90% in remedying misconceptions, surpassing the effectiveness of blended methods and traditional classes, especially when a conceptual change approach is applied [14]. Online modules based on inquiry and digital laboratories also significantly improve understanding by directly targeting common misconceptions, yielding better results than conventional online curricula [15].

Various e-learning tools, such as narrative feedback, interactive modules, and realistic videos, contribute significantly to reducing misconceptions, particularly in physics topics such as free fall motion [16]. Technology-based interactive activities, including educational games and targeted exercises, have also proven effective in correcting misconceptions and improving post-test scores in mathematics and science [17], [18]. Additionally, diagnostic technologies such as multi-tiered tools, now widely used online, enable more accurate identification of misconceptions for more targeted interventions [4] and also support teacher training to better recognize and address student misconceptions effectively [19].

Research on misconceptions in science education has seen significant growth in recent decades, with a primary focus on diagnostic tools [9], [20], [21], conceptual understanding [22], [23], and interventions [24], [25]. These studies have not been able to describe global trends in research on misconceptions. Therefore, the issue of bibliometric analysis has emerged as a new focus in misconception studies. This issue arises to bridge the lack of information on global trends in misconception studies. Bibliometric studies in the field of science have been reported previously. For example, [26] revealed general trends in research on conceptual change from 2004 to 2024. This research shows consistent growth and significant contributions from figures such as Stella Vosniadou and Andrea diSessa. Additionally, learning technology, although mentioned implicitly, is identified as a factor supporting the surge in publications during a certain period.

Other studies explore trends in physics education more specifically. As in Turkey, for example, misconceptions and learning difficulties are the main focus [27]. These studies emphasize that global trends influence local focus, and that social dynamics and institutional policies also determine the direction of research. Meanwhile, a broader bibliometric analysis of articles on misconceptions in science successfully identified a surge in interest after 2010, a map of country collaborations, and the most productive figures and journals [28]. However, these three studies emphasize general trends in misconceptions in science education without distinguishing in depth the context of technology as a means of remediation.

Although previous bibliometric studies have successfully mapped trends, key figures, and main topics in research on misconceptions and conceptual change in science education, there are still limited studies that specifically map the development, impact, and future direction of research on misconceptions intervened through technology-based approaches. In fact, learning technology has proven effective in remedying misconceptions, whether through hybrid learning, online modules, interactive videos, or digital diagnostics.

The absence of scientific mapping focused on “technology-enhanced misconception research” has led to a lack of understanding of the extent to which this approach has developed, who the main actors are, and in which disciplines this approach is predominantly used. This makes it difficult for researchers, policymakers, and educators to develop evidence-based strategies for effectively addressing misconceptions in the digital age. Therefore, this study aims to conduct a bibliometric analysis of the field of science with a focus on “technology-enhanced misconception research.”

This research offers novelty by being the first bibliometric study to specifically map the landscape of misconception research in science education involving technology as the primary intervention. Not only will it evaluate publication trends, collaboration, and the influence of scientists, but this study will also explore the future direction and impact of technological approaches in addressing misconceptions, providing strategic contributions to the science education community in the era of digital transformation.

Research Question:

RQ1: What is the yearly trend of publication numbers?

RQ2: What are the top countries, affiliations, authors, and published journals?

RQ3: What are the keyword trends and network visualization?

II. Method

Explaining the research chronologically, including the research design, research procedures (in the form of algorithms, Pseudocode, or other), how to test, and data acquisition [29]–[31]. The description of the course of research should be supported references, so the explanation can be accepted scientifically [32], [33]. Figures 1-2 and Table 1 are presented center, as shown below and cited in the manuscript [29], [34]–[39]. The student responses based on their region of origin have been illustrated in Figure 1(a) and mastery of regional languages has been illustrated in Figure 1(b).

This study uses a bibliometric analysis approach with a quantitative design [40], [41]. Bibliometric analysis was chosen because it provides a comprehensive overview of publication patterns, scientific collaboration, and the dynamics of topics developing in studies on technology-based misconception remediation in science education. This approach not only enables the identification of key actors in the field of science but also maps the conceptual relationships between studies in a visual and systematic manner.

Data sources were obtained from the Scopus database, widely recognized as one of the largest and

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most credible scientific databases for literature mapping purposes. The data search process was conducted using the Advanced Search feature with a combination of keywords designed to capture relevant documents related to misconceptions, educational technology, and science learning. The keywords used include terms such as misconception, conceptual change, digital learning, simulation, augmented reality, AI in education, as well as other phrases closely related to science education such as science education, STEM, physics, biology, and chemistry. The search was limited to documents published between 2000 and 2024

Search keyword combinations:

(TITLE-ABS-KEY (misconception* OR "conceptual change" OR "concept remediation") AND TITLE-ABS-KEY (technology OR "digital learning" OR "educational technology" OR "interactive media" OR "multimedia learning" OR simulation OR "virtual lab" OR "augmented reality" OR "virtual reality" OR gamification OR "AI in education") AND TITLE-ABS-KEY ("science education" OR physics OR chemistry OR biology OR "science learning" OR STEM)) AND PUBYEAR > 2000 AND PUBYEAR < 2024

The initial search results yielded 595 documents. After filtering based on inclusion criteria, namely publications in the form of articles and conference papers, written in English, and sourced from journals, the final number of eligible documents was 280. These documents were then exported in CSV format for further analysis.

The bibliometric analysis was conducted using the VOSviewer software [42], [43]. The metadata analyzed included titles, abstracts, keywords, author names, affiliations, publication sources, and reference lists. The analysis focused on key aspects, including co-authorship, co-word analysis, and co-citation analysis. The results of the overall analysis were presented in the form of a network map visualization to provide a comprehensive overview of the structure and direction of research development in the field of technology-based remedial learning in science education.

III. Results and Discussion

RQ1: What is the yearly trend of publication numbers?

Annual publication trends can help future researchers assess whether interest in technology-based remedial learning topics in science is increasing, stagnating, or declining [44], [45]. These trends also make it easier for researchers to identify the phases of development of these topics, such as the early phase (emerging), growth phase (growing), or maturity phase (mature). In addition, annual publication data allows for connections between these trends and changes in curriculum, pandemics (such as COVID-19), or the emergence of new technologies that drive innovation in learning. A visualization of the trend in the number of publications on technology-based remedial learning in science education over two decades is presented in Figure 1.

Figure 1 shows the trend of publications on technology-based misconception remediation in science education over two decades. The trend of research publications on technology-based misconception remediation in science education shows increasingly consistent development. In the early period (2004–2010), the number of publications was still relatively low, with a maximum of 15 documents in 2010. This indicates that the topic of technology integration in remedial learning is still in its early exploratory stages and has not yet become a widespread concern within the scientific community.

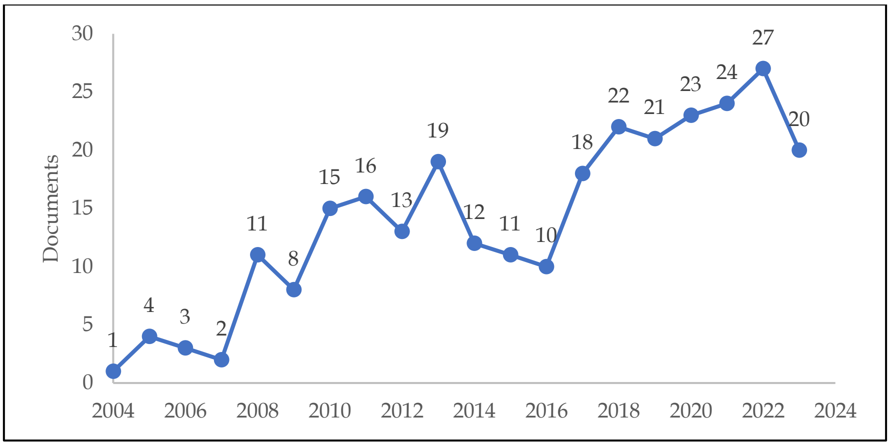

Figure 1. Yearly trend of the number of publications on technology-based misconception remediation in science education

Since 2011, there has been a gradual increase, which then experienced a significant surge in 2016, reaching its peak in 2022 with 27 publications. This upward trend was likely triggered by the COVID-19 pandemic, which necessitated the implementation of online learning. Interestingly, although 2023 shows a slight decline (20 documents), this figure still reflects a strong interest in the topic of technology-based misconception remediation. Overall, the trend visualized in Figure 1 indicates that research in the field of technology-based misconception remediation learning continues to grow and gain global recognition. This is driven by the demands of 21st-century education, which requires pedagogical innovation and better conceptual understanding [46].

RQ2: What are the top countries, affiliations, authors, and published journals?

Top 10 Country production

An overview of the most productive countries in terms of producing research articles on technology-based misconception remediation in science education can help identify centers of knowledge production, indicate global trends and dominance, and support international collaboration. In addition, this information also plays a role in encouraging research growth in developing countries. Data on the most productive countries is presented in Figure 2.

Figure 2 shows the most productive countries in producing research articles on technology-based misconception remediation in science education. Based on Figure 2, the analysis results show that the United States dominates the number of publications with 97 documents, confirming its position as the main center of research in this field. It is followed by Turkey (29 documents), the United Kingdom and Germany (19 documents each), as well as other countries such as Canada, Spain, and Australia, which also actively contribute. Interestingly, Indonesia ranks eighth with 11 publications, indicating the increasing involvement of developing countries. This data is important for mapping potential collaboration centers and shows that the issue of misconceptions in science education is global. Going forward, researchers from developing countries such as Indonesia need to strengthen their international networks and access to reputable journals so that their contributions are increasingly recognized. Additionally, opportunities for cross-border collaboration can be leveraged to enrich local approaches with global insights. Therefore, this map shows that the issue of science misconceptions has become a global concern across regions and levels of technological development [47], [48].

Most productive affiliations

The overview of the most productive affiliations in the field of technology-based misconception remediation in science education not only shows institutional expertise, but also helps identify leading research institutions that can be used as academic references and scientific references. Additionally, this information opens up opportunities for cross-institutional collaboration and encourages benchmarking and performance improvement processes within institutions in developing strategies to strengthen research capacity and scientific publication [49], [50]. Data on the most productive affiliations in producing research articles on technology-based misconception remediation in science education are presented in Table 1.

Table 1. Publications by affiliations on technology-based misconception remediation in science education

No	Affiliation	Documents
1	Atatürk Üniversitesi	6
2	Purdue University	6
3	National Taiwan Normal University	5
4	Universitas Pendidikan Indonesia	5
5	University of South Africa	4
6	Arizona State University	4
7	Universität Bayreuth	4
8	Université McGill	3
9	The Ohio State University	3
10	Iowa State University	3

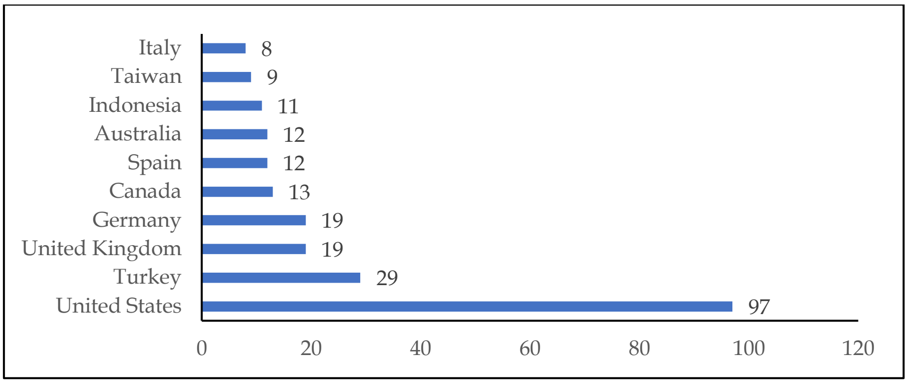

Figure 2. Top 10 countries in producing publications on technology-based misconception remediation in science education.

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Based on Table 1, Atatürk University (Turkey) and Purdue University (USA) rank at the top with 6 publications each. These findings indicate that both affiliations are leaders in research on technology-based misconception remediation. In addition to these two universities, National Taiwan Normal University and Universitas Pendidikan Indonesia follow with five publications each, reflecting significant contributions from the Asian region, including from Indonesian institutions. It is worth noting that the University of South Africa and Universität Bayreuth also demonstrate active involvement from the African and European continents in this issue. The presence of universities from various continents reflects that attention to technology-based misconception remediation is global.

Thus, this data is important for identifying centers of research excellence and opening up opportunities for international collaboration. Researchers from other institutions can use these affiliations as strategic partners or models for similar research development. Furthermore, cross-institutional collaboration has the potential to strengthen technology-based pedagogical innovation in addressing science misconceptions [51], [52]. In addition, institutions in developing countries can use this information to promote research capacity building and expand access to reputable international publication networks [47], [48].

Most productive authors 2004–2024

An overview of the most productive authors can help identify key figures in the field of technology-based misconception remediation in science education [53]. The works of these figures then become the main scientific references for further studies. On the other hand, these active researchers also have the potential to become strategic collaboration partners, either as collaborators, mentors, editors, or reviewers. The most productive authors in producing research articles on technology-based misconception remediation in science education are presented in Table 2.

Based on Table 2, Samsudin, A., Dilber, R., and Bogner, F.X. are the most productive authors over the past two decades in producing research articles in the field of technology-based misconception remediation in science education, with four publications each in various journals. They are followed by a number of other authors who have 2–3 documents. The presence of Samsudin, Wibowo, and Suhandi reflects the active role of Indonesian researchers in global contributions. Among their four publications, the one on microscopic virtual simulation for student understanding is the most impactful [54]. This publication was published in Advanced Science Letters in 2017. Meanwhile, Bogner and Scharfenberg from Germany demonstrate Europe's consistency in science pedagogy research, while Thacker and Ibbott represent contributions from America, and Veermans from Finland adds another European perspective.

Table 2. Most productive authors on technology-based misconception remediation in science education (2004–2024)

No.	Author's name	Documents
1	Samsudin, A.	4
2	Dilber, R.	4
3	Bogner, F.X.	4
4	Wibowo, F.C.	3
5	Vidak, A.	3
6	Thacker, I.	3
7	Suhandi, A.	3
8	Scharfenberg, F.J.	3
9	Ibbott, G.	3
10	Veermans, K.	2

This composition shows that research in the field of technology-based misconception remediation in science education is interdisciplinary and transnational, reinforcing the importance of global collaboration in addressing the challenges of modern science education [55]–[57]. These findings can be utilized by new researchers to find key references, explore scientific collaborations, or develop academic networks. Additionally, this mapping also helps identify key figures who can become strategic partners in strengthening research capacity, both at the national and international levels.

Top 10 most Published Journal

A list of journals with the highest number of publications can help researchers understand where most of the scientific discussion on technology-based misconception remediation in science education takes place. This information is also useful in selecting relevant journals that are more likely to accept manuscripts on similar topics. By knowing which journals are most active, researchers can evaluate research directions and trends, as well as identify areas that are still underrepresented. Table 3 presents the top ten journals with the highest number of publications related to technology-based misconception remediation in science education.

A bibliometric analysis of the most productive journals in publishing articles related to technology-based misconception remediation in science education reveals that the Journal of Chemical Education ranks first with 15 publications. This journal ranks in the 79th percentile in the field of Education and 61st in the field of General Chemistry, indicating a strong focus on chemistry education. The Journal of Science Education and Technology (10 documents) and the International Journal of Science Education (8 documents) are also active and rank highly in the Education category (96th and 81st percentiles, respectively). Interestingly, the Journal of Computer Assisted Learning has the highest SJR value (2.000), reflecting its high scientific influence and close relevance to technology-based approaches in learning. The article by [58] on the integration of multimedia in the field of misconceptions, published by

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the Journal of Computer Assisted Learning, has the highest number of citations.

This analysis provides important benefits, particularly in helping researchers determine the appropriate and strategic target journals. Additionally, the presence of journals from various subdisciplines (chemistry, physics, biology, educational technology, and geosciences) reflects the interdisciplinary nature of this field. These findings also indicate that most research is published in high-reputation journals with regular publication frequencies, which can serve as a strong indicator of editorial stability and consistent publication opportunities. Researchers are advised to consider these journals when developing long-term publication strategies.

RQ3: What are the keyword trends and network visualization?

Keyword trend mapping and network visualization can be used to identify emerging topics and issues, map conceptual relationships between topics, and even discover research gaps. Keywords that rarely appear or are not closely connected within the network can serve as indicators of under-explored areas, thereby presenting opportunities for new, original, and promising research topics.

Table 3. Top 10 journals on technology-based misconception remediation in science education.

No	Journal	Docs	SJR 2024	Category (Percentile) 2024	SCC 2024	Freq. of publication
1	Journal of Chemical Education	15	0.596	Education (79th) General Chemistry (61th)	664	12
2	Journal of Science Education and Technology	10	1.579	Education (96th) General Engineering (93th)	87	6
3	International Journal of Science Education	8	0.672	Education (81th)	181	18
4	Journal of Research in Science Teaching	7	1.36o	Education (93th)	83	10
5	Physics Education	5	0.523	Education (39th) General Physics and Astronomy (32th)	261	6
6	Eurasia Journal of Mathematics Science and Technology Education	5	0.554	Applied Mathematics (74th) Education (72th)	179	3
7	Education Sciences	5	0.730	Physical Therapy, Sports Therapy and Rehabilitation (84th) Education (84th) Public Administration (82th) Developmental and Educational Psychology (76) Computer Science (miscellaneous) (72) Computer Science Applications (68)	1413	12
8	American Biology Teacher	5	0.219	Education (23th) General Agricultural and Biological Sciences (21th) Agricultural and Biological Sciences (miscellaneous) (20th)	61	9
9	Journal of Geoscience Education	4	0.433	Education (67th) General Earth and Planetary Sciences (62th)	47	4
10	Journal of Computer Assisted Learning	4	2.000	Education (96th) Computer Science Applications (88th)	251	6

*SCC = Scopus content coverage

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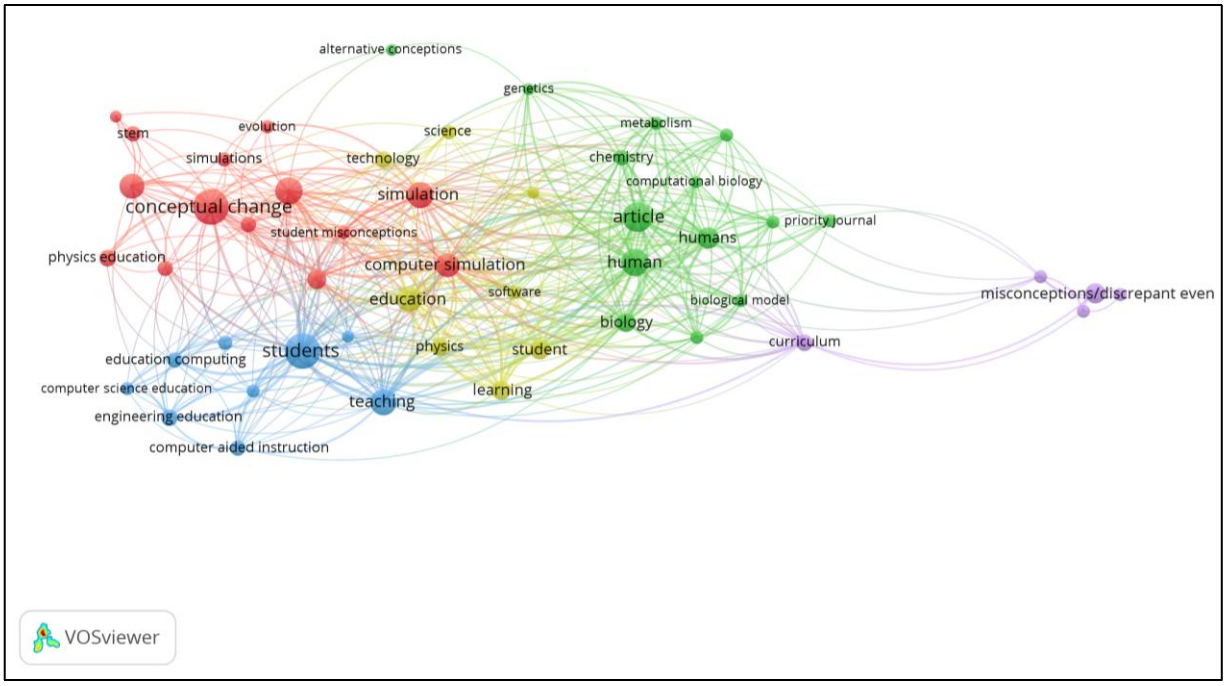

Figure 3. Keyword trends and Network visualization

From 280 documents from 2004 to 2024, a total of 1,999 keywords were identified to identify potential research topics in the field of technology-based misconception remediation in science education. Keyword network visualization was developed using VOSviewer software [42], [43]. Figure 3 presents the visualization of the keyword network during the period 2004–2024, with a minimum frequency of occurrence of five times. The size of the circle represents how often a keyword appears in the reviewed documents, while the thickness of the line connecting two keywords indicates the intensity of their interconnection or simultaneous occurrence in a single research context.

Based on Figure 3, the keyword visualization results show the formation of five complementary thematic clusters. The first and second clusters are each formed by 14 keywords. Cluster 3 is formed by 9 keywords. Clusters 4 and 5 are formed by 8 and 5 keywords, respectively. Cluster 1 focuses on misconceptions of scientific concepts and the use of simulations and active learning to support concept understanding, particularly in physics education and contemporary science issues such as climate change and evolution. This is the core of the topic of technology-based misconception remediation. Cluster 2 reinforces these findings with a focus on biology and chemistry, highlighting the use of biological models, experimental procedures, and control studies in examining misconceptions. Keywords such as computational biology and genetics indicate a data-driven and technology-based approach. Clusters 3 and 4 underscore the role of learning technology through computer-aided instruction, education computing, and learning systems, indicating the direction of technology integration in the context of STEM education and engineering. Cluster 5, though narrower, highlights important areas such as first-year chemistry and discrepant events, which are highly relevant in the context of early remediation of foundational misconceptions.

The results of keyword trend analysis and network visualization provide strategic benefits in shaping the direction and strategy of scientific publications [59]. First, researchers can identify popular and interdisciplinary topics, such as simulation, STEM, and computer science education, which have a high chance of being accepted in reputable journals because they are in the mainstream of science. Second, cluster visualization helps identify research gaps that have not been extensively explored [60], [61]. For example, the emergence of climate change in the same cluster as misconceptions indicates potential research on the use of learning technology for environmental issues that are rarely addressed in pure technology clusters. Third, keyword mapping enables researchers to formulate titles, abstracts, and keywords using terms aligned with publication trends, such as conceptual understanding, active learning, and simulations, thereby increasing visibility and citation opportunities. Thus, keyword analysis not only serves as a thematic overview but also as a tactical tool to enhance the quality, relevance, and competitiveness of scientific manuscripts at the national and international levels.

IV. Conclusion

This study comprehensively maps the research landscape on technology-based misconception remediation in science education through a bibliometric approach. The results of the analysis of annual trends show a significant increase over the past two decades, indicating growing interest in this topic in line with developments in educational technology and 21st-century learning challenges. In terms of global contributions, the United States, Turkey, and European countries dominate publications, while Indonesia is beginning to show promising participation. The identified productive affiliations and authors can be potential partners in research collaboration and key scientific references. Meanwhile, journals such as the Journal of Chemical Education and the Journal of Science Education and Technology are the most active publication channels, indicating the direction and opportunities available for new researchers. Finally, keyword visualization underscores the importance of interdisciplinary approaches and the use of cutting-edge technology in addressing science misconceptions. These findings form an important foundation for the development of more targeted, collaborative, and contextual research.

This study is limited to publication data indexed in specific databases, so there may be relevant works that are not covered. Additionally, bibliometric analysis only provides a quantitative overview without delving into the qualitative aspects of the research content. Further research is recommended to combine qualitative methods to explore in depth the approaches and effectiveness of technology-based misconception remediation. Additionally, the scope of data sources should be expanded, and new technological developments should be considered to capture more up-to-date trends and strengthen interdisciplinary and international collaboration

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Declarations

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