BIBLIOMETRIC ANALYSIS OF INQUIRY-BASED LEARNING MODELS IN BIOLOGY ONLINE EDUCATION FOR ENHANCING HIGHER-ORDER THINKING SKILLS (HOTS) FROM 2013 TO 2023

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Abstract: The rapid development of educational technology and increasing emphasis on Higher-Order Thinking Skills (HOTS) have made inquiry-based learning models in biology online education a crucial area of research. This study aims to analyze inquiry-based learning models in biology online learning using bibliometric analysis, focusing on publications from 2013 to 2023 sourced from the Google Scholar database. Out of an initial 298 articles, 53 relevant articles were identified and analyzed. The research methodology involved systematic stages, including keyword searches, refinement of results, data compilation, and analysis using tools like Microsoft Excel and VOSviewer software. The findings reveal that the number of publications on inquiry models in biology online learning fluctuates annually. Articles were categorized based on criteria such as the type of inquiry model (e.g., guided inquiry, free inquiry), variables studied, research locations, citation counts, HOTS components (e.g., critical thinking, problem-solving), types of online learning (e.g., interactive content, blended learning), and bibliometric visualizations. Notably, the study identified critical thinking and problem-solving as dominant HOTS aspects, while interactive content emerged as the most frequently used online learning type. The bibliometric visualization generated 14 thematic clusters, providing insights into research trends and gaps. This study offers valuable insights for researchers, educators, and policymakers interested in biology online learning. It highlights the potential for further exploration of underrepresented areas, such as decision-making and empirical research. The findings also serve as a guide for future studies to enhance the effectiveness of inquiry-based learning in fostering HOTS.

Keywords: *bibliometrics; biology; higher-order thinking skills; online learning.*

INTRODUCTION

Learning inquiry, as a dynamic teaching approach, plays a critical role in engaging students to explore and investigate various subjects systematically, critically, and analytically. It empowers learners to derive their own conclusions with confidence, fostering deeper understanding and cognitive growth (Berie et al., 2022). This model requires teachers to implement effective instructional strategies that enhance student participation and engagement during the learning process. Teachers' ability to develop such models directly impacts students' ability to learn actively and happily, which ultimately optimizes academic outcomes (Stone et al., 2020). Effective learning strategies are rooted in a teacher's deep understanding of classroom dynamics and students' developmental stages (Grob et al., 2017).

Inquiry-based learning has become a cornerstone of modern educational practices, emphasizing active student engagement through exploration and investigation. This pedagogical

approach encourages students to pose questions, conduct investigations, and develop solutions, thereby fostering critical thinking and problem-solving skills (Akuma & Callaghan, 2019; Berie et al., 2022). Teachers play a crucial role in facilitating inquiry-based learning by designing effective instructional models that promote meaningful student participation (Stone et al., 2020). The success of these models depends on educators' understanding of curriculum design, teaching methods, and classroom dynamics (Grob et al., 2017; Ab Halim et al., 2021).

In the context of biology education, inquiry-based learning has shown significant potential in enhancing students' higher-order thinking skills (HOTS). Biology, with its complex concepts such as evolution, ecology, and biochemistry, offers ample opportunities for students to engage in deep analysis and critical evaluation (Bulić & Blažević, 2022; Aýun & Irwansyah, 2022). Research indicates that students who participate in inquiry-based biology learning exhibit improved abilities in synthesizing information, formulating hypotheses, and applying scientific methods (Chiang et al., 2014a; Lin et al., 2022). Such approaches not only deepen understanding of biological concepts but also prepare students for real-world problem-solving (Brahler, 2002; Brahler et al., 2002).

Advancements in Information and Communication Technology (ICT) have revolutionized educational methodologies, particularly in enhancing inquiry-based learning. The integration of technologies like augmented reality (AR) and virtual laboratories has enabled more interactive and immersive learning experiences in biology (Nuha et al., 2021; Lin et al., 2022). AR and virtual labs allow students to visualize complex biological processes and conduct experiments in a simulated environment, thereby deepening their conceptual understanding (Chiang et al., 2014b; Muhammad et al., 2022). These technological tools have been instrumental in making abstract concepts more accessible and engaging (Rossi et al., 2021; Ichsan, 2021).

The rise of online learning platforms has further expanded the reach of inquiry-based learning in biology education. Online systems offer connectivity, accessibility, and flexibility, making learning more adaptable to students' needs (Hikmahwati et al., 2022; Oka & Asih, 2021). Studies have shown that online inquiry-based learning can be effective in promoting student engagement and facilitating HOTS, especially during times when traditional classroom settings are disrupted (Hejase & Chehimi, 2020; Parentela & Vargas, 2021). However, challenges such as ensuring interactive participation and maintaining educational quality in online environments remain areas for improvement (Putri et al., 2022; Valishvili et al., 2022).

Bibliometric analysis has emerged as a valuable method for examining research trends, publication patterns, and the development of scientific fields (Dervis, 2019; Ellegaard & Wallin, 2015). In the realm of inquiry-based learning and biology education, bibliometric studies have been used to map out the progression of research, identify key contributors, and highlight emerging themes (Haryani & Sudin, 2020; Aribowo, 2019a). Such analyses help in understanding the interaction between science and technology and in identifying gaps in the current literature (Nani Rahayu & Sobari, 2021; Zakiyyah et al., 2022). They also provide insights into the effectiveness of integrating technologies like AR and virtual laboratories in educational practices (Muhammad et al., 2022; Tupan et al., 2018).

Despite the advancements, there are notable gaps in the full implementation of inquiry-based learning within biology education. One significant challenge is the lack of emphasis on higher-order thinking skills in the curriculum, where traditional rote learning methods still prevail (Chandrasekaran, 2022; Stephenson et al., 2007). Additionally, while technology integration offers substantial benefits, limitations such as insufficient resources, lack of teacher training, and resistance to change hinder its widespread adoption (Chiang et al., 2014a; Muhdi et al., 2020). Addressing these challenges requires a concerted effort to revise educational policies, invest in teacher professional development, and improve infrastructure (Ab Halim et al., 2021; Akuma & Callaghan, 2019).

The integration of inquiry-based learning models with advanced technologies holds significant promise for enhancing biology education and developing students' HOTS. There is a growing recognition of the need for innovative pedagogical approaches that combine these elements to create more effective and engaging learning experiences (Lin et al., 2022; Rossi et al., 2021). Future research is directed toward exploring the best practices for implementing these models, assessing their impact on learning outcomes, and overcoming existing barriers (Chiang et al., 2014b; Grob et al., 2017). Such endeavors are essential for preparing students to meet the complex demands of the 21st century and for fostering a generation

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of critical thinkers and problem solvers (Berie et al., 2022; Stone et al., 2020).

Despite the proven potential of inquiry-based learning in promoting critical thinking and problem-solving, its implementation in specific subjects like biology remains underdeveloped. Current biology instruction often prioritizes memorization over critical analysis, synthesis, and evaluation (Chandrasekaran, 2022; Muhdi et al., 2020). Additionally, while digital technologies are increasingly integrated into education, their use in fostering HOTS in biology learning is not yet fully optimized (Chiang et al., 2014a). This gap highlights the need for pedagogical approaches that effectively combine inquiry-based learning with advanced digital tools to enhance learning outcomes in biology education.

This study seeks to fill the gap by analyzing the role of inquiry-based learning models in developing HOTS in biology education. Using bibliometric analysis, it explores trends, collaborations, and thematic focuses in research on inquiry-based learning over the past decade. By leveraging data from the Google Scholar database (2013–2023), the study provides insights into the potential of augmented reality (AR), virtual laboratories, and other digital tools in supporting inquiry-based biology education. This innovative approach offers new perspectives on integrating technology to advance critical thinking and problem-solving skills in biology classrooms (Haryani & Sudin, 2020; Lin et al., 2022).

This research provides valuable insights for educators, policymakers, and researchers by identifying effective strategies for implementing inquiry-based learning in biology. For educators, it offers practical guidance to design engaging lessons that foster higher-order thinking skills (HOTS) and critical analysis. Policymakers can utilize these findings to develop curricula that integrate HOTS with inquiry-based approaches and digital tools like augmented reality and virtual laboratories, aligning education with 21st-century demands. For researchers, the study contributes to academic discourse through comprehensive bibliometric analysis, revealing trends, gaps, and opportunities in inquiry-based and technology-supported learning, paving the way for innovative pedagogical advancements.

METHOD

This research employs a bibliometric approach using data sourced from Google Scholar, including journal articles and conference proceedings. The study was conducted by performing an online search using the Publish or Perish (PoP) application from August 23 to September 5, 2023. The process involved searching for article "inquiry, online learning, biology" published between 2013 and 2023. The detailed steps of this research are illustrated in Figure 1.

Figure 1. *Steps in conducting bibliometric analysis*

The data search was conducted using the Publish or Perish (PoP) application, yielding 53 documents that met the search criteria out of a total of 298 documents from 2013 to 2023. The collected data was saved in RIS format for further processing. The data was then analyzed using various programs, including Microsoft Excel and VOSviewer, to perform bibliometric and network analyses (Nurfauzan & Faizatunnisa, 2021). VOSviewer was utilized to explore research trends related to inquiry, including the publication profile, geographic distribution of inquiry-related research, categorization of manuscripts by subject area, dissemination patterns based on research methods, and trends from 2013 to 2023. Additionally, keyword co-occurrence analysis was performed using VOSviewer, which employs the Visualization of Similarities (VOS) algorithm as an alternative to multidimensional scaling (Aribowo, 2019a). The overall research procedures are illustrated in Figure 2.

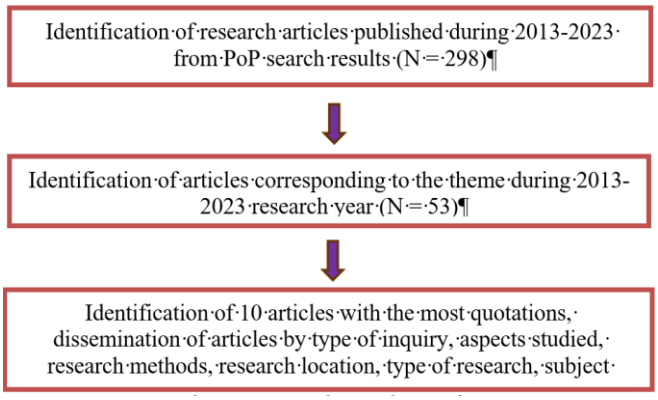

Figure 2 . *Procedure outline study*

RESULTS AND DISCUSSION

The bibliometric analysis of articles obtained through the Publish or Perish application allowed researchers to categorize the articles based on several criteria. These criteria include the type of inquiry, studied variables, research methods, citation counts, country of origin, aspects of higher-order thinking skills (HOTS), types of online learning, trends in inquiry research within online biology education, and the visualization of research trends.

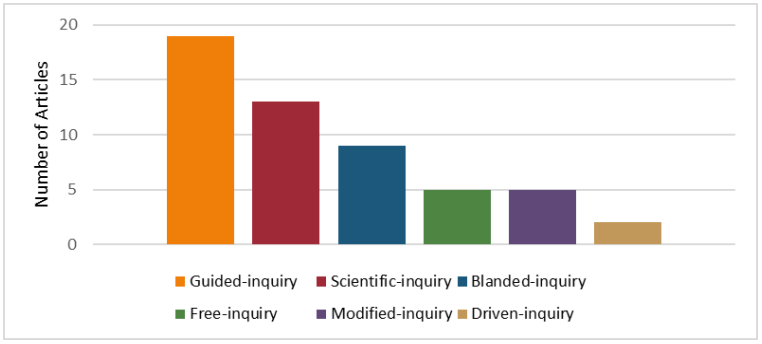

Figure 3. *Distribution of articles based on types of inquiry*

The figure illustrates the distribution of articles categorized by different types of inquiry-based learning approaches. The analysis reveals that Guided Inquiry is the most studied approach, with nearly 20 articles focusing on this method, highlighting its popularity and perceived effectiveness in educational research. This is followed by Scientific Inquiry and Blended Inquiry, which have moderate representation, indicating their graowing relevance in integrating inquiry with scientific and blended learning approaches. Free Inquiry and Modified Inquiry show lower frequencies, suggesting limited exploration or application in research contexts. Finally**,** Driven Inquiry **has** the least representation, which could point to it being a less common or emerging area of interest within the scope of inquiry-based learning.

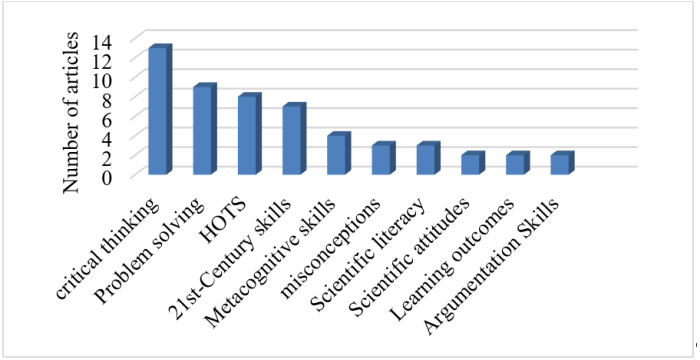

Figure 4. *Focus areas in inquiry-based learning research*

The figure presents the number of articles focusing on different areas of inquiry-based learning research. The most frequently studied areas are critical thinking and problem-solving,

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each appearing in more than 12 articles, emphasizing their importance in fostering essential cognitive skills through inquiry-based learning.

Higher Order Thinking Skills (HOTS) and 21st-Century Skills are also prominent topics, highlighting the role of inquiry-based learning in preparing students for modern educational and professional challenges. Metacognitive skills follow closely, reflecting the interest in how students regulate and evaluate their own learning processes.

Topics such as misconceptions, scientific literacy, and scientific attitudes have moderate representation, suggesting a growing but less dominant interest in addressing specific learning challenges and promoting scientific understanding. Finally, learning outcomes and argumentation skills have the lowest frequency, indicating these areas are less explored but may represent opportunities for future research to expand the scope of inquiry-based learning studies.

Figure 5 highlights the different research methods employed in articles published during the period from 2013 to 2023.

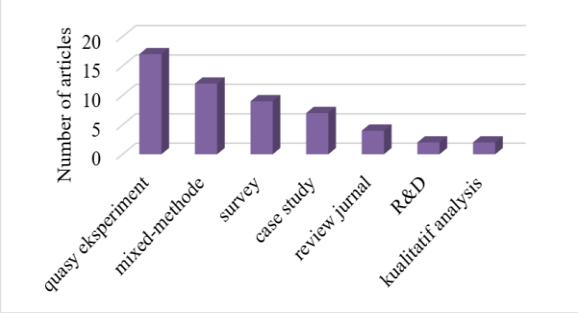
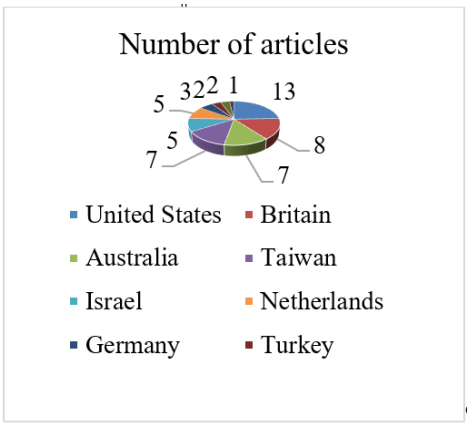


Figure 5 . *Distribution manuscript inquiry publication based on research methods*

Common research methods used in inquiry-based studies include quasi-experimental approaches, followed by mixed methods, surveys, case studies, journal reviews, action research, and qualitative analysis.



Distribution manuscript inquiry based publications amount citation

Figure 6 . *Distribution manuscript inquiry based publications number of citations*

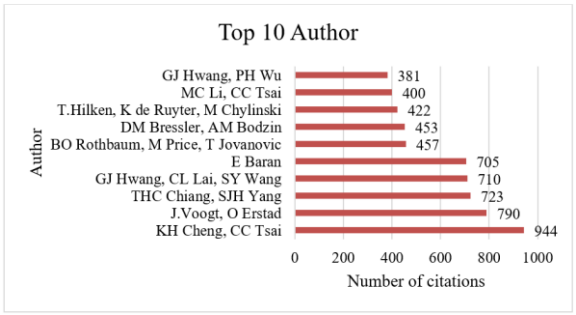


Figure 7. *Distribution of inquiry manuscript publications by research location*

The distribution of inquiry-related manuscript t number of publications during the 2013–2023 period, with 13 articles. This is followed by England with 8 articles, and Australia and Taiwan with 7 articles each. These four countries emerge as the leading contributors during this timeframe. The data highlights that the topic of inquiry continues to be a popular research trend among scholars.

Distribution manuscript inquiry based publications HOTS aspect

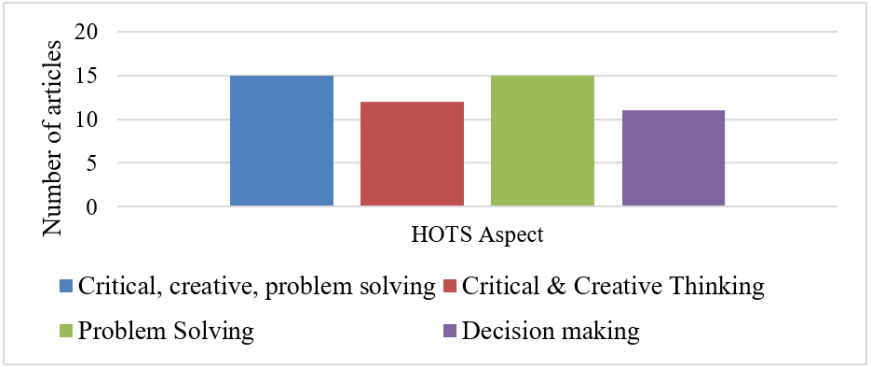


Figure 8. *Distribution of inquiry manuscript pulications based on HOTS aspects*

Figure 8 highlights the specific HOTS (Higher-Order Thinking Skills) components that have been the focus of research in inquiry-based learning publications from 2013 to 2023. The data shows that critical thinking, creative thinking, and problem-solving were collectively addressed in 15 articles, with another 15 articles focusing solely on problem-solving. Additionally, 12 articles emphasized both critical and creative thinking, while 11 articles explored decision-making as a HOTS component. HOTS plays a vital role in fostering independent and creative learners capable of solving problems and applying scientific knowledge in real-world contexts (Ichsan, 2021). Defined as a complex, non-algorithmic cognitive process, HOTS often involves generating multiple solutions. In the context of science education, HOTS-oriented inquiry activities include formulating research questions, planning experiments, controlling variables, drawing conclusions, and constructing justifications. These skills demand advanced cognitive engagement and align with the higher levels of Bloom's taxonomy (Rivers, 2002; Brahler et al., 2002).

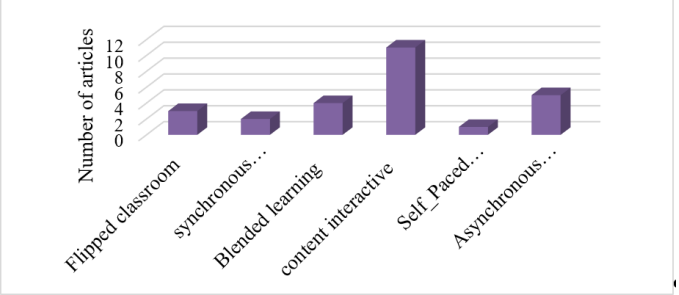


Figure 9. *Distribution of inquiry manuscript publications based on online learning types*

Figure 9 illustrates the various types of online learning methods utilized in inquiry-based research during 2013–2023. The findings reveal that interactive content-based learning is the most frequently used method, incorporating multimedia , gamification, augmented reality, videos, and online quizzes to enhance student engagement and develop higher-order thinking skills. Other forms of online learning featured in the research include flipped classrooms, synchronous learning, blended learning, gamification, self-paced learning, and asynchronous learning. These varied approaches reflect the diverse strategies employed to make online learning more effective and engaging in promoting inquiry-based education.

Research trend visualization of inquiry studies using VOSviewer

Bibliometric mapping using VOSviewer software provides a visual representation of research trends in the field of inquiry-based learning. VOSviewer enables researchers to create, visualize, and explore network maps, illustrating connections between citations and publications (Ab Halim et al., 2021). This research relies on Scopus and Google Scholar databases, two of the largest and most reputable scientific publication repositories (Purnomo et al., 2020). Using VOSviewer, the researchers analyzed 298 inquiry-related manuscripts retrieved via the Publish or Perish tool. The visualization resulted in 14 clusters, offering an overview of inquiry-based research in biology online learning from 2013 to 2023.

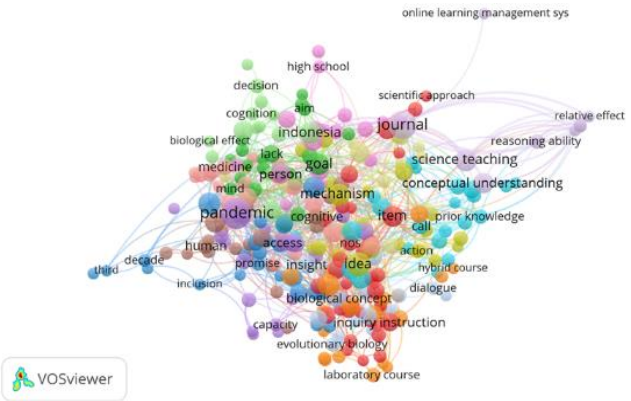


Figure 10. *Network visualization of inquiry research in biology online learning*

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Figure 10 presents the network visualization of research on inquiry-based learning in biology online education during 2013–2023. These clusters help identify groups of authors or journals that focus on specific aspects of scientific thinking (Muhammad et al., 2022). They provide insights into trends in scientific thought and the research methods employed within specific academic disciplines (Zakiyyah et al., 2022). Additionally, these clusters contribute to the development of teaching strategies or training programs aimed at enhancing scientific thinking in targeted fields (Royani & Idhani, 2018).

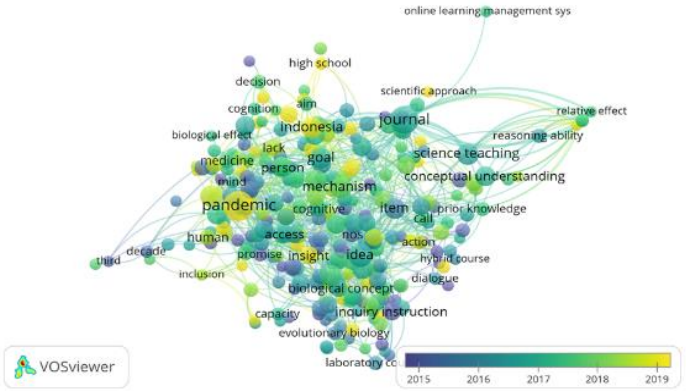

Figure 11. *Overlay visualization of inquiry research in biology online learning*

Figure 11 displays an overlay visualization generated by VOSviewer, which highlights the novelty of research topics. Brighter colors in the visualization indicate newer research areas, providing valuable insights for identifying emerging trends and gaps in the field.

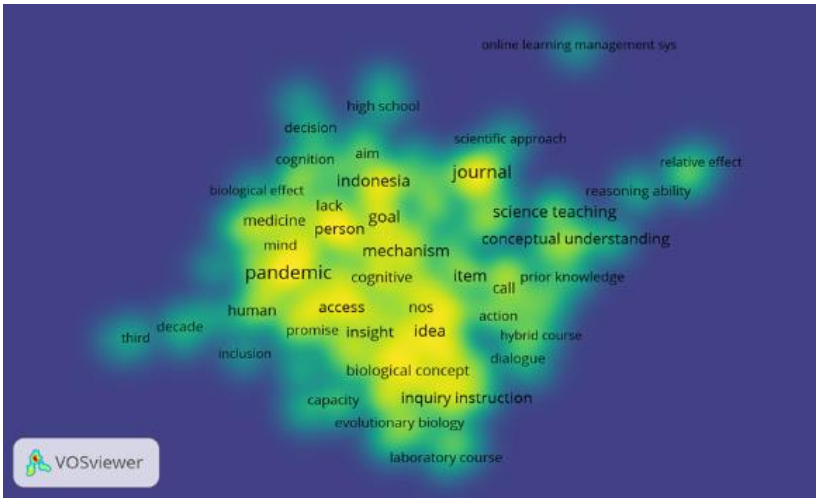

Figure 12. *Density visualization of inquiry research in biology online learning*

Figure 12 presents a density visualization from VOSviewer, illustrating the frequency of research conducted on specific topics. Darker colors indicate less frequently explored areas, such as online learning, biology achievement, reasoning ability, decision-making, and empirical research. These less-studied topics present opportunities for future research to address existing gaps in the literature.

CONCLUSION

This study employs bibliometric methods to analyze the state of research on inquiry-based learning in biology online education. The analysis covers various aspects, including types of inquiry, research variables, methodologies, total citations, geographic distribution of publications, HOTS components, online learning methods, and research trend visualizations using VOSviewer software from 2013 to 2023.

The visualization of research trends using VOSviewer identified 14 primary clusters represented by distinct colors, including red, green, blue, yellow, purple, turquoise, orange, brown, and pink. These findings provide valuable insights into global trends in inquiry-based research on biology online learning and offer recommendations for future research directions.

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