JESE 6 (1) (2026)

Journal of Environmental and Science Education

http://journal.unnes.ac.id/sju/index.php/jese

# The Influence of Interactive Slide Design on Cognitive Load in Biology Learning: A Bibliometric Analysis

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**DOI: 10.15294/jese.v6i1.40488**

## Article Info

Received February 2026
Accepted March 2026
Published April 2026

*Keywords:*
Interactive slides, cognitive load, biology learning, bibliometric analysis, instructional media

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## Abstract

Biology learning often involves complex and abstract information that can increase students' cognitive load and affect learning effectiveness. Therefore, cognitive load has become an important topic in science education research. This study aims to analyze the development and research trends related to cognitive load in biology learning using a bibliometric approach. Data were collected from the Scopus database, focusing on journal articles and review papers published between 2014 and 2024. A total of 200 documents were analyzed using Biblioshiny. The analysis included co-occurrence, co-authorship, citation, and thematic mapping techniques. The results show an increasing trend in publications, indicating growing attention to cognitive load in biology learning. The findings also reveal that research in this field is interdisciplinary and has shifted from basic cognitive studies toward more applied approaches, particularly in instructional design and learning media. Key authors, journals, and highly cited documents play an important role in shaping research development. Overall, this study provides an overview of research trends and highlights opportunities for future studies in developing effective learning strategies based on cognitive load principles.


ISSN 2775-2518

## INTRODUCTION

Biology learning involves complex concepts that require students to process various types of information, both visual and verbal, at the same time (Mayer, 2021). This situation often increases students' cognitive load, especially when the learning materials are presented through multimedia without considering the limitations of working memory. When too much information is delivered in an unstructured way, it can reduce learning efficiency and make it more difficult for students to understand biological concepts (Ljubojević et al., 2025). Therefore, managing cognitive load is an important aspect to ensure that the learning process can run effectively, particularly in biology learning, which often involves abstract concepts and complex visual representations that can increase students' cognitive demands (Leppink & van den Heuvel, 2015).

In multimedia-based learning, the way instructional materials are designed has a strong influence on how students process information. Based on Cognitive Load Theory, learning will be more effective if instructional design can manage intrinsic, extraneous, and germane cognitive load properly (Sweller et al., 2019). This concept has also been supported by recent studies emphasizing the role of cognitive load in optimizing learning processes (Kalyuga, 2015). Learning media that contain too many unnecessary elements or are not well organized can increase extraneous cognitive load, which may distract students and reduce their focus on the main material (Skulmowski & Xu, 2022). For this reason, instructional media should be designed carefully so that students can process information more efficiently and achieve better understanding (Clark et al., 2011). Along with the rapid development of educational technology, interactive learning media such as videos, animations, and interactive slides are increasingly used in the learning process.

These media provide opportunities for students to be more actively involved, for example through navigation features, feedback, and interactive components, which can enhance engagement and support learning when designed effectively (Makransky & Petersen, 2019). Several studies have shown that different types of media can affect cognitive load in different ways depending on how they are designed and the complexity of the material (Fan et al., 2024). Well-designed interactivity can help direct students' attention and support understanding, but if it is not designed properly, it can actually increase cognitive burden and reduce learning effectiveness (Beege & Plotzner, 2024).

In biology learning, interactive slides are considered a relevant medium because they can help present complex and abstract processes in a more structured and understandable way. In addition, interactive slides allow students to control the flow of information, which can potentially support better cognitive load management. However, studies related to cognitive load in biology learning are still spread across various topics and research approaches. There is still limited research that provides a comprehensive overview of how this topic has developed over time, especially in relation to interactive learning media.

Therefore, a bibliometric analysis is needed to examine the development of research on cognitive load in biology learning in a more systematic way. Through this approach, it is possible to identify publication trends, influential authors, major sources, and research themes in this field. This study aims to analyze the development, trends, and patterns of cognitive load research in biology learning, as well as to identify potential directions for future research, particularly in designing effective instructional media.

## METHOD

This study uses a bibliometric analysis approach to examine the development of research related to cognitive load in biology learning (Donthu et al., 2021). This approach was chosen because it allows researchers to explore publication trends, identify research patterns, and understand the structure of the field based on existing scientific literature. The data were obtained from the Scopus database in December 2025 using keywords related to “cognitive load” and “biology learning”. The search was limited to journal articles and review articles published between 2014 and 2024 to ensure the relevance and quality of the data. The initial search identified 200 documents. The data selection process followed basic inclusion criteria based on document type, publication year, and relevance to the research topic.

The collected data were exported in CSV format and analyzed using Biblioshiny, a web-based interface of the Bibliometrix package in the R programming language (Aria & Cuccurullo, 2017). This tool was used to organize, process, and visualize the bibliographic data to facilitate interpretation. Several bibliometric techniques were applied in this study to provide a more comprehensive analysis. Co-occurrence analysis was used to examine relationships between keywords, while co-authorship analysis was conducted to identify collaboration patterns among researchers. Citation analysis was used to determine influential publications, and thematic mapping was applied to explore the development of research themes over time. In addition, word cloud and trend topic analyses were used to identify dominant terms and the evolution of research focus in this field. The results of the analysis are presented in the form of visualizations such as graphs and thematic maps to support clearer interpretation. Through this approach, this study provides an overview of research trends and patterns related to cognitive load in biology learning.

## RESULT AND DISCUSSION

The results of the bibliometric analysis show a consistent increase in publications related to cognitive load in biology learning. This finding is also supported by previous studies on multimedia learning, which highlight the importance of cognitive processes in understanding complex information (Mayer, 2021). This pattern becomes more noticeable in recent years, indicating that cognitive load is receiving growing attention in science education research. This increase reflects a rising awareness among researchers of the challenges students face when dealing with complex biological information, especially in learning environments that rely heavily on multimedia and digital technologies.

From a theoretical point of view, this trend aligns with Cognitive Load Theory, which highlights the importance of managing cognitive resources to support effective learning (Sweller et al., 2019). This finding is also consistent with recent research highlighting the role of cognitive load in shaping learning effectiveness in multimedia environments (Mutlu-Bayraktar et al., 2019). Since biology often involves abstract concepts and complex visual representations, this is also consistent with evidence-based instructional design principles, which emphasize the importance of reducing unnecessary cognitive load during learning (Clark et al., 2011).

At the same time, the fluctuations observed in certain years suggest that the development of research in this area is not entirely consistent. These variations may be influenced by changes in research priorities, technological advancements, or the introduction of new educational approaches. This indicates that, while interest in the topic is increasing, there is still room for further exploration, particularly in understanding how cognitive load can be effectively managed across different learning contexts.

Overall, this trend highlights the importance of continuing research in this field, especially as digital learning environments become more widely used and increasingly complex. However, the increase in the number of publications does not necessarily reflect the depth of research in this field. Many studies still focus on general aspects of cognitive load without exploring more specific contexts in biology learning.

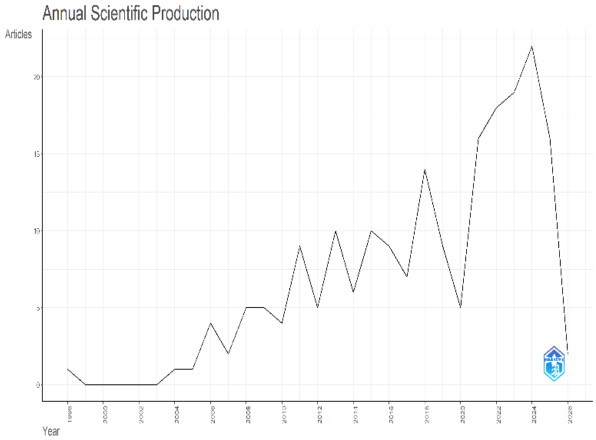


**Figure 1.** Trend in the number of cognitive load research publications in biology learning based on the results of bibliometric analysis (2014–2024)

The analysis of the most relevant authors shows that research on cognitive load in biology learning is shaped by a number of key contributors who consistently publish in this area. The presence of these highly productive authors suggests that there are core researchers and research groups that play an important role in advancing the field. Their continuous contributions help to build a more structured and evolving body of knowledge, particularly in areas related to learning design, instructional media, and cognitive load management. This pattern also reflects the inherently collaborative nature of scientific research. Some researchers appear to be more active and influential, contributing not only to theoretical discussions but also to practical applications in educational settings. From a bibliometric perspective, the prominence of certain authors may indicate the existence of research networks that guide the direction of future studies and shape the development of key themes in this field.

At the same time, this concentration of publications among a limited number of authors may suggest that the field is still somewhat centralized. While this can strengthen the consistency and depth of research, it may also limit the diversity of perspectives. Therefore, broader participation from researchers with different backgrounds and contexts would be beneficial in enriching the study of cognitive load in biology learning. Overall, identifying these key contributors is useful for future researchers, as it helps highlight influential works, map the development of the field, and open opportunities for collaboration and further exploration.

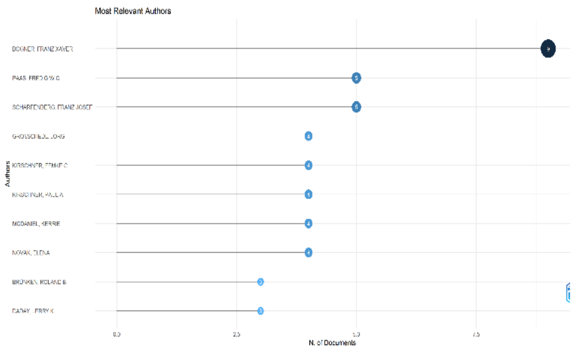


**Figure 2.** The most relevant authors on cognitive load research in biology learning

This pattern suggests that research in this field is strongly centered on human learners, particularly students, as the primary focus of investigation. This is consistent with the core idea of Cognitive Load Theory, which emphasizes how individuals process information and manage mental effort during learning activities (Sweller et al., 2019). The frequent appearance of terms such as learning and cognition highlights the close relationship between cognitive load and the processes through which students understand complex biological concepts. It indicates that research in this area is not limited to how content is delivered, but also explores how learners actively construct knowledge and cope with cognitively demanding information.

In addition, the presence of terms such as students, controlled study, and review suggests that much of the research is grounded in empirical and systematic approaches. This reflects a growing tendency among researchers to test instructional strategies and evaluate learning designs in real educational settings, rather than relying solely on theoretical perspectives. Such an approach aligns with the increasing emphasis on evidence-based practices in science education.

However, the dominance of general terms like human and article may also indicate that the field remains relatively broad and not yet highly specialized. Many studies appear to address cognitive load from a general perspective, without focusing deeply on specific biological topics or particular learning contexts. This highlights an important opportunity for future research to move toward more focused investigations, such as examining cognitive load in specific biological concepts, different types of instructional media, or diverse learner characteristics.

This suggests that research in this field is still relatively broad and lacks specificity, indicating the need for more focused studies on particular biological topics. Overall, the word cloud provides a meaningful overview of the current orientation of research on cognitive load in biology learning, which largely focuses on understanding learners' cognitive processes and developing strategies to support more effective and meaningful learning experiences.


**Figure 3**. Keyword visualization (word cloud) research cognitive load in biology learning

The trend topics analysis shows that the focus of research on cognitive load in biology learning has gradually evolved over time. In the earlier phase, research topics were primarily centered on fundamental cognitive aspects such as memory, brain function, and general cognitive processes. This suggests that initial studies were more concerned with understanding the basic mechanisms underlying Cognitive Load Theory and how individuals process information at a general level.

As the field developed, the focus of research began to shift toward the context of learning. This transition is reflected in the increasing prominence of terms such as learning, students, and biology. It indicates that the concept of cognitive load has moved beyond theoretical exploration and is increasingly being applied to real educational settings, particularly in biology learning. In more recent years, research topics appear to have become more practical and application-oriented. The emergence of terms such as instruction, teaching, review, and controlled study suggests that researchers are placing greater emphasis on instructional design, the use of learning media, and the evaluation of teaching strategies. This reflects a growing tendency among researchers to test instructional strategies and evaluate learning designs in real educational settings, rather than relying solely on theoretical perspectives. Such an approach aligns with the increasing emphasis on evidence-based practices in science education. This tendency is also supported by recent studies emphasizing the importance of evidence-based instructional design in managing cognitive load in digital learning environments (Andersen & Makransky, 2021).

From a theoretical perspective, this progression aligns with the development of Cognitive Load Theory, which has evolved from a conceptual framework into a practical guide for designing effective instruction (Sweller et al., 2019). The shift toward application-oriented research indicates that the field is becoming increasingly relevant to the needs of modern education, particularly in addressing the complexity of biological content and the integration of technology in learning.

Overall, the evolution of these trend topics highlights a meaningful transition—from foundational cognitive research toward more applied and context-specific studies. This development not only demonstrates the maturity of the field but also opens up opportunities for future research to explore more innovative and context-driven approaches to managing cognitive load in biology learning.

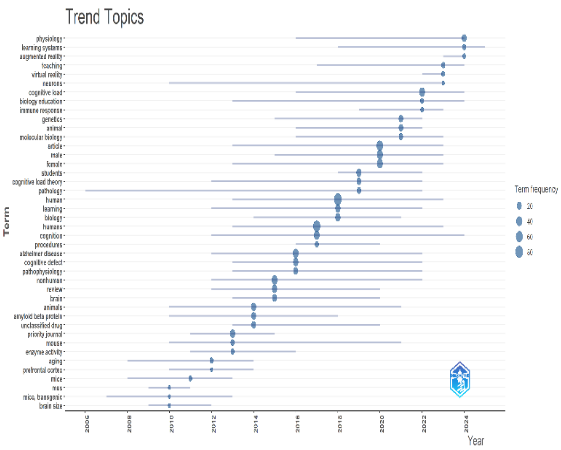


**Figure 4**. Development of cognitive load research topics (trend topics) in biology learning

The thematic map provides an overview of how research on cognitive load in biology learning is currently structured, showing a range of themes with different levels of development and relevance. This distribution reflects that the field is still evolving, with some areas already well-established, while others are still growing or shifting in focus.

Themes located in the motor themes quadrant, such as nonhumans and animals, represent topics that are both well-developed and highly relevant. Their presence suggests that cognitive load research is not only limited to human learning contexts, but also extends to broader studies of cognitive processes. Although these studies contribute to a deeper understanding of cognition, their direct connection to classroom learning in biology may still need further exploration.

In the basic themes quadrant, topics such as cognitive load and students appear as central but not yet fully developed. These themes are closely related to the core of learning processes, yet their position indicates that more work is needed to connect theoretical understanding with practical application, especially in real learning environments.

Meanwhile, themes such as human and cognitive loads are found in the emerging or declining themes quadrant. This suggests that the focus of research is gradually shifting. Some topics may be moving away from general discussions toward more specific and applied studies, while others may be losing prominence. At the same time, this shift highlights potential research gaps that can be explored further.

Overall, the thematic map shows that research on cognitive load in biology learning is dynamic and continues to develop. It reflects a gradual movement from broad theoretical discussions toward more applied and context-based studies. This development is important, especially in supporting the design of more effective learning strategies that align with the principles of Cognitive Load Theory (Kim et al., 2025).


**Figure 5.** Thematic map of cognitive load in biology learning

The analysis of the most relevant sources shows that research on cognitive load in biology learning is published across a wide range of journals with diverse academic backgrounds. This distribution indicates that the topic is not confined to a single discipline, but rather intersects with multiple fields.

Among the identified sources, PLoS Computational Biology appears as the most dominant journal, followed by Computers in Human Behavior. This pattern suggests that cognitive load research in biology learning is closely connected not only to science education, but also to areas such as cognitive science, human behavior, and the use of technology in learning environments.

In addition, several other journals, including Journal of Biological Chemistry, Journal of Computer Assisted Learning, Research in Science Education, and CBE Life Sciences Education, also contribute to this field, although with a smaller number of publications. The presence of these journals further highlights the interdisciplinary nature of the topic, combining perspectives from biology, education, and technology.

Overall, these findings suggest that cognitive load research in biology learning is supported by a variety of scholarly communities. This cross-disciplinary engagement is important, as it allows the topic to be explored from different perspectives and encourages the integration of knowledge across fields, ultimately contributing to a more comprehensive understanding of learning processes.

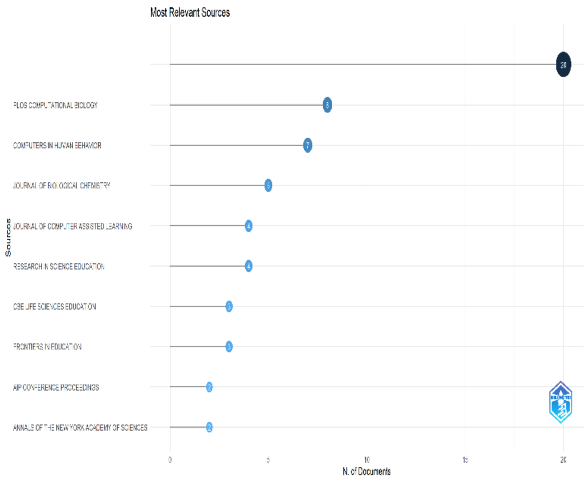


**Figure 6.** The most relevant sources in cognitive load research in biology learning based on bibliometric analysis results

The map of countries' scientific production shows that research on cognitive load in biology learning has been conducted across various regions of the world. This distribution indicates that the topic has gained global attention and is considered relevant in different educational contexts.

However, the level of research contribution appears to be uneven, with some countries producing a significantly higher number of publications than others. These differences are likely influenced by variations in research capacity, access to resources, and the strength of educational and academic systems in each country. Countries with more developed research infrastructures tend to contribute more actively to the advancement of studies related to cognitive load and learning.

At the same time, the involvement of countries from diverse geographical regions highlights the broad relevance of this topic. It suggests that challenges related to cognitive load in biology learning are not limited to a specific region, but are shared across different educational systems. This global participation also opens opportunities for greater international collaboration and knowledge exchange.

Overall, the distribution of scientific production reflects that research on cognitive load in biology learning is not only growing, but also expanding globally. This development provides a strong foundation for future studies, particularly those that aim to integrate perspectives from different countries and educational contexts.

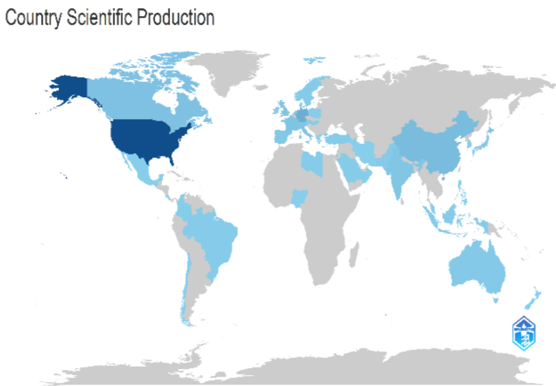


**Figure 7.** Distribution of countries' scientific production of cognitive load research in biology learning

The analysis of globally cited documents shows that several key articles have received a high number of citations and play an important role in shaping research on cognitive load. These highly cited works are generally published in well-established international journals and are widely used as references by researchers across different fields. The high citation counts suggest that these studies have made significant contributions to the understanding of cognitive load and its application in learning, including in the context of biology education.

A closer look at these influential articles reveals that many of them focus on fundamental aspects of cognitive load, such as cognitive processes, instructional design, and the use of media and technology in learning. This indicates that research on cognitive load in biology learning is strongly influenced by foundational and cross-disciplinary studies, which provide the theoretical and practical basis for further research developments.

At the same time, the dominance of these key references highlights how certain core studies continue to guide the direction of research in this field. While this provides a strong theoretical foundation, it also suggests the importance of developing new studies that can expand existing perspectives and address more specific contexts in biology learning.

Overall, the results confirm that highly cited documents play a central role in shaping the development of cognitive load research. They serve not only as important references, but also as a foundation for future studies aimed at improving learning design and educational practices.

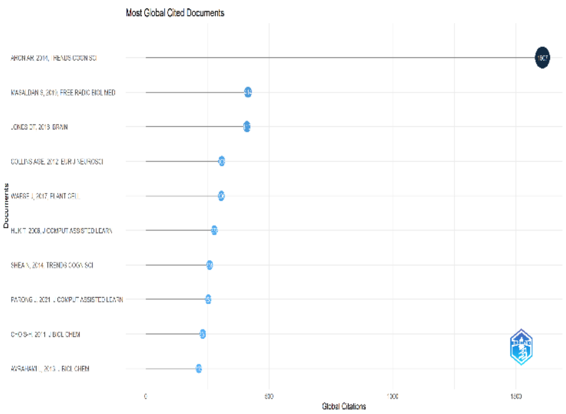


**Figure 8**. Document with the most globally cited documents in cognitive load research in biology learning

Overall, the series of bibliometric findings, including publication trends, key authors, major sources, country distribution, and highly cited documents, provides a comprehensive picture of how research on cognitive load in biology learning has developed over time. These results indicate that the field continues to grow and is supported by contributions from various disciplines, reflecting its broad relevance in science education. The global involvement of researchers further highlights that cognitive load is not only a theoretical concern, but also an important issue in addressing real challenges in learning processes.

Furthermore, the mapping of research topics through word cloud, trend topics, and thematic analysis reveals a clear shift in research focus. Earlier studies were primarily concerned with fundamental cognitive processes, while more recent research increasingly emphasizes practical applications in learning contexts. This transition suggests that cognitive load research is moving toward a more applied direction, particularly in the design of instructional strategies and learning media that can effectively support students' understanding.

This development is consistent with the evolution of Cognitive Load Theory, which has expanded from a conceptual framework into a practical guide for instructional design (Sweller et al., 2019). As a result, the findings of this study not only describe the current state of research, but also highlight its potential to contribute to the improvement of learning practices. Therefore, this study provides a useful foundation for future research, especially in exploring more context-specific and innovative approaches to managing cognitive load in biology learning.

## CONCLUSION

This study provides a comprehensive bibliometric overview of the development of research on cognitive load in biology learning. The findings indicate that this field has experienced significant growth over time, with increasing attention from researchers across different disciplines and regions. This growth reflects the importance of cognitive load as a key factor in understanding and improving learning processes, particularly in subjects such as biology that involve complex and abstract concepts.

This study also highlights a clear shift in research focus, from fundamental cognitive studies toward more applied and context-based approaches. Recent research increasingly emphasizes the design of instructional strategies and learning media that can effectively support students in managing cognitive load. This shift demonstrates that Cognitive Load Theory is not only relevant as a theoretical framework, but also plays a practical role in guiding the development of effective learning designs.

Furthermore, the results reveal that research on cognitive load in biology learning is inherently interdisciplinary and globally distributed, although contributions are still concentrated in certain regions and among specific research groups. This suggests the need for broader participation and more diverse perspectives to enrich the development of this field.

The findings of this study contribute by mapping research trends, identifying key contributors, and highlighting thematic developments in cognitive load research. These insights can serve as a valuable reference for researchers and educators in designing more effective and evidence-based learning practices.

However, this study is limited to data obtained from a single database (Scopus), which may not fully represent all relevant publications. Therefore, future research is recommended to include multiple databases and explore more specific contexts, such as particular biological topics, types of instructional media, or learner characteristics. Further studies can also focus on empirical investigations to strengthen the practical application of cognitive load principles in biology learning.

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