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Divulging two decades of multimedia applications in biology education

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Abstract: Biology is an indispensable component of Science, Technology, Engineering, and Mathematics (STEM) education. Accordingly, effective biology teaching necessitates multimedia to assist students in fathoming complex scientific themes. This study aims to examine the bibliometrics of preceding publications on multimedia applications in biology education from the Scopus and Web of Science databases. This study explores descriptive publishing patterns and the emergence of academic discourse about multimedia applications in biology education using ScientoPy and VOSviewer. The results reveal publications on this topic have been volatile, with less than ten publications in both databases. The United States has bested others as the most noteworthy multimedia applications in biology education publication hubs. The top three keywords yielded by ScientoPy were "biology education", "visual literacy", and "science education". The keywords "active learning," "science education," "visual literacy," and "anatomy diagrams" generated by VOSviewer have been among the most employed keywords since 2016. In the abstract's content analysis, the keywords "visual representation" and "image" have often been utilised. This study provides an overview of the applications of multimedia in biology education. It will aid researchers interested in advancing or discovering new knowledge in this domain and developing splendid biology education research ideas and practices.
Keywords: multimedia, biology education, bibliometrics

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INTRODUCTION

Integrating information, communication, and technology (ICT) into the educational system profoundly affects students' abilities and academic quality (Park & Weng, 2020). One plausible explanation is that the increased utilisation of the internet and Android networks has resulted in the influence of technology on education, particularly in learning methods, learning media, and assessment (Nana et al., 2023). Thus, it is critical to employ technology-supported teaching strategies that meet the needs of the 21st-century generation. Integrating ICT into education is an urgent and well-established tactic in the modern world; as information technology advances in the 21st-century, many developed countries have gained a competitive edge (Hermawan, Deswila, & Yunita, 2018).

Science, Technology, Engineering, and Mathematics (STEM)-based education is a viable alternative considering the demands of the modern workplace, which require students to master science, technology, engineering, and mathematics and is critical for future success. For this reason, the world is moving toward a future in which students entering the STEM workforce of the 21st-century will need computational skills such as programming, data analysis, visualisation, and simulation (McDonald, Roberts, Koeppe, & Hall, 2022). The use of ICT-related educational aids has significantly expanded. Policymakers have frequently been enthusiastic about the favourable impacts of ICT on learning outcomes. However, research has failed to provide strong evidence to support this claim (Fernández-Gutiérrez, Gimenez, & Calero, 2020).

Contingent on the 21st-century generations who have grown up surrounded by technology, it is asserted that incorporating technology into lessons aids students in learning the subject. Consequently, new technologies must be better suited for classroom and learning activities. Educational research indicates that the STEM approach has gained widespread acceptance as a modern teaching technique in recent years (Li, Wang, Xiao, Froyd, & Nite, 2020). Despite the fact STEM literacy is considered critical for individuals' and homelands' economic success and health worldwide, it is crucial to consider various groups' diverse interpretations of STEM education (Holmlund, Lesseig, & Slavit, 2018). Thus, teachers must first become familiar with the STEM approach, adapt it, and plan the activities used in their lessons (Arı & Meço, 2021).

Arı and Meço (2021) advocated that teachers require a resource that contains academically relevant, valid, and reliable activities to accomplish their endeavours. A likely reason is that design thinking is a necessary component of creativity and innovation and has gained prominence in recent years as part of the current push to develop and implement integrated STEM education (Li et al., 2019). Additionally, the benefits of STEM education, with a particular emphasis on the degree of integration of STEM disciplines, should be explicit in describing the various levels of integration's strengths and weaknesses (Martín-Páez, Aguilera, Perales-Palacios, & Vílchez-González, 2019).

Biology is a STEM subject that should not be abandoned because it is an influential science that profoundly affects our daily lives and is critical in developing societies worldwide (Abdullah, 2022). Numerous advancements in biology education have reshaped much of pedagogy and learning through the efforts of a growing, disciplined educational research community that has embraced evidence-based teaching practices motivated by research findings (Aikens, 2020). Thus, biology courses must provide more than curriculum content to assist learners in acquiring relevant skills, particularly in developing higher-level critical thinking skills while enhancing their creative and critical thinking abilities (Reiss, 2020). In doing so, critical thinking should be emphasised to facilitate effective 21st-century learning, but it cannot be denied that constructive development of essential thinking skills continues to be extremely limited (Budiarti & Harlis, 2020).

In education, instruction is planned and constantly changing to student needs. Recent research in biology education encourages researchers to draw on theories and methodologies from other disciplines to understand better the processes by which students generate sophisticated ideas (Scott, Wenderoth, & Doherty, 2020). Significant reforms in biology education have been made through concerted efforts to teach students to coordinate their conceptual knowledge as experts. Still, methods for quantifying this initiative are insignificant in terms of numbers (Bissonnette et al., 2017).

Notably, biology education reforms should align with the advancement of ICT and the world without borders. ICT includes technology for creating, storing, and exchanging information over high-speed communication networks conveying data, audio, and video. When multiple of these are used in a communication process, it is known as multimedia (Kareem, 2018). Multimedia's multimodal nature allows it to simultaneously stimulate numerous senses in the audience. It could excite students' intentions in the biology classroom and facilitate interaction between students and professors (Kareem, 2018).

Furthermore, Rosamsi et al. (2019) discovered that the use of multimedia in class could improve students' mastery of concepts by being supported by multiple senses, such as the use of image size and colour to attract students' attention to learning. Additionally, video animation is one of the teaching mediums in the form of interactive multimedia that can introduce something new throughout the learning process (Rosamsi et al., 2019). The use of multimedia in studying human physiology equips students with critical thinking skills because multimedia can overcome the limitations of the senses in understanding the concept (Hidayati & Irmawati, 2019).

This study aims to gain insight from a bibliometric analysis of multimedia applications in biology education by evaluating publication trends and the emergence of academic discourse. Bibliometric study on multimedia applications in biology education is limited. Based on the Google Scholar database, Yuliani et al. (2022) have undertaken a bibliometrics review of multimedia biology education. Abdullah (2022) has examined publishing patterns in biology education without considering other variables. Thus, this study will likely provide a comprehensive picture of the future of multimedia applications in biology education research based on Scopus and Web of Science (WoS) databases to aid readers and researchers in their investigations. The methods employed in this bibliometrics analysis could add significantly to contemporary biology education research. Inevitably, the current study analyses each observable

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parameter in depth. A likely reason is that best practices in metric-based research, particularly bibliometric evaluation, require researchers to hold accountable for conducting dataset checks with responsibility for producing credible results (Hicks, Wouters, Waltman, de Rijcke, & Rafols, 2015).

METHODOLOGY

Bibliometric analysis is a quantitative technique that calculates the frequency and percentage of productivity of measurable parameters such as prominent authors, countries, publication sources, and research institutions (Ellegaard & Wallin, 2015). Remarkably, nowadays, the findings of the bibliometric study are outstanding due to their innovative visualisations and thematic map graphics (Abdullah, 2022; van Eck & Waltman, 2010). This study runs a bibliometric analysis to dig into the burgeoning publication inclinations and the emergence of academic discourse on the multimedia application in biology education. Since convincing arguments have persuaded researchers to pursue research interests and novel insights, bibliometric analysis has become a prominent method for digging into research trends of a particular subject (Aziz, Abdullah, & Samsudin, 2021).

The collection of publications employed in this study was based on the Scopus and Web of Science (WoS) databases. These databases were chosen as they were two significant databases that indexed relevant periodicals to the social sciences (Hicks et al., 2015), particularly educational studies. Most previous scholars have denoted them as standard, reliable and reputable databases for bibliometric analysis (Abdullah & Sofyan, 2023). In addition, Donthu et al. (2021) averred that Scopus and WoS databases provide comprehensive and integrated data for evaluating large-scale publications that have increased over the past decade. Adopting the Scopus and WoS databases is thus an authoritative intermediate for scholarly harvesting outputs that benefitted many scholars for further research exploration.

Increasingly, data is employed to comprehend a study, and data evaluation is dependent on metrics. Hicks et al. (2015) quantified that research that focuses on solving societal problems is distinct from research that expands the frontiers of academic knowledge. A review may be based on merits relating to policy, industry, or the public rather than literary quality (Hicks et al., 2015). Consequently, bibliometric analysis in this study has followed the procedure suggested by Ruiz-Rosero et al. (2019) to combat bias tendencies, depicted in Figure 1.

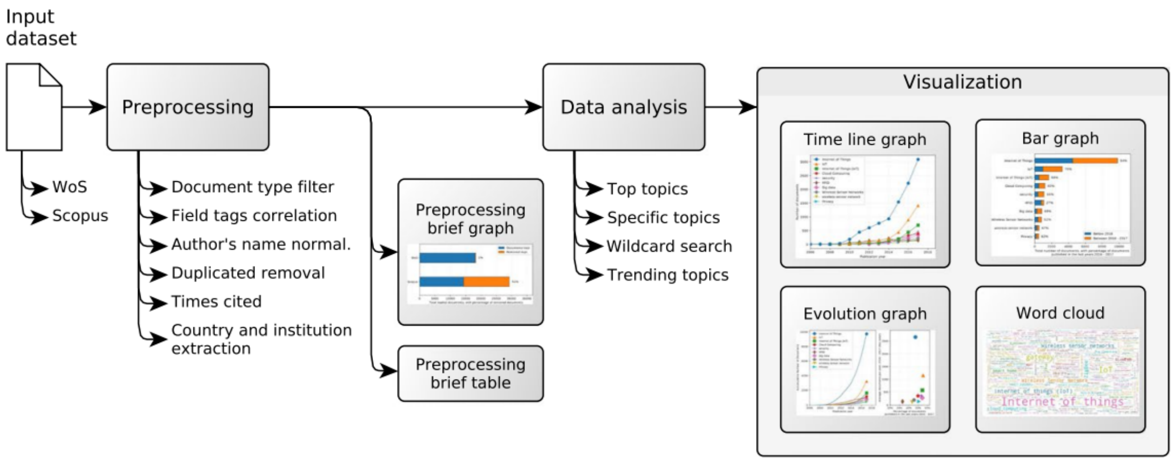

Figure 1. Bibliometric Analysis Procedure

Retrieve the bibliographic dataset from Scopus and WoS databases

This section covers how to retrieve the dataset from Scopus and WoS databases. The first step is to develop a set of search criteria for the subject. For this reason, the datasets of the Scopus database were compiled using the following query: (TITLE-ABS-KEY ("multimedia" OR "interactive media" OR "image" OR "visual" OR "graphic" OR "audio" OR "hypermedia" OR "audio-visual" AND "biology education")). At the same time, the datasets from WoS were collected based on topic searching using the following query: ("multimedia" OR "interactive media" OR "image" OR "visual" OR

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"graphic" OR "audio" OR "hypermedia" OR "audio-visual") AND "biology education". Those keywords were retrieved on 1st January 2023 without considering specific publication years or language selection.

Executing ScientoPy scripts

In this section, we will go over the ScientoPy scripts that were used to prepare and analyse the bibliometric data. Before continuing to explore the measurable parameters, the first thing to perform is to preprocess the downloaded dataset. All the downloaded files are combined into a single file during this preliminary procedure. Additionally, this operation will get rid of any duplicated files. Preprocessing the data involves changing any commas in author names to semicolons, removing any dots, commas, or unusual accents, and removing any samples with the same author and title. The consistency and accuracy of the datasets are enhanced by this method (Ruiz-Rosero et al., 2019).

After preliminary processing, the data were compiled into a single dataset. Table 1 depicts the preprocessing of datasets, with the number of raw datasets being 185. After sorting based on the document types, there were 174 datasets. Eventually, after eliminating the redundant documents, this study obtained 114 reliable and valid datasets for executing the subsequent analysis.

Table 1. Information Concerning Preprocessing of Datasets

Information	Number	Percentage (%)
Raw datasets (Scopus and WoS)	185	100.00
Sorting based on document types (only include ScientoPy default)	11	5.90
Total datasets after removal of omitted documents	174	94.10
WoS datasets	68	39.10
Scopus datasets	106	60.90
Redundant documents	60	34.50
Eliminated redundant documents from WoS	0	0.00
Eliminated redundant documents from Scopus	60	56.60
Redundant documents with various mentioned by references	35	58.30
Reliable and valid datasets	114	64.00
Reliable and valid datasets from WoS	68	59.60
Reliable and valid datasets from Scopus	46	40.40

Determine the Measurable Factors

Table 2 tabulates 12 ScientoPy criteria for determining the most critical subjects or topics. The interpretation of measurable factors is described based on the research conducted by Ruiz-Rosero et al. (2019). Nonetheless, in most cases, the objectives or study questions that the researchers established are connected to these observable characteristics. In layman's words, the selection of these measurable factors varied on the research objectives decided by the researchers.

Analyse Measurable Factors

It is worth noting that, top topic discovery and evolution, specific topic evolution, wildcard search, and subject trends are just a few examples of the diverse data analysis that ScientoPy can perform (Ruiz-Rosero et al., 2019). Impressively, ScientoPy can execute complex tasks, for instance, finding singular and plural varieties of a word, such as "student" and "students," which may be a real pain without the help of wildcards. Using an asterisk as a wildcard to locate phrases or words that begin with or end with the specified letters is helpful. Indirectly, the spelling differences will combine automatically in the ScientoPy.

ScientoPy employs three topic growth metrics to determine trending subjects' relative or absolute growth (Ruiz-Rosero et al., 2019). ScientoPy identifies the most popular trending topics with the highest

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average growth rate (AGR). The AGR is the average difference between the number of papers released in one year and the previous year's number of documents. The average number of documents per year (ADY) is an absolute indicator that reflects the average number of papers published for a specific topic within a given time frame. The percentage of documents in the previous year (PDLY) is a relative statistic that reflects the proportion of the ADY in comparison to the total number of documents for a particular topic.

The outcomes of analysing measurable parameters are then displayed in a table or diagram. There are five sorts of graphs based on the charts: (i) time-line, (ii) horizontal bars, (iii) horizontal bar trends, (iv) evolution, and (v) word cloud.

Table 2. Measurable Factors in ScientoPy

Measurable Factors	Interpretation
Author	This factor pertains to the last name and initial of the author
Source Title	The source title refers to the name of the publication or journal
Subject	The subject is pertinent to the research areas. It simply provides inputs from the WoS datasets
Author Keywords	Author keywords are the terms that authors use to describe their research. It is located following the abstract
Index Keywords	Index keywords are the keywords generated based on the index of databases; in WoS, they usually correspond to Keyword Plus, and in Scopus, they are referred to as Scopus Indexed.
Both Keywords	Both keywords are denoted as the author keywords and index keywords.
Abstract	An abstract is the summary of a document. It can be used with pre-set topics and the asterisk wildcard.
Document Type	ScientoPy, by default, filters publications that are categorised as one or more of the following document types: Conference Paper, Article, Review, Proceedings Paper, and Article in Press.
Database	A database is an ordered collection of data that is electronically stored and accessible. ScientoPy can simultaneously analyse the Scopus and WoS databases.
Country	Country determined based on the author's affiliations.
Institution	Institution determined based on the author's affiliations.
Institution with Country	Institution and country are determined based on the author's affiliations.

Analysis of co-occurrence of authors' keywords and text mining from abstract

VOSviewer is a piece of software made specifically for making, viewing, and navigating bibliometric maps of scientific literature (van Eck & Waltman, 2010). VOSviewer can inspect bibliometric parameters that were not limited to citation links between publications or journals, collaboration relations between researchers, and co-occurrence interactions between scientific terms (Al Husaeni & Nandiyanto, 2021). This study uses VOSviewer to draw keywords from the abstract's text and detect where authors' keywords appear. VOSviewer's text mining features facilitate the generation of corpus-based word maps (Zahedi & Eck, 2015). A term map is a conceptual map that uses the closeness of two terms to determine their amount of relatedness. In most instances, the proximity of two phrases is proportional to the similarity of their meanings, and the co-occurrences define the link between the two terms (Abdullah, 2021).

RESULTS AND DISCUSSION

This study investigates publication trends and the emergence of academic discourse on multimedia applications in biology teaching. In this study, publication trends are measured quantitatively, whereas the emergence of academic discourse is a qualitative phenomenon that benefits from content analysis. The following results and discussion deliver potential readers and researchers with new insights and paradigms for further exploration of the rapport between multimedia and biology education.

Descriptive Inputs of Publication Trends

Figure 2 illustrates the development of publications on multimedia applications in biology education in both databases. Compared to the WoS database, the publication trajectory in Scopus

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dramatically increased in 2008, and WoS experienced a marked increase in 2012. Regrettably, the overall publications on multimedia applications in biology education have been volatile (fluctuated), and less than ten publications have been released since 2001.

Biology education is a crucial component of STEM education, which significantly impacts our daily lives and is essential for the development of all communities (Abdullah, 2022). Nevertheless, student performance in biology for a particular topic is not encouraging, especially in understanding complex concepts (Akinbadewa & Sofowora, 2020). This scenario indicates that greater focus should supposedly be positioned on multimedia as a teaching and learning strategy that might stimulate students' interest and increase their understanding of complex biological concepts. Therefore, more studies need to be conducted on the application of multimedia in biology education to improve student performance in biology.

In addition, information technology is vital in the modern era, and promoting information technology development is said to awaken research concerning multimedia applications indirectly (Kareem, 2018). This is pertinent in simplifying access to resources and instructional materials on biological topics that are highly complex and challenging for students to grasp from textbooks. Inferentially, multimedia in instructional media potentially awakened students' interest in biology due to their visual, dynamic, and interactive attributes (Sukenda, Anjani, & Yustim, 2019). Through the evolution of information technology and the ever-increasing use of technology today, biology-teaching and -learning-facilitating software and multimedia should be developed and created. Moreover, teachers and students have adopted the widespread use of smartphones; thus, creating programmes that can be used on mobile devices is anticipated to aid students in learning complex biology topics.

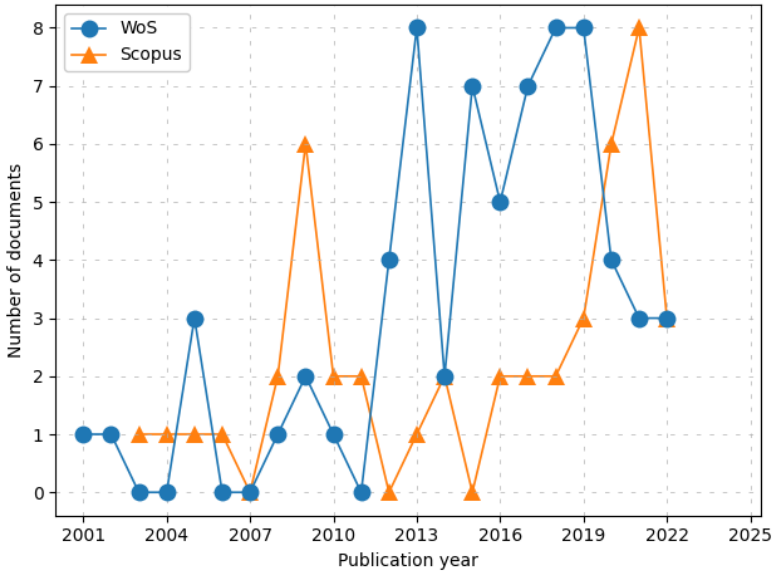

Figure 2. Scopus and WoS Timeline Graph

Based on an analysis of published datasets on multimedia applications in biology education in high-impact journals (see Figure 2), it is concerning that the rate of publications on this issue is decreasing. Therefore, experts in biology education must undertake more extensive research and collaborate internationally to implement a global reform agenda in the biology education system. This is because multimedia with exciting visuals and motion graphics are necessary for enhancing students' understanding of biological principles such as osmosis, diffusion, and photosynthesis. Another compelling reason is that multimedia can improve comprehension of basic biological notions and yield better results than conventional teaching techniques (Kareem, 2018).

Figure 3 displays the top 10 most productive countries from this analysis. With 33 publications, the United States has become the leading publisher countries on the topic of multimedia applications in biology teaching. With 15 publications, Indonesia ranked second, followed by Germany in third position, with seven.

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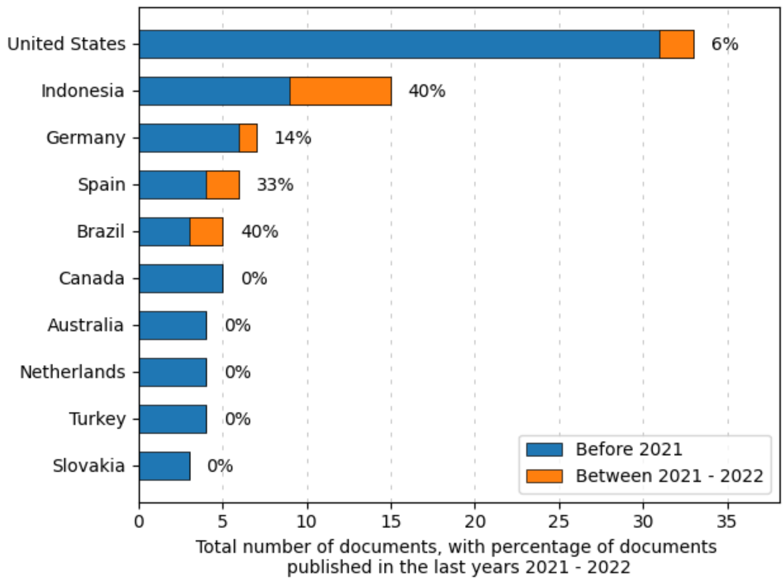

Figure 3. Country bar Trends Graph

The United States has eclipsed all other countries as the leading publication hub for biology-related multimedia publications. In effect, the magnitude and availability of government research expenditures considerably impact research production. Government financing for research is widespread in the United States, with the National Science Foundation providing one of the most prestigious grants. The National Science Foundation is an independent government body that sponsors all federally financed fundamental research undertaken at American colleges and institutions. This explains in a significant portion why the United States is the leader in this field of study.

Consistently, this study discovered that Indonesia produced a sizable number of publications on biology education. Universities' primary outputs are human capital development, new knowledge, and technology. The Indonesian government is making strenuous efforts to provide professional development opportunities for in-service teachers and governmental and non-governmental organisations to consider teachers' needs better when developing biology education content (Faisal & Martin, 2019). Based on these findings, the publications produced by researchers within a country may rely on government-funded research assistance. Identifying potential research opportunities is of utmost importance as it facilitates funding organisations and policymakers in identifying areas of research that can impact society significantly (Badenhorst et al., 2016). Thus, government assistance and initiatives such as increasing publication grants should be implemented year-to-year to continue increasing the number of publications.

Figure 4 grants a list of the ten most productive institutions. Universitas Pendidikan Indonesia has published five papers pertinent to multimedia applications in biology education and has become the leading institution. The University of Castilla–La Mancha in Spain was the second most prolific institution, with three publications. These institutions have been recognised as leading institutions over these two decades. It is evidence that Indonesia is the most productive country in researching multimedia applications in biology education. When it comes to quantitative parameters like a test, value, instrument, assessment, and statistics, as well as qualitative parameters like competence, needs, practise, impact, and challenge, Indonesian institutions have demonstrated their pre-eminence in the field of research on Technological Pedagogical Content Knowledge (TPACK) (Suprapto et al., 2021). TPACK was developed to describe the range of skills and understandings in which teachers must integrate technology successfully into their classrooms and lessons (Sickel, 2019).

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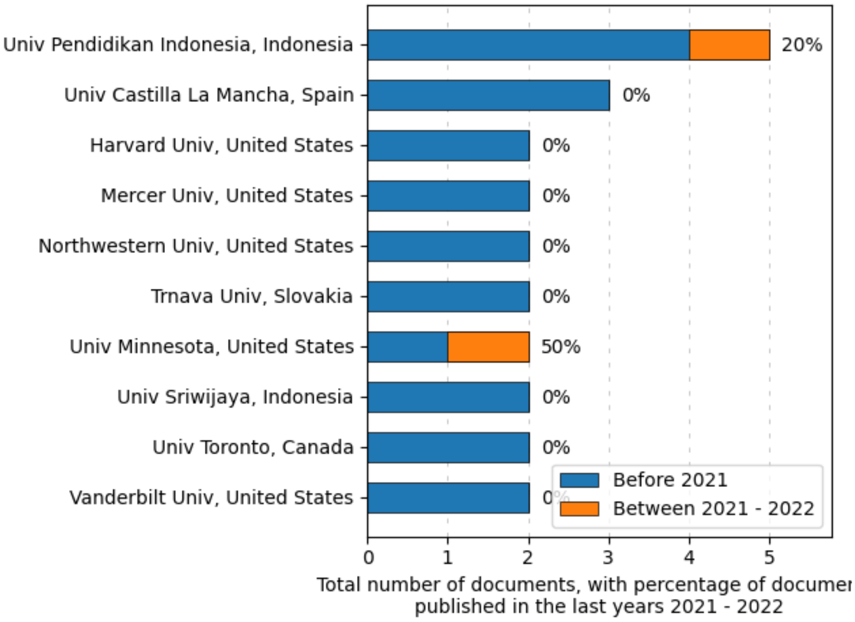

Figure 4. Institution Bar Trends Graph

In order to evaluate the efficacy of biology education resources, a TPACK instrument for learning media is required (Nevrita, Oprasmani, & Sarkity, 2022). It appears that the use of technology in the learning process aids students in comprehending subject matter in biology, which is always associated with abstract concepts. Prospective teachers must design conceptual learning to be more concrete, contextual, or realistic based on the level of thinking of their students using technology. Effective teachers must utilise the potential of technology to increase student comprehension, pique their interest in learning, and enhance their skills. These aspects have been crucial to the use of multimedia in biology instruction, and additional research on this topic is thought critically.

The Emergence of Academic Discourse

The emergence of academic discourse applicable to multimedia applications in biology education is associated with the ten authors' keywords from ScientoPy, the overlay visualisation of co-occurrences of authors' keywords, and text mining of the abstracts. Authors' keywords are denoted to the keywords chosen by the authors to describe their document's content immaculately. It is widely apparent that authors could inscribe their keywords if they incorporate the study topics.

As illustrated in Figure 5, the keyword "biology education" is the most frequently drawn on, followed by "visual literacy" and "science education". Even though Figure 5 displays the first ten keywords, ScientoPy allows us to view unlimited keywords. Besides, Figure 5 depicts the percentage of papers published in the previous years (PDLY) (2021–2022) for measuring relative growth. With this indicator, we can see that "visual literacy", "anatomy diagrams", and "Science education" are the keywords that account for more than 25% of PDLY. Without a doubt, these topics have grown massively in the last two years compared to other keywords.

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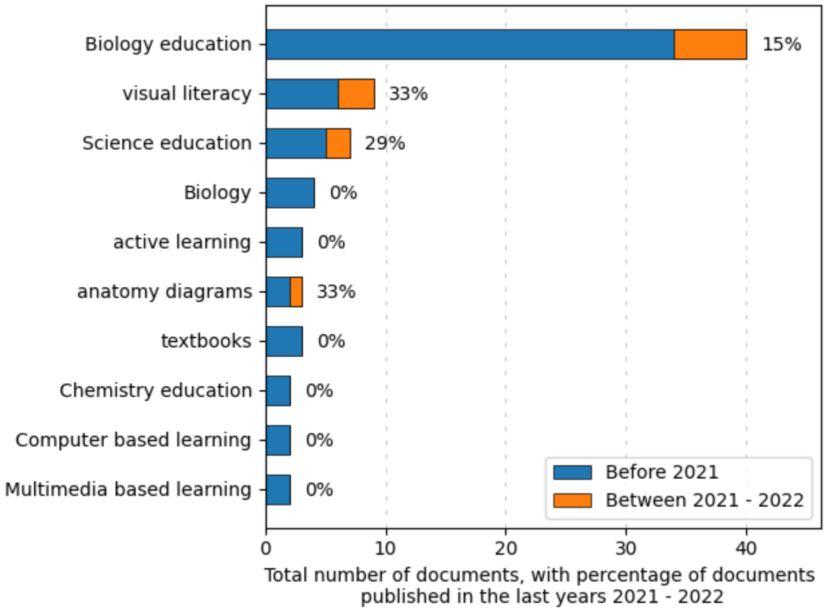

Figure 5. Author's Keywords Bar Trends Graph

Cluster mapping was used in this study to determine the co-occurrence of the authors' keywords. It intends to identify the nexus of themes or topics that evolved over the years (see Figure 6). The dataset was preprocessed with SientoPy before being used to generate a network map with the VOSViewer (a combination of Scopus and WoS metadata). This study used a thesaurus file to map the co-occurrence of the authors' keywords before mapping them to accomplish well-grounded results. Thesaurus files are essential for concatenating related terms, spelling variations, and singular or plural terms.

Figure 6 offered a network representation of the keywords in which colour, node sizes, font widths, and thickness of the connecting lines illustrate the link with other keywords. The minimum number of keyword occurrences in this enquiry is 3, and 9 of the 288 keywords met this criterion. The brightest colour of the boxes on the diagram represented the most recently discovered terms, while the darkest one described an earlier period of exploring the terms.

Based on Figure 6, the most used terms by researchers before 2016 were "biology", "undergraduate biology education", "textbooks", "multimedia-based learning", and "biology education". In contrast, "active learning", "science education", "visual literacy", and "anatomy diagrams" are among the most popular search terms since 2016 ahead. The keyword "biology education" in the largest rectangle represented 42 occurrences with an entire link of 22. The keyword is having close to "textbooks", "anatomy diagrams", and "science education".

Content analysis in the abstract reveals the terms and phrases used most in past studies and is also worth scrutinising. This data simultaneously renders the facets of earlier studies devoted to the implementation of multimedia in biology instruction. The abstract-based visualisation of term occurrences is shown in Figure 7. A strong correlation is depicted by thicker lines between larger box frames, while larger box frames show a higher frequency of occurrences. In completing this text-mining analysis, an additional thesaurus file was included to combine different spellings, singular and plural forms, and abbreviations of the terms.

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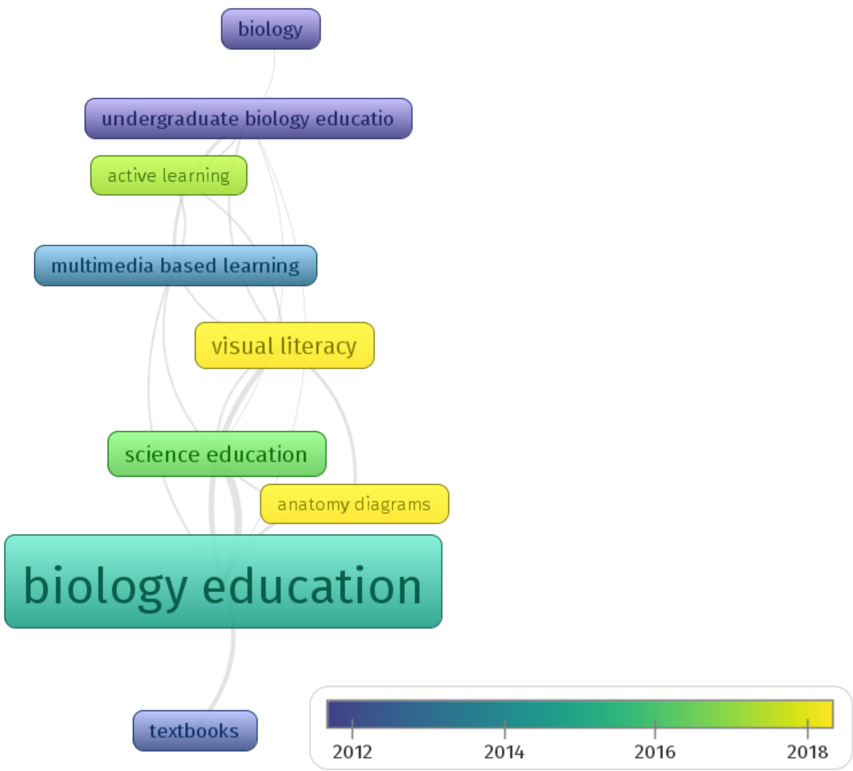

Figure 6. The Overlay Representation of The Co-occurrence of Authors' Keywords

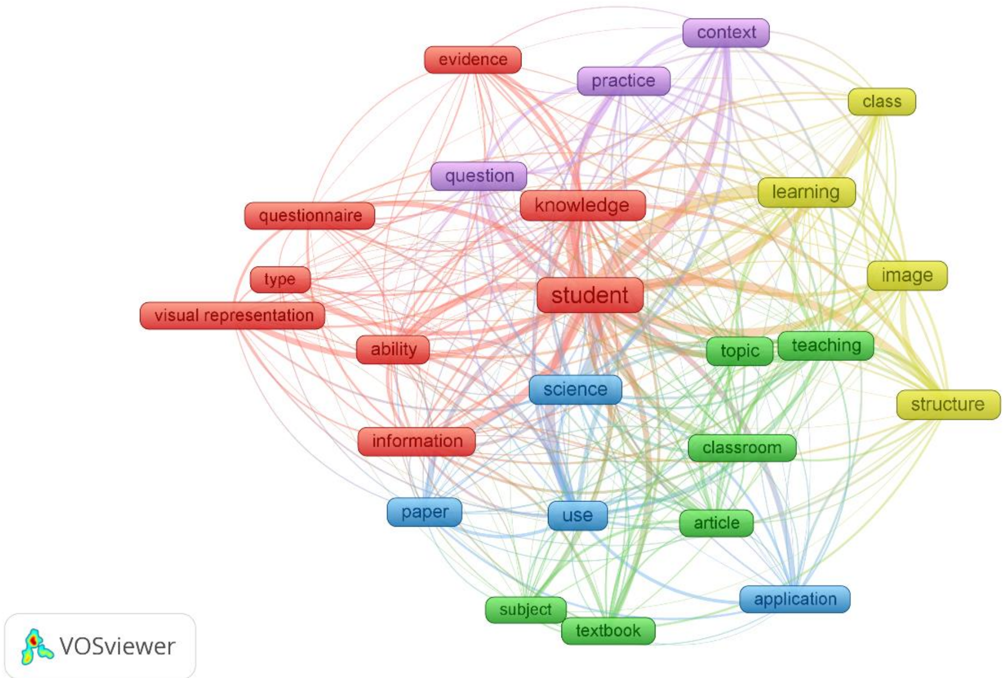

Figure 7. Network Visualisation of a Term Co-Occurrence in Abstract

The minimal number of occurrences of a term used for abstract analysis in this study is ten. As a result, 42 out of 2,899 terms satisfied the requirements and were assigned a relevance score. 60% of the most relevant phrases were selected as the default selection based on this score. Finally, 25 terms have been selected to accomplish the abstract analysis. The clusters in Figure 4 are colour-coded as red, green, yellow, and blue. Figure 7 shows two terms related to multimedia that have been frequently used in the abstract of the previous studies. The terms are "visual representation" and "image". The term "visual

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representation" was linked to 21 additional terms with a total link strength of 58 and 12 occurrences. Clusters of the term "visual representation" are coloured red. Another term clustered in yellow is "image," which is connected to 22 other terms with a total link strength of 89 and 24 occurrences.

Based on Figure 5, the keyword "visual literacy" emerged as a trending research topic between 2021 and 2022. It is also grouped in the same cluster as "anatomy diagrams" indicated in Figure 6 that rendered these terms were trending since 2018. Literacy typically refers to the understanding of a written or printed text. Still, visual literacy broadens this definition to include the ability to comprehend, negotiate, and construct meaning from information delivered in the form of an image. According to Duchak (2014), visual literacy refers to a group of vision competencies that a person can acquire by simultaneously observing and integrating other perceptual experiences. In addition to visual literacy, the increasing usage of computers and other digital media places a high focus on media literacy abilities when assessing the skills required to be digitally literate (Osterman, 2012). Exposure to characteristics that enable students with a high degree of digital literacy will result in positive learning outcomes, demonstrating the importance of digital literacy in the learning process, particularly for online learning employing a variety of features and digital learning platforms (Latip, Sutantri, & Hardinata, 2022).

Technology, information, and communication have all advanced to the point where the digital world's narrative simplifies learning in the 21st century (Yarni & Kusuma, 2022). It is; thus, visual literacy must be developed before engaging in visual communication or understanding the rhetorical potential of an item, image, or text (DeTora & Hinson, 2023). A likely reason is that these days, visuals play a much more prominent role in communication than they ever have before. Images as forms of communication are pervasive in our daily lives, especially among the young (Kędra & Žakevičiūtė, 2019). Visual literacy skills among biology students are critical because visualisation tools are essential for understanding and researching specific topics such as molecular and cellular (Schönborn & Anderson, 2006). Despite this, Matusiak et al. (2019) discovered that students lack fundamental visual literacy skills in selecting, assessing, and utilising images. In recent years, there has been an increase in the desire to learn about visual literacy in biology courses.

Content analysis in the abstract reveals that the terms "visual representation" and "image" have frequently been used in previous abstracts (see Figure 7). Modern classrooms use various visual aids to help students grasp complex concepts. This is because the natural sciences are inherently tricky, posing unique challenges for students and teachers. Some problems biologists encounter includes the seemingly infinite variety of biological processes that occur inside and between organisms, the hierarchical structure of nature from the molecular to the ecological levels, and the sheer abundance of species and their forms (Anđić et al., 2022). The visual representation and image can improve students' understanding of biological concepts like osmosis, which multiplies their overall comprehension and ability to think critically about the subject matter.

Considering the potential of representation to address students' misconceptions, future studies may employ visual representation and images to generate cognitive expression or visualisation of real-world biological ideas that can aid in comprehending complex biology subjects. Education measurement helps students achieve academic success and motivates them to study (Wilson, 2018). Also, a growing, disciplined educational research community that has embraced evidence-based teaching practices inspired by research findings has reshaped much of pedagogy and learning (Aikens, 2020). One of the necessary conditions for scientific success is the maintenance of faith in science, which is imitated in the role of the educational system (Nurse, 2016). Biology is advancing at a breakneck pace to meet the challenges of an uncertain future. Biology education as a subject might benefit an individual's development to lead a healthy and harmonious social life. Hence, biology education would equip students with the practical skills, knowledge, and attitudes necessary for ethical material processing. Facts in science can be detrimental following a life journey. A scientific fact is backed up by facts and shows a strong connection between education, learning, and science.

CONCLUSION

According to the present bibliometric analysis, it has been observed that the research trends on multimedia applications in biology education, as examined through the Scopus and WoS databases, have exhibited fluctuations. Educators and researchers should undertake supplementary measures to conduct research that surpasses anticipated outcomes. The significance of this matter lies in the fact that

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multimedia can serve as a component of educational resources that have the potential to augment students' understanding of intricate biological concepts. The progress of technology can also serve as a catalyst for research in this field, as evidenced by prominent research topics such as “visual literacy" and "active learning”.

Limitations

Despite the unique characteristics of the bibliometric analysis, the study has significant limitations that must be mentioned to provide readers with a complete perspective. Primarily, this study is restricted to the Scopus and WoS databases as the principal document sources. Additional databases such as ERIC, Google Scholar, and Dimensions may be utilised in subsequent investigations. Another limitation related to the analysis of publications based on the extended results list is not detailed in this study. This becomes more interesting when the scoping review technique is combined with it. Additionally, research themes for each year can be formed by analysing the data format combined via ScientoPy with SciMAT software.

Future Research Directions

In order to improve the research on multimedia applications in biology teaching, additional research should be undertaken. Analysis of trending keywords gleaned from ScientoPy and VOSviewer can be utilised in various studies. Using systematic literature review or scoping review procedures, educators, researchers, and anyone interested in the topic might continue their investigation based on this study’s findings. In addition, based on the accomplished keyword analysis, the outcomes of this study can provide researchers with ideas for conducting empirical research on multimedia applications in biology teaching. Also, the findings of this study may assist future researchers in identifying research gaps to render novel contributions to the existing body of knowledge, theory, or practices. In conclusion, as a result of this bibliometric analysis, readers, educators, and researchers will be better equipped to discover crucial information for evaluating or examining multimedia applications in advanced biology education in future research.

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