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Unveiling Research Gaps in Biology Teaching Materials for Secondary Science Education: A Bibliometric Review of Scopus (2000–2024)

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Abstract. Teaching materials for biology education help to form scientific literacy and critical thinking skills of secondary school students. This study explored the trends in research, thematic structures, and emerging gaps in developing biology teaching materials for secondary school science education through a bibliometric approach. In total 198 journal articles indexed by Scopus and published between 2000 and 2024 were systematically analyzed using the R-based Biblioshiny tool, VOSviewer, and OpenRefine. The results indicate a significant increase in publications since 2018, with the Journal of Biological Education being the most prolific journal, Phillips Exeter Academy leading in institutional contributions, and the United States emerging as the dominant country. Aivelo, Eilks, and Markic are recognized as the most influential authors in the field. Studies that garnered the highest citation counts are those published in 2007 by Folcik, in 2010 by Riess, and in 2011 by Clough, which highlight their substantial impact on the development of biology teaching materials. Thematic analysis revealed key topics, such as "education," "teaching," and "human," and uncovered the emerging themes of "health education," "self-efficacy," and "controlled study." These trends suggest a shift toward a learner-centered and cross-disciplinary approach to biology education. The findings emphasize the need to develop contextual, evidence-based teaching materials that integrate psychological and social dimensions in secondary school science education. Future research can build on these insights to design innovative curricula and pedagogical models that align with current educational and scientific challenges.

Keywords: biology education; bibliometric review; secondary education; science education; teaching materials

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1. Introduction

Biology teaching materials play a role in shaping students' conceptual understanding of fundamental biology principles and fostering active engagement in the scientific learning process at the secondary school level. Well-designed instructional materials deliver scientific content effectively and promote critical thinking, problem-solving skills, and the practical application of concepts in everyday life (Bustami et al., 2018; Yaki, 2022). An instructional approach that has been found to support these outcomes is inquiry-based learning, which facilitates active student participation through experimentation and discussion to deepen students' grasp of scientific concepts (Manishimwe et al., 2022; Tan et al., 2020).

Moreover, enriching the biology curriculum by integrating social and ethical dimensions, including bioethics, can enhance students' educational experiences and increase their awareness of the broader societal implications of science (Chan et al., 2020; Cuaderes & Yap-Figueras, 2023). When they are confronted with ethical dilemmas, students are encouraged to engage in more profound critical thinking, which broadens their understanding of the role of science in society (Rizvi & Shekhani, 2022).

Despite various innovative efforts to enhance the quality of biology teaching materials, several challenges remain—particularly in addressing the diverse learning needs of students, which are often insufficiently accommodated. The implementation of educational technology also varies significantly across regions owing to infrastructure limitations and shortcomings in teacher training (Almuqbil, 2020; Aumann et al., 2024; Sprowls, 2020).

Additionally, biology instruction still largely relies on traditional pedagogical approaches, which overlook the potential of technological advancements and fall short of embracing inclusivity in the learning process (Ziherl & Torkar, 2022). Studies highlight a disconnect between certain content areas in biology and the pedagogical strategies required to integrate technology effectively in the context of secondary school education (Drits-Esser et al., 2021; Moreno et al., 2018).

A systematic and comprehensive mapping of the literature on developing biology teaching materials at the secondary school level was needed to address these challenges. A promising method for achieving this goal is bibliometric analysis, which enables researchers to identify key themes, evaluate inter-topic relationships, and examine the methodological approaches employed for developing educational resources (Donthu et al., 2021; Salido et al., 2024). Furthermore, bibliometric analysis provides valuable insights into patterns of international collaboration, publication trends, and the evolution of topics in biology education over time.

This approach has the potential to reveal underexplored research areas and to support the integration of advanced technologies in the curriculum, thereby facilitating the development of more inclusive and contextually relevant teaching materials for students from diverse backgrounds (Donthu et al., 2021; Nasrum et

al., 2025). By analyzing bibliometric data, researchers can uncover underexplored areas and identify new opportunities for future research, such as integrating emerging technologies in curricula or developing more inclusive teaching materials for diverse student populations.

This study presents a novel bibliometric review and science mapping analysis of Scopus-indexed articles published between 2000 and 2024. By using R-based tools such as Biblioshiny, VOSviewer, and OpenRefine, this study aimed to reveal research trends, productivity patterns, and thematic structures in biology teaching materials for secondary school science education. Specifically, the study examined publication trends, key journal sources, influential authors, author affiliations, collaboration patterns among countries, and the main research themes, including emerging topics that warrant further investigation. This paper highlights innovative future research directions by providing a comprehensive overview of the current landscape. The following three research questions guide the study:

1. What are the research trends and productivity patterns of and influential contributors to the study of biology teaching materials for secondary school science education from 2000 to 2024?
2. How are the thematic structure and evolution of research on biology teaching materials conceptualized through science mapping techniques?
3. What are possible themes for further exploration in the area of biology teaching materials for secondary school science education?

2. Methodology

2.1 Research Design

This study employed a quantitative bibliometric approach to examine publication trends, intellectual structures, and research gaps concerning biology teaching materials in secondary school science education. Bibliometric techniques enable the systematic analysis of metadata of scholarly publications, thereby facilitating the visualization of performance metrics and structural mappings (Aria & Cuccurullo, 2017; van Eck & Waltman, 2010). This paper is organized around two main analytical dimensions that align with the research questions: (1) research performance analysis, which examines trends, productivity patterns, and influential contributors, and (2) science mapping, which examines thematic structures, conceptual evolution, and possible future research themes in the field of biology teaching materials for secondary school science education.

2.2 Data Source and Search Query

The dataset for this study was retrieved from the Scopus database, and was selected for its extensive coverage of peer-reviewed journals in education, science, and interdisciplinary studies (Nasrum et al., 2025; Salido et al., 2024). A search conducted on April 12, 2025, focused on journal articles published between 2000 and 2024. Structured Boolean queries were applied to titles, abstracts, and keyword fields, with restrictions set for documents published in English, classified as final-stage articles, and published in academic journals. The search query used was: (TITLE-ABS-KEY (“Teaching Materials” OR “Instructional Resources” OR “Educational Resources” OR “Science Education”) AND TITLE-

ABS-KEY (Biology) AND TITLE-ABS-KEY (Secondary)) AND PUBYEAR > 1999 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (LANGUAGE, "English")). In total 198 documents were retrieved from this search—they served as the primary data source. The data were exported in comma-separated values (CSV) format, which contained complete metadata, including titles, abstracts, authors, affiliations, keywords, citations, sources, and references.

2.3 Data Analysis and Tools

To ensure the accuracy and reliability of the analysis, the data analysis process of this study was carried out through three steps, namely, data cleaning, data analysis, and reporting results. The raw CSV dataset was refined using the OpenRefine tool during data cleaning. This process involved removing duplicates, standardizing author name variations, aligning institutional affiliations, and correcting typographical inconsistencies (Verborgh & De Wilde, 2013).

Subsequently, the Biblioshiny-R tool and VOSviewer were utilized during the data analysis phase. Biblioshiny facilitates descriptive analyses of annual scientific production, key authors and sources, relevant institutions, and the productivity of countries and institutions (Aria & Cuccurullo, 2017). In turn, VOSviewer was employed to map the principal research themes explored in the literature and to identify possible areas for future research. Finally, the analysis results were compiled and reported descriptively, which was followed by a critical discussion of related studies.

3. Results

3.1 General Landscape and Publication Trends

A long-term overview of publication trends demonstrates a consistent increase in research outputs related to biology teaching materials in secondary school science education. An overview of this trend is presented in Figure 1.

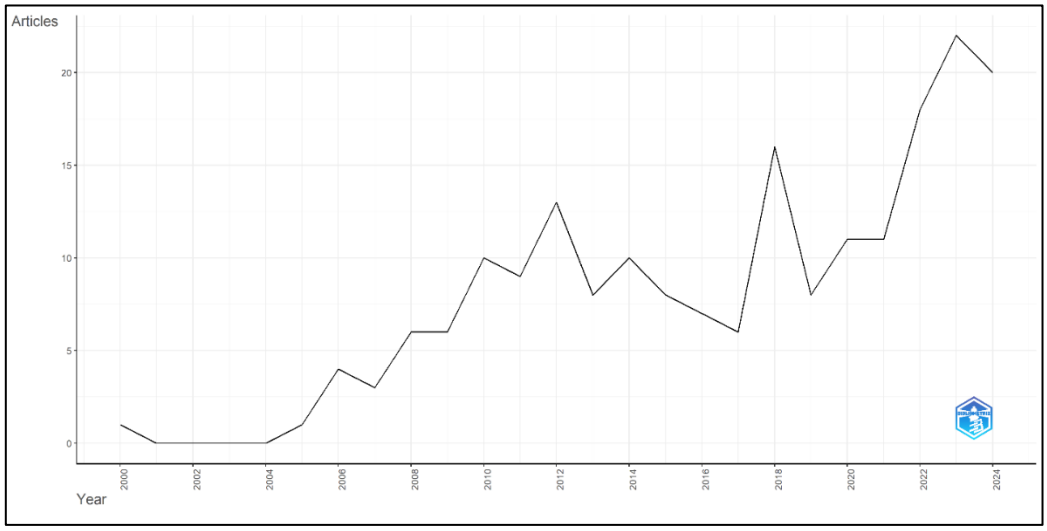

Figure 1. Landscape of Publications on Biology Teaching Materials for Secondary School Science Education (2000–2024)

As illustrated in Figure 1, between 2000 and 2024, the annual scientific output on this topic exhibits a fluctuating yet upward trajectory. In the early 2000s, the number of publications was low and relatively stagnant, with only a handful of studies published until 2006. Then, the period from 2007 to 2012 witnessed a gradual increase, culminating in an initial peak of approximately 13 articles in 2012. After a brief decline, scientific production increased significantly again, particularly from 2018 onward. The peak occurred in 2023, with over 22 publications. Although a slight decrease is projected for 2024, the publication volume remains comparatively high, which reflects growing scholarly interest—especially over the past five years.

Further analysis using the R-Biblioshiny tool identified several journals that contributed substantially to disseminating research on biology teaching materials for secondary school science education. The most prolific journal in this field is the *Journal of Biological Education*, which published 13 articles, followed closely by the *International Journal of Science Education* (12). The *Eurasia Journal of Mathematics, Science and Technology Education* follows with 11 articles, while *Research in Science Education* contributed 10. Other key journals include the *Journal of Baltic Science Education* and the *Journal of Research in Science Teaching* (eight articles each), *Education Sciences* (6), *American Biology Teacher* (5), the *International Journal of Science and Mathematics Education* (5), and *Frontiers in Education* (4). The output of these 10 most relevant journals is visualized in Figure 2.

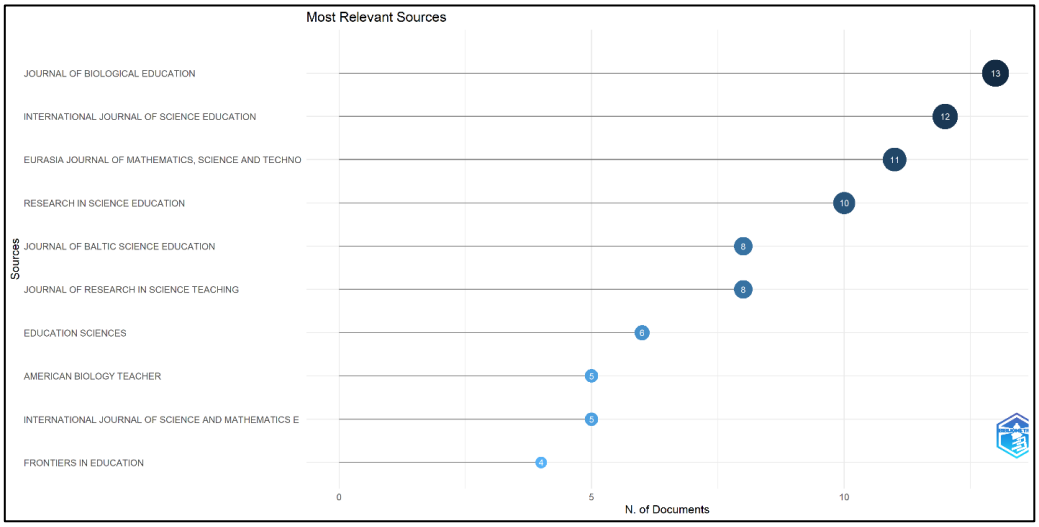

Figure 2. Top 10 Journals Publishing Studies on Biology Teaching Materials in Secondary School Science Education (2000–2024)

An author-level analysis reveals several key contributors to the field. Among the most prolific authors are Aivelo, Eilks, and Markic, with three publications each. Other notable contributors, with two articles each, are Boersma, Bogner, Bogeholz, David, De Smet, De Wever, and Dreesmann. These findings are summarized in Figure 3.

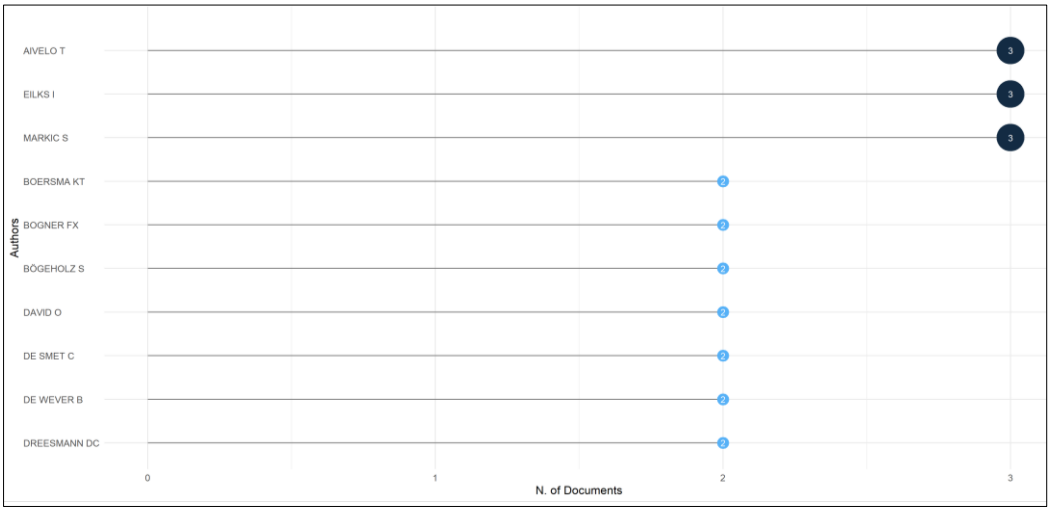

Figure 3. Top 10 Prolific Authors in Research on Biology Teaching Materials for Secondary School Science Education (2000–2024)

Geographic analysis of corresponding authors, as shown in Figure 4, indicates that most publications originated from the United States (44 articles; 22.2%). Germany follows with 17 articles (8.6%), then Canada (9 articles; 4.5%), and the Netherlands and Sweden (8 articles each; 4%). Spain and Turkey each contributed seven articles (3.5%). Other contributing countries include Portugal (6), Australia (5), Finland (5), and the United Kingdom (5), each representing 2.5% of the total. Countries with more minor yet notable contributions are Austria and Rwanda (4 articles each; 2%), Indonesia, Ireland, and Slovenia (3 each; 1.5%), and Belgium,

Denmark, Estonia, and Hong Kong (2 each; 1%). A number of these publications were the result of international collaborations, denoted in red in Figure 4 as multiple-country publications (MCP), whereas those authored in a single country are indicated in green as single-country publications (SCP).

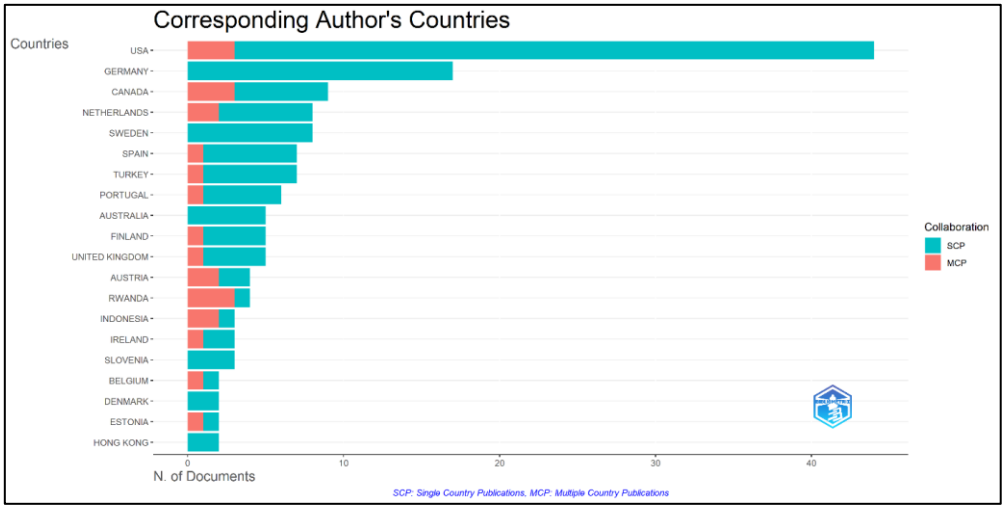

Figure 4. Countries of Origin of Corresponding Authors in Biology Teaching Materials Research for Secondary School Science Education (2000–2024)

Institutional analysis, presented in Figure 5, identifies leading affiliations contributing to this research area. Phillips Exeter Academy stands out, with 87 publications. Prominent universities include the University of Bremen and Utrecht University (9 publications each), followed by Ghent University (8). Johannes Kepler University and the University of Tartu produced eight publications, while Universidad Nacional de Quilmes-Conicet followed with seven publications. The University of Tennessee, the University of Vienna, and the University of Warsaw also contributed seven publications each.

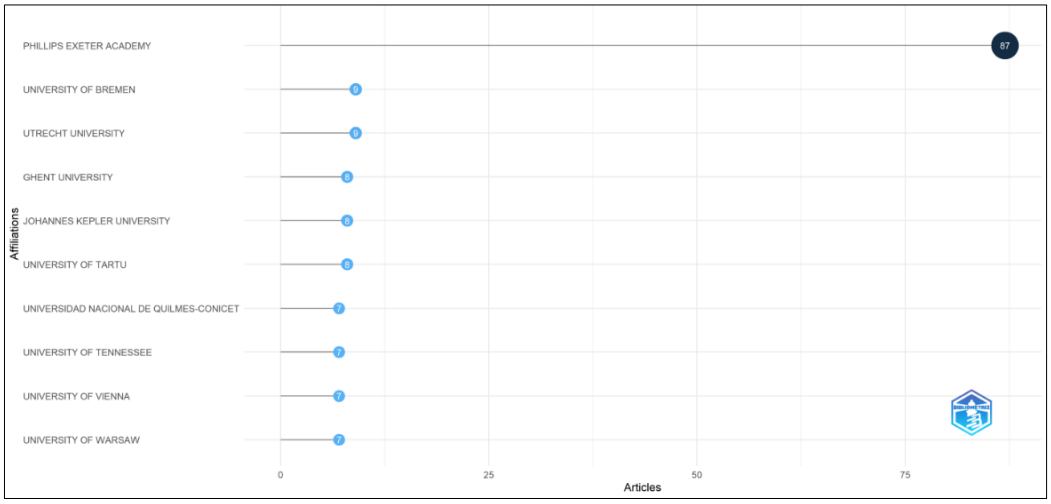

Figure 5. Top 10 Institutions Contributing to Research on Biology Teaching Materials for Secondary School Science Education (2000–2024)

The most highly cited works in this field are listed in Table 1. The leading article, by Folcik (2007), which was published in *Theoretical Biology and Medical*, has been

cited 123 times. This is followed by Riess (2010) in the *International Journal of Science Education*, with 111 citations, and Clough (2011) in *Science Education*, with 108 citations. Other significant works include Taştan (2018), with 100 citations; Irez (2009), with 95 citations; and Dorion (2009), with 93 citations. Other influential publications are Furtak (2014; 87 citations), Verhoeff (2018; 86 citations), Lathwesen (2021; 67 citations), and Martin (2016; 67 citations).

Table 1. Top 10 Most Cited Publications on Biology Teaching Materials for Secondary School Science Education (2000–2024)

Paper, Source	Title	Total citations
Folcik et al. (2007), *Theoretical Biology and Medical*	The basic immune simulator: an agent-based model to study the interactions between innate and adaptive immunity	123
Riess and Mischo (2010), *International Journal of Science Education*	Promoting systems thinking through biology lessons	111
Clough, (2011), *Science Education*	The story behind the science: Bringing science and scientists to life in post-secondary science education	108
Taştan et al. (2018), *Eurasia Journal of Mathematics, Science and Technology Education*	The impacts of teacher's efficacy and motivation on student's academic achievement in science education among secondary and high school students	100
Irez, (2009), *Science Education*	Nature of science as depicted in Turkish biology textbooks	95
Dorion, (2009), *International Journal of Science Education*	Science through drama: A multiple case exploration of the characteristics of drama activities used in secondary science lessons	93
Furtak & Heredia (2014), *Journal of Research in Science Teaching*	Exploring the influence of learning progressions in two teacher communities	87
Verhoeff et al. (2018), *Frontiers in Education*	The theoretical nature of systems thinking. Perspectives on systems thinking in biology education	86
Lathwesen & Belova (2021), *Education Sciences*	Escape rooms in stem teaching and learning—prospective field or declining trend? A literature review	67
Martin et al. (2016), *Journal of Research in Science Teaching*	The role of a museum-based science education program in promoting content knowledge and science motivation	67

3.2 Science Mapping and Thematic Structures

The thematic map generated via Biblioshiny, as shown in Figure 6, illustrates the distribution of research themes according to centrality and density. Themes such as education, teaching, and human are located in the upper right quadrant as motor themes, indicating both strong development and high relevance across related fields. Themes including students, science education, and secondary education are positioned in the lower right quadrant as basic themes, suggesting high relevance but limited development, and highlighting the need for further research. In contrast, themes such as sustainability and engineering education are found in the lower left quadrant, identifying them as emerging or declining. Finally, health and motivation in the upper left quadrant represent well-developed niche themes that are less central to the broader field.

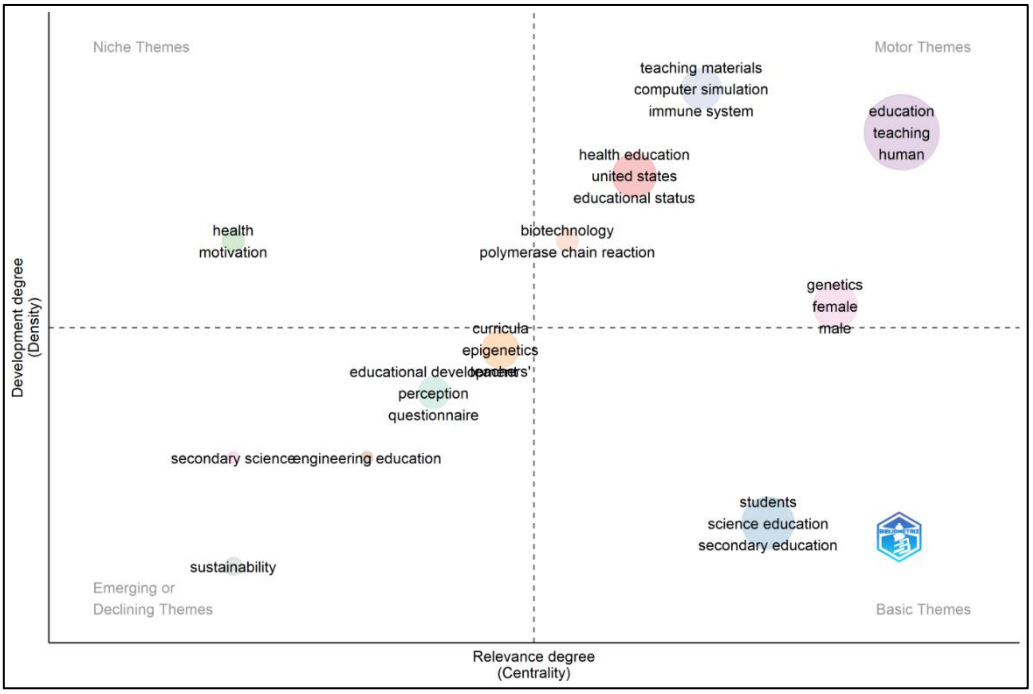

Figure 6. Thematic Map of Research on Biology Teaching Materials for Secondary School Science Education (2000–2024)

The keyword co-occurrence network (Figure 7), visualized using VOSviewer, identifies five major thematic clusters based on keyword frequency (minimum occurrence set to four). The first cluster includes terms related to school-level contexts and learner attributes: adolescent, adult, controlled study, health education, high school, human, knowledge, learning, school, secondary school, and self-efficacy. The second cluster emphasizes teacher-related themes and includes biology education, motivation, professional development, science education, secondary school education, secondary school science education, socio-scientific issues, student, teacher education, and teacher training.

The third cluster focuses on molecular biology and content-based approaches, encompassing keywords such as chemistry, computational biology, education, genetics, methodology, molecular biology, and problem-based learning. The fourth cluster addresses conceptual elements in biology education, including biology, curriculum, evolution, and the nature of science. Lastly, the fifth cluster, the smallest, contains only two keywords—mathematics education and teaching—and refers to interdisciplinary integration in educational research.

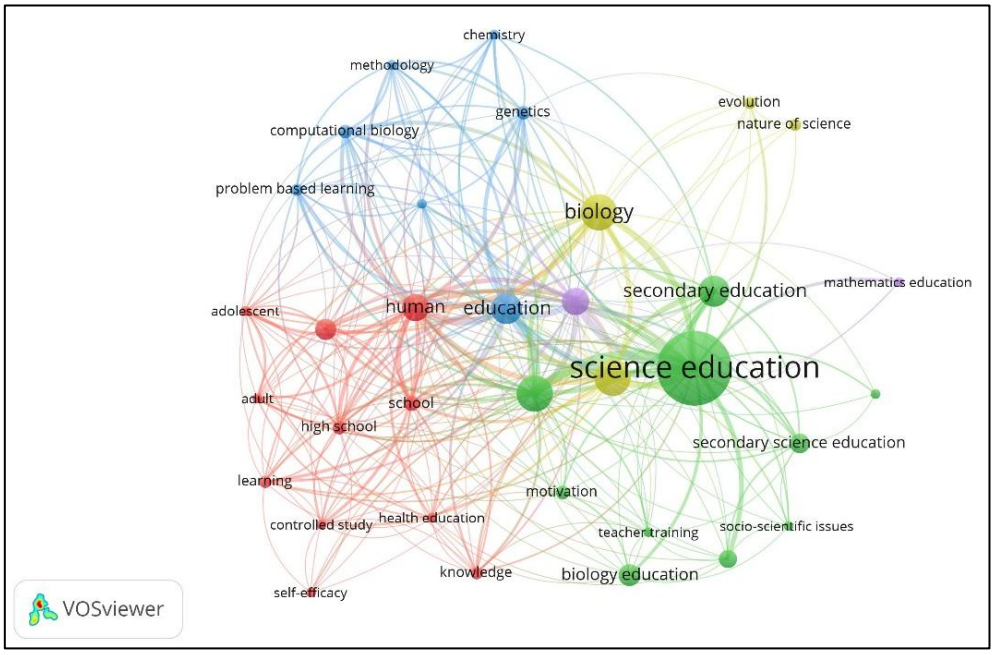

Figure 7. Keyword Co-Occurrence Network of Biology Teaching Materials Research in Secondary School Science Education (2000–2024)

3.3 Potential Themes for Future Research

Keyword trend analysis, as visualized in Figure 8, indicates evolving research interests over time. For example, computational biology emerged in 2008 and gained traction between 2010 and 2011. Keywords such as biology, genetics, and molecular biology gained prominence after 2010 and remained relevant until 2021, peaking between 2014 and 2021. Similarly, terms such as teaching, education, and human gained popularity from around 2011 through 2022.

Furthermore, education-focused keywords—students, curriculum, learning, and secondary school education—show increased usage from 2016 to 2023. Newer terms, such as health education, which first appeared in 2023, point to a growing focus on health-related curricula in secondary school education. Increased frequencies in keywords such as school, knowledge, and curricula since 2016 reflect this trend further.

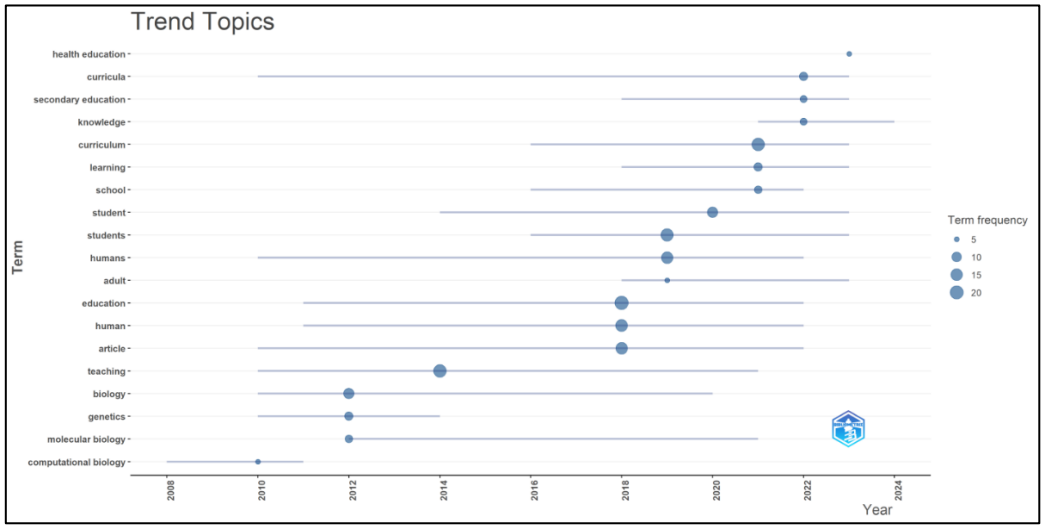

Figure 8. Keyword Trend Analysis in Research on Biology Teaching Materials for Secondary School Science Education (2000–2024)

Overlay visualization of keyword co-occurrence by VOSviewer, shown in Figure 9, highlights emerging keywords from 2020 to 2022. Prominent terms include health education, controlled study, self-efficacy, secondary education, high school, nature of science, and adolescent. These emerging keywords suggest recent research directions that focus on intervention-based learning, the development of student self-concept, and broader applications of biology teaching in the context of secondary education.

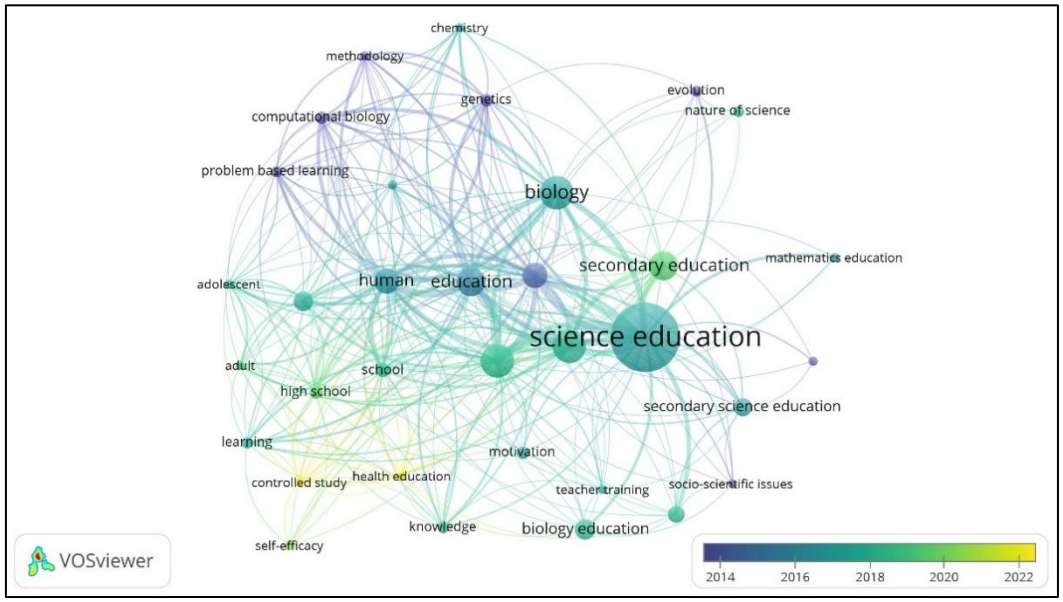

Figure 9. Keyword Co-Occurrence Overlay Visualization of Biology Teaching Materials Research in Secondary School Science Education (2000–2024)

4. Discussion

4.1 General Landscape and Publication Trends

The increasing volume of scientific publications in recent years underscores a heightened awareness of the importance of developing contextual and innovative biology teaching materials at the secondary school education level. This upward trend reflects a broader global initiative to enhance the quality of science education, especially in addressing 21st-century challenges such as scientific literacy, sustainability, and technology integration into learning environments. These developments align with evolving education policies across various countries that emphasize science, technology, engineering, and mathematics (STEM) education and competency-based curricula designed to prepare students for a rapidly changing world (Anastácio et al., 2023; Johnson et al., 2022). Notably, the marked increase in publications post-2018 can be attributed to policy-driven efforts—both national and international—that promote a more responsive and transformative approach to science education.

However, despite the overall growth, the fluctuations observed in annual publication trends suggest that sustained research efforts in this field continue to face significant challenges. These include limited funding, varying institutional research priorities, and disparities in access to academic resources, particularly in developing regions (Ziherl & Torkar, 2022). To mitigate these issues, a more coordinated strategy is essential—one that fosters cross-border and inter-institutional collaborations (Nuora & Välisaari, 2018). As Sprowls (2020) highlight, classroom-based research grounded in the contextual needs of local learners can offer valuable contributions to the global discourse, particularly from underrepresented regions.

Regarding publication sources, leading journals in science and biology education—such as the *Journal of Biological Education* and the *International Journal of Science Education*—play a critical role in disseminating research related to secondary school biology teaching materials. The prominence of these journals underscores a consistent research focus on instructional methodologies and the design of adequate educational resources. For instance, a study by Ziherl and Torkar (2022) emphasizes the importance of pedagogical depth in developing student-centered teaching materials. This theme continues to resonate in the current literature on education innovation at the secondary school level.

The contributions of prominent authors such as Aivelo, Eilks, and Markic have significantly shaped the discourse in this domain, reflecting a dedicated scholarly engagement with the development of biology teaching at the secondary school level. Their work demonstrates a structured and sustained research trajectory, often supported by interdisciplinary approaches. Similarly, in multiple publications, authors such as Boersma and Bogner represent the diversification of research perspectives and methodological approaches in this field. The presence of a broad author base indicates that multidisciplinary collaboration is vital for producing teaching materials that are pedagogically sound and globally relevant.

Institutional diversity, furthermore, illustrates the international scope of this research field. Institutions such as Phillips Exeter Academy, the University of Bremen, and Utrecht University have substantially contributed to advancing and disseminating knowledge in science education. Research produced by these institutions offers a variety of perspectives and affirm the importance of international collaboration to create teaching materials that address the evolving demands of global education. This collaborative ethos reinforces the notion that developing biology teaching resources is a shared international endeavor that is not limited by geographical boundaries.

Moreover, this field's most highly cited publications demonstrate substantial academic impact, as they often appear in respected and influential journals. Seminal works such as those by Folcik (2007) and Riess (2010) have garnered large numbers of citations, which indicate their foundational role in guiding subsequent research in biology education. Contributions by Clough (2011) and Irez (2009) have also significantly advanced understanding in this area, particularly regarding methodological innovations and the theoretical underpinnings of curriculum design. The high citation rates of these studies suggest that they serve as critical reference points in the ongoing development of effective science education practices.

Finally, an analysis of the countries of origin of contributing authors reveals that a substantial proportion of publications originates from countries with robust higher education systems, notably the United States, Germany, and Canada. The United States leads in publication volume, followed by European countries such as Germany and the Netherlands. These nations predominantly produce SCPs, which suggests that much of their research is domestically focused and not widely collaborative across borders. This finding reflects strong national research capacities and localized policy support for science education.

In contrast, countries such as Austria, Rwanda, and Indonesia display a higher incidence of MCPs, with Rwanda, notably, achieving an MCP rate of 75%. This indicates that scholars in these countries are more actively engaged in international research collaborations, which can broaden perspectives and contribute to the global relevance of biology teaching materials. Meanwhile, countries such as Ireland and Hong Kong, with lower MCPs, demonstrate regionally concentrated collaborations that can still enhance the local utility and contextual adaptability of research outcomes.

4.2 Science Mapping and Thematic Structures

Thematic mapping of research on biology teaching materials reveals that "education" and "teaching" are the dominant themes, as evidenced by the frequent occurrence of these keywords in the literature. This pattern highlights the centrality of pedagogical considerations and instructional strategies in the literature on biology education. The emphasis on these aspects aligns with previous research that underscores the value of humanistic approaches in biology learning, particularly those focused on effective teaching methods (Chikaluma et al., 2022; Mapulanga et al., 2023). Moreover, the prominence of these themes

supports the notion that biology teaching materials should present accurate and up-to-date scientific content. They should also incorporate pedagogical approaches—such as contextual learning or inquiry-based instruction—that enhance students' conceptual understanding and long-term retention of knowledge.

Basic themes such as "students," "science education," and "secondary education" reflect foundational aspects that require further development in the context of secondary schooling. As Ziherl and Torkar (2022) state, more targeted research is needed to connect biology teaching materials to the specific needs of students at the level of secondary school, particularly in the context of increasing global diversity. This finding indicates the necessity for curriculum frameworks that are both content-driven and socially and culturally responsive. Meanwhile, the emergence of "sustainability" as a new thematic element highlights rising awareness of environmental issues in science education. According to Solis-Foronda (2020), integrating sustainability into science curricula is imperative, especially in light of pressing global challenges such as climate change and ecological degradation. Nonetheless, its weak linkage to core themes suggests that this area remains underexplored and warrants further investigation by future biology education research.

The co-occurrence analysis of keywords resulted in five major thematic clusters, each representing distinct research foci in the development of biology teaching materials for secondary education. The first cluster focuses on student learning and personal development, which includes self-efficacy, knowledge acquisition, and adolescent health education. Research in this cluster typically uses quantitative methodologies, such as intervention studies evaluating the impact of structured educational programs, such as that of Drits-Esser et al. (2021), who reports that integrated learning units can improve students' skills in science. The presence of terms such as "controlled studies" and "health education" indicates a growing interest in using structured, evidence-based approaches to foster life skills and promote student well-being. This finding is supported by Mankelow et al. (2023), who found that providing deeper learning about students' beliefs and knowledge in the context of health, can lead them to more positive attitudes in the future.

The second cluster focuses on teacher professional development and the relevance of science education approaches. Keywords such as "teacher education," "professional development," and "socio-scientific issues" dominate this area. Findings from this cluster emphasize the critical role of teacher readiness to address contemporary scientific and societal challenges—such as climate change and emerging technologies—through classroom instruction (Gericke & Ewen, 2023). These insights align with calls for teacher training programs that equip educators to integrate socially relevant science content into their pedagogy (Solis-Foronda, 2020; Ziherl & Torkar, 2022).

The third cluster explores scientific content and problem-based learning approaches, particularly in the domains of genetics and molecular biology.

Keywords such as "problem-based learning," "molecular biology," and "computational biology" underscore efforts to design dynamic, content-rich instructional strategies. Similarly, Marthaliakirana et al. (2022) state that problem-based learning strategies have been found to be effective in improving students' critical thinking and problem-solving skills, especially in the context of biology learning, including genetics and molecular biology. This implementation strategy allows students to be actively involved in their learning process, thus building a deeper understanding of complex concepts in biology (Gericke & Ewen, 2023).

The fourth cluster examines the conceptual and philosophical aspects of biology education, by encompassing topics such as "evolution" and the "nature of science." This cluster highlights the need for a deeper epistemological engagement in biology curricula, by encouraging students to understand scientific facts and the processes by which scientific knowledge is constructed (Kvello & Gericke, 2021; Solis-Foronda, 2020). Developing such an understanding is essential for fostering scientific literacy, because it enables students to evaluate scientific claims critically, recognize the tentative nature of scientific knowledge, and apply evidence-based reasoning in real-world contexts. These skills are crucial for preparing informed citizens who can actively participate in societal discussions and decision-making related to science and technology.

Finally, the fifth cluster underscores the interdisciplinary linkage between biology and mathematics, by highlighting the potential of integrated STEM education. Including keywords such as "mathematics education" and "teaching" reflects a growing recognition that cross-disciplinary approaches can strengthen students' comprehension of scientific concepts and their applications. As Lathwesen and Belova (2021) argue, incorporating mathematical reasoning into biology instruction allows learners to engage with science more holistically and meaningfully.

4.3 Potential Themes for Future Research

Emerging research trends in secondary school biology education reveal an increasing emphasis on integrating core biology concepts with technological innovations. Themes such as computational biology, genetics, and molecular biology—which became more prominent after 2010—reflect a pedagogical shift toward incorporating data analysis, algorithmic thinking, and digital tools into biology instruction. This finding suggests a shift toward more complex, interdisciplinary, and technology-driven approaches that align with real-world scientific practices.

Further studies are needed to investigate how computer-based tools, simulations, and educational software can facilitate teaching of advanced biology topics in interactive and accessible ways. This suggestion is particularly critical given the rapid pace of technological development in biotechnology, which offers students opportunities to gain practical, in-depth exposure to scientific processes even when they are subject to classroom constraints (Srougi et al., 2024; Wu, 2024). Additionally, research suggests that integrating computer simulations with

traditional laboratory instruction can significantly improve student performance (Whitworth et al., 2018).

In parallel, the growing frequency of keywords such as "education," "students," "curriculum," and "learning" since 2016 indicates a sustained research interest in how biology curricula are structured and delivered to meet the developmental needs, learning styles, and socio-cultural contexts of secondary-level school learners. This trend reflects a broader effort to design instructional content that not only conveys scientific knowledge but also fosters student engagement, critical thinking, and practical application in the real world. Future research should explore how biology curricula can be aligned with contemporary scientific and social issues—such as climate change, sustainability, and global health—to enhance students' engagement and science competencies.

As noted by Tran et al. (2024) and Jackson et al. (2023), embedding such themes into educational content can provide meaningful real-world contexts that foster a more profound understanding and personal connection to scientific knowledge. Furthermore, implementing curricula that incorporate ideological awareness and address topics such as representation in STEM and environmental issues can enhance students' understanding of the relationship between science and society (Adams et al., 2023; Beatty et al., 2021).

Additionally, overlay visualization analysis reveals a recent surge (2020–2022) in the usage of interdisciplinary keywords such as "health education," "controlled study," "self-efficacy," and "secondary education." These trends point to a growing interest in the convergence of biology, education, and developmental psychology. Incorporating health-related topics into science curricula is especially timely, as global challenges—such as pandemics, mental health issues, and lifestyle-related diseases—have underscored the urgent need for individuals to understand and apply health information in daily life.

Enhancing health literacy through biology education equips students with the knowledge and skills they need to make informed decisions about their well-being, critically evaluate health-related claims, and engage with public health issues in a scientifically grounded manner. Future investigations may focus on the effectiveness of interdisciplinary interventions in enhancing students' scientific literacy and self-efficacy—particularly for adolescents. Studies assessing the psychological and cognitive impacts of such teaching strategies can yield valuable insights into how science education can support the development of critical thinking, problem-solving, and informed decision-making concerning both scientific and societal challenges (Chan & Erduran, 2024; Nagele et al., 2024). Studies also emphasize the importance of considering individual and gender-based cognitive differences in self-regulated learning approaches (Uus et al., 2022).

5. Conclusion

This study explored the research landscape of biology teaching materials for secondary school science education. It sought to identify thematic gaps by

conducting a bibliometric analysis of 198 Scopus-indexed articles published between 2000 and 2024. Using R-Biblioshiny and VOSviewer, the study mapped publication trends, key contributors, and thematic structures that define the evolution of this research area. The results indicate a significant increase in publication output after 2018, which suggests an increase in scholarly interest in pedagogical innovations for biology education at the secondary school level. The *Journal of Biological Education* emerged as the most prolific source, followed by the *International Journal of Science Education* and the *Eurasia Journal of Mathematics, Science and Technology Education*. Leading contributors include Aivelo, Eilks, and Markic, with high-impact work being published by Folcik (2007), Riess (2010), and Clough (2011). Phillips Exeter Academy stood out as the most productive institution, with 87 publications, while the United States led in national contributions.

Thematic analysis revealed a strong emphasis on pedagogical and humanistic approaches, as indicated by keywords such as "education," "teaching," and "human." Established themes, such as "students," "science education," and "secondary education" remain central but still require further development. More recently, emerging themes, such as "health education," "self-efficacy," and "controlled study," signal a shift toward research addressing interdisciplinary concerns, including health literacy, evidence-based instruction, and psychological factors that influence learning.

The findings highlight important implications for future research and curriculum development in secondary school biology education. The consistent focus on pedagogical strategies suggests a growing need to design instructional materials that not only convey scientific content but also support student engagement, critical thinking, and self-efficacy. The rise of health-related and psychological themes presents opportunities to integrate broader interdisciplinary perspectives, such as health education and developmental psychology, into biology instruction.

These shifts reflect the evolving demands of contemporary education, in which fostering scientific literacy involves addressing both content mastery and the cultivation of life-relevant competencies. Researchers, educators, and policymakers should consider these insights when they develop curricula, train teachers, and design research agendas, to ensure biology education remains responsive to scientific advancements and societal needs.

Despite providing a comprehensive research mapping, this study acknowledges two main limitations. First, the analysis is limited to Scopus-indexed publications and exclude relevant studies in databases such as Web of Science and ERIC. Second, the bibliometric approach adopted is quantitative and descriptive and did not assess individual studies' methodological rigor or content quality. Future research should incorporate systematic content analysis and expand the dataset to enhance representativeness. Additionally, further exploration of emerging themes—particularly health education and self-efficacy interventions in secondary schools—could enrich the discourse and foster the development of more relevant and context-sensitive biology teaching materials.

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