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Conceptual Understanding in Physics and Astronomy: A Bibliometric Analysis

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ABSTRACT

This study presents a bibliometric analysis of research related to conceptual understanding in physics and astronomy (CUPA), analyzing publication trends, the most contributors, and emerging research directions from 2006 to 2025. The analysis was conducted on 447 documents using VOSviewer and Biblioshiny, as well as Microsoft Excel and Origin to aid data visualization. The analysis revealed a steady increase in the number of publications over time, particularly from 2017 to 2021, reflecting growing interest in this field. Collaborative efforts, both locally and internationally, are prominent, with a strong foundation in the previous literature. The main topics identified include e-learning, computer-aided instruction, and quantum optics, illustrating the influence of educational technology and advanced scientific research. Although research on CUPA has developed significantly, future studies should explore the integration of artificial intelligence (AI) in learning, investigate differences in conceptual understanding across educational systems, and address gaps in research conducted in non-English languages. This study highlights the importance of international collaboration and the need for further research to connect conceptual understanding with critical thinking and problem-solving skills, which are essential in 21st-century education.

Keywords: Conceptual understanding, physics and astronomy, bibliometric analysis.

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Pemahaman Konsep pada Fisika dan Astronomi: Sebuah Analisis Bibliometrik

ABSTRAK

Studi ini menyajikan analisis bibliometrik tentang penelitian terkait pemahaman konseptual dalam fisika dan astronomi (CUPA), dengan menganalisis tren publikasi, kontributor utama, dan arah penelitian yang sedang berkembang dari tahun 2006 hingga 2025. Analisis dilakukan pada 447 dokumen menggunakan VOSviewer dan Biblioshiny, serta Microsoft Excel dan Origin untuk membantu visualisasi data. Analisis menunjukkan peningkatan yang stabil dalam jumlah publikasi seiring waktu, terutama dari tahun 2017 hingga 2021, mencerminkan minat yang semakin besar terhadap bidang ini. Upaya kolaboratif, baik secara lokal maupun internasional, sangat menonjol, dengan landasan yang kuat dalam literatur sebelumnya. Topik utama yang diidentifikasi meliputi e-learning, komputer-aided instruction, dan optika kuantum, yang menggambarkan pengaruh teknologi pendidikan dan penelitian ilmiah yang canggih. Meskipun penelitian tentang CUPA telah berkembang secara signifikan, studi masa depan sebaiknya menjelajahi integrasi kecerdasan buatan (AI) dalam pembelajaran, menyelidiki perbedaan pemahaman konseptual di berbagai sistem pendidikan, dan mengatasi kesenjangan dalam penelitian yang dilakukan dalam bahasa non-Inggris. Studi ini menyoroti pentingnya kolaborasi internasional dan kebutuhan akan penelitian lebih lanjut untuk menghubungkan pemahaman konseptual dengan keterampilan berpikir kritis dan pemecahan masalah, yang esensial dalam pendidikan abad ke-21.

***Kata kunci**: Pemahaman konsep, fisika dan astronomy, analisis bibliometrik*

INTRODUCTION

Physics and astronomy are two fundamental branches of science in understanding the universe and the phenomena that occur within it. Physics studies the properties and behaviour of matter and energy, which form the basis for many technologies and scientific developments. Many everyday occurrences can be explained by physics (Taqwa & Faizah, 2016; Wahyuni & Taqwa, 2022). In addition, physics is essential for solving various problems, from simple to complex ones. Meanwhile, astronomy focuses on the study of celestial objects and cosmic phenomena that help humans understand our position and origin in this vast universe. These two disciplines not only provide theoretical knowledge but also practical applications that are highly significant in everyday life, ranging from communication technology to space exploration. Additionally, physics and astronomy often complement each other in modern scientific research and development (Boyarchuk & Keldysh, 1999; Ginzburg, 1999; Saha, 2002). Therefore, both play a strategic role in the advancement of science and technology.

Conceptual understanding in physics and astronomy (CUPA) is key to the development of these fields. In the context of learning, conceptual understanding is one of the most important goals that every student must achieve (Asnaini, 2024; Azizah et al., 2020; Taqwa et al., 2022; Taqwa & Rivaldo, 2019). Without a deep understanding of basic concepts, the knowledge gained will be mechanical and unable to effectively explain new or complex phenomena (Aminuddin et al., 2024; Zamani & Suyudi, 2024). In addition, a strong grasp of concepts can improve the ability to connect various aspects of knowledge systematically and maturely. Some studies even show that conceptual understanding is related to several thinking skills, such as problem-solving

(Docktor & Mestre, 2014), argumentation skills (Aydeniz et al., 2012; Cetin, 2014), critical thinking (Hartini et al., 2020), and creative thinking (Dewi et al., 2019). Therefore, in the context of education and research, conceptual understanding serves as the foundational pillar that must be continuously developed and evaluated on an ongoing basis.

Over time, research on concept understanding in physics and astronomy has developed significantly. Various studies have been conducted to identify the difficulties experienced by students and researchers in understanding core concepts (e.g. Mutsvangwa, 2020; Taqwa et al., 2020), as well as to develop more effective teaching and learning methods (Sahara et al., 2020; Suriano et al., 2025; Tania et al., 2020). This research encompasses a range of approaches, from educational experiments and cognitive models to the use of technology as a learning aid. However, this research still faces challenges, particularly in measuring the quality of understanding and applying research results in educational and research settings. Therefore, evaluations and methodological updates continue to be carried out to explore the dynamics of conceptual understanding in greater depth, thereby contributing more significantly to the field.

Bibliometric analysis is an important tool for systematically reviewing and evaluating the development of research on CUPA. Using this method, it is possible to map publication patterns, citations, collaboration between researchers, and emerging research trends (Aksnes et al., 2019; Li et al., 2021). Bibliometric analysis also provides an objective overview of research areas that have been extensively explored and those that have received little attention, thereby serving as a foundation for setting research directions and educational policies. Additionally, this approach helps researchers and educators effectively identify relevant resources and literature.

Bibliometric analysis on the development of conceptual understanding research is still very rare. Oya et al. (2024) have focused on conducting a bibliometric analysis on the impact of project-based assessment on conceptual understanding in STEM education. In addition, Wandi et al. (2023) have conducted a bibliometric analysis of conceptual understanding in physics education, but a comprehensive performance analysis and science mapping have not been conducted. Bibliometrics has many strengths, not only providing an overview of research trends from year to year, but also providing an overview of the authors, affiliations, and countries that contribute most to a particular area of research (Donthu et al., 2021; Hassan & Duarte, 2024). This information on top contributors is important to provide readers with information for several purposes, such as research collaboration, key references for research to be developed, or becoming a reviewer for a journal. On the other hand, bibliometric analysis can perform quantitative analysis of terms that are developing on a research topic to see interrelated research sub-topics and provide insight into the direction of future research (Huang et al., 2020; Kipper et al., 2021). Therefore, this article conducts a bibliometric analysis in an effort to provide more comprehensive insights while supporting the development of science and education in the fields of physics and astronomy. This article aims to answer several research questions (RQ), including:
RQ1. What is the main information about the research trends of CUPA?
RQ2. What are the trends in publications on CUPA?
RQ3. Which authors, affiliations, and countries have made the most significant contributions to research on CUPA?
RQ4. What is the most relevant words about CUPA?
RQ5. What will be the focus of future research on CUPA?

METHOD

This article is a literature review using bibliometric analysis, a quantitative approach used to analyze scientific publications in a specific field. In the context of this research, the field of focus is the Conceptual Understanding in Physics and Astronomy (CUPA). The steps involved include collecting data from relevant databases, cleaning and refining the data, and using various bibliometric methods (the next steps in generating meaningful information) (Passas, 2024). Bibliometric analysis is very important because it can provide information to guide future research (Hulland, 2024). Furthermore, the results of the bibliometric analysis can also be used by journal managers to identify the most relevant reviewers for articles (Berger & Baker, 2014).

Investigating Scope

The sources analyzed in this study were obtained from the Scopus database. The Scopus database was chosen because it has several advantages. Scopus includes a wide range of journals in the social sciences and humanities, providing extensive coverage that is beneficial for researchers in social education fields (Chamorro-Atalaya et al., 2024; Norris & Oppenheim, 2007). Scopus supports advanced bibliometric tools such as Biblioshiny and VOSViewer, which are commonly used by researchers. Scopus metadata enables researchers to analyze citation networks, author collaboration patterns, and thematic clusters. This is very useful for identifying influential authors, publications, and emerging research trends (Sharma et al., 2024). The search was conducted using the keyword “conceptual understanding” in TITLE-ABS-KEY. The data analyzed were limited to a period of two decades, from 2006 to 2025 (June 4th). We limited the documents to subject areas, document types, source types, and languages (see Table 1). All data obtained was exported in CSV format.

Table 1. Summary of Data Characteristics of The Bibliometric Study

Category	Specific standard requirements
Research database	Scopus
Search query	(TITLE-ABS-KEY "conceptual understanding")
Searching Periode	2006 to 2025 (June 4th)
Subject area	Physics and Astronomy
Documents type	Article
Source type	Journal
Language	English
Data Export Format	CSV

Data Processing

The document selection process used the PRISMA guidelines (Page et al., 2021), which are explained in detail in Figure 1. Based on the results of a Scopus database search using the keywords “conceptual understanding,” 10,897 documents were obtained. Next, the documents were limited to publications from 2006 to 2025. At this stage, 1,098 documents were excluded, leaving 9,799 documents. Subsequently, the exclusion process based on criteria such as subject area, document type, source type, and language eliminated 9,346 documents, leaving 453 documents. In this study, we only analyzed articles with primary data, while articles with

secondary data were excluded. At this stage, 6 documents were eliminated, leaving 447 documents to be analyzed.

Data Analysis

Data analysis was conducted on 447 documents containing metadata such as title, author, affiliation, abstract, author keywords, index keywords, and so on. Data analysis was performed using VOSviewer and Biblioshiny. In addition, to help visualize the data for easier understanding, we used Origin and Microsoft Excel. Biblioshiny is used to analyze main information, publication trends, most significant contributors (authors, affiliations, and countries), and future research focus. VOSviewer, with its visualization capabilities, is used to analyze the most relevant words and future research on the topic of CUPA.

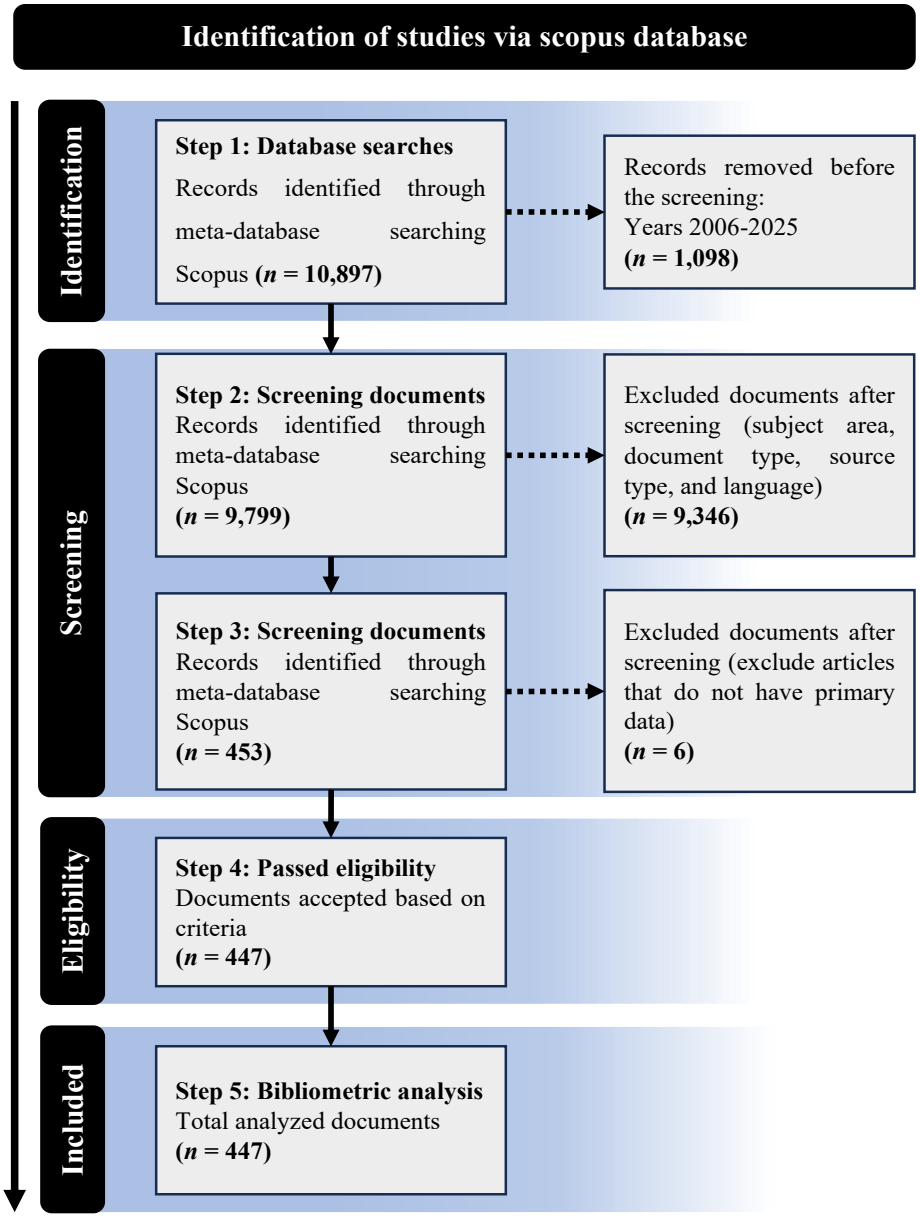


Figure 1. The process of article selection

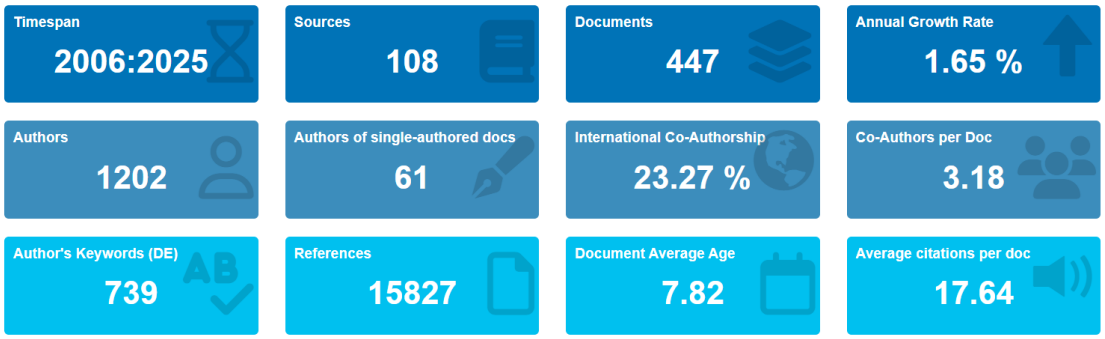
RESULT AND DISCUSSION

The Main Information about The Research Trends of CUPA

Research on CUPA shows steady and collaborative development between 2006 and 2025 (see Figure 2). During this period, 447 documents were published in 108 different sources, indicating that this topic has received attention from various scientific journals and conferences. Although the growth rate is moderate, at 1.65% per year, this indicates that this topic remains a relevant focus among researchers. This topic of concept understanding is important and continues to evolve because it is related to specific topics in each discipline. Even the genetics concepts in secondary school students in Nigeria, especially in Ondo, have not been studied (Ojo, 2024). This is likely to be the case for other topics and countries, so research on concept understanding will continue to evolve, including in physics and astronomy.

Of the 1,202 authors involved, only 61 documents were written by a single author, indicating that most research in this field is conducted collaboratively. Additionally, approximately 23.27% of the documents involve international collaboration, indicating that this research has a global dimension despite being limited to certain regions. The average number of co-authors per document is 3.18, further evidence that teamwork plays an important role in this research. Active cooperation between communities and researchers is essential in developing research strategies to address issues faced by communities (Kone et al., 2000). Not only that, researchers with high positions such as lecturers, senior lecturers, and professors have more diverse collaboration patterns than those in lower positions (Mwantimwa & Kassim, 2023). This is because researchers with high positions recognize the importance of collaboration.

This research also appears to be highly connected to previous literature, as reflected in the large number of references used, namely 15,827 references for 447 existing documents. The average age of these documents is 7.82 years, indicating that although most of the research is relatively recent, the topic already has a strong foundation. With an average of 17.64 citations per document, it can be seen that these works are quite influential and have received widespread attention from the academic community. All these indicators suggest that conceptual understanding in Physics and Astronomy continues to evolve through extensive collaboration, and research in this field remains highly relevant and makes significant contributions to the advancement of scientific knowledge. Astronomy is one of the most important disciplines in science education for increasing students' interest and curiosity in science, which is developing rapidly (Şensoy & Kocakuşak, 2025), as is physics.

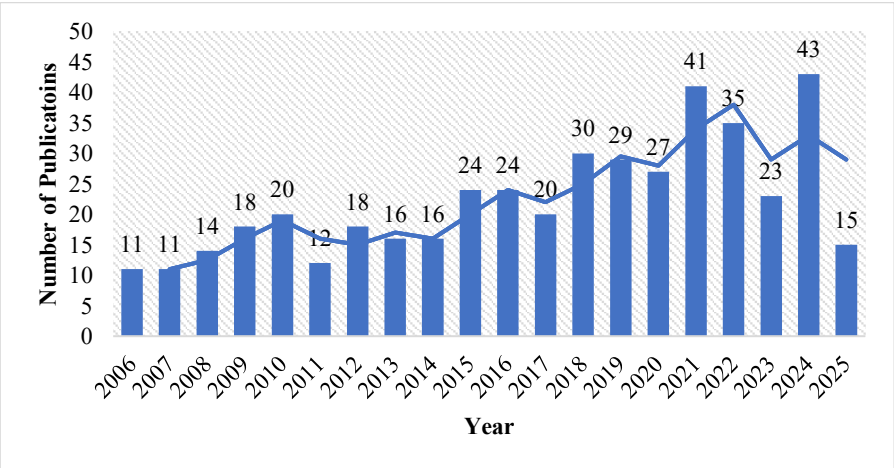


(*Source: results of data analysis using biblioshiny*)

Figure 2. The Main Information About The Research Trends of CUPA

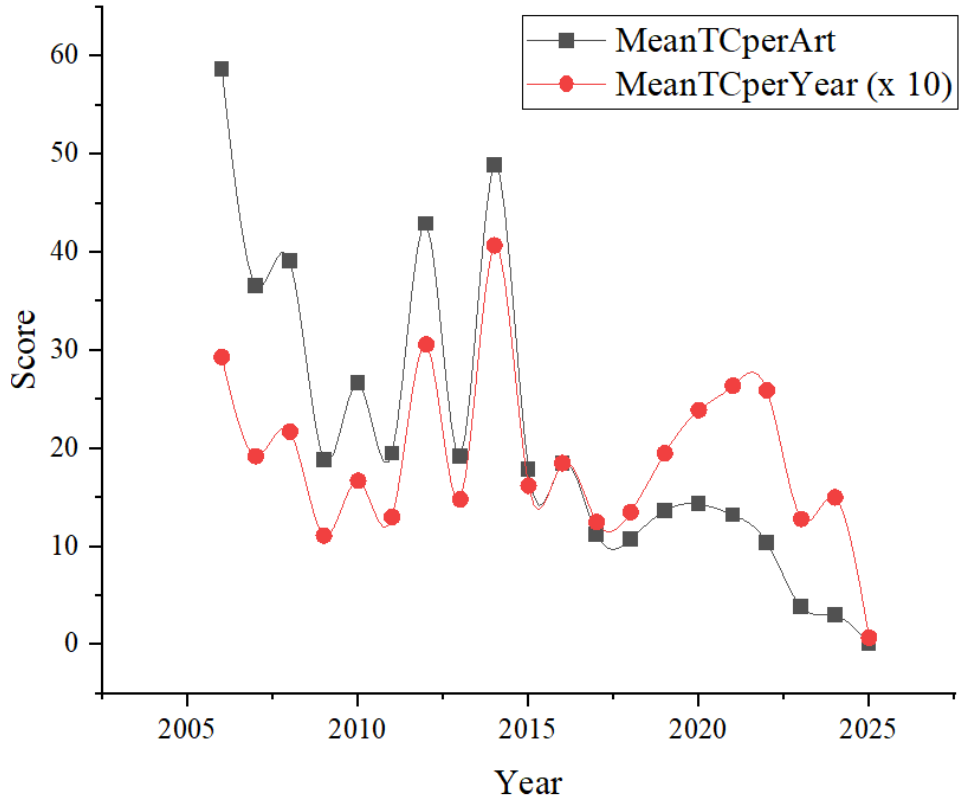
The Trends in Publications on CUPA

Figure 3 shows the number of publications on CUPA from 2006 to 2025. Overall, there has been a significant increase in the number of publications over time. In 2006, only 11 publications were recorded, and this number gradually increased, reaching a peak of 41 publications in 2021. A sharp increase was observed during the period from 2017 to 2021, which may have been influenced by external factors such as increased research funding, technological advancements, or changes in educational curricula that place greater emphasis on conceptual understanding in Physics and Astronomy. Despite fluctuations from year to year, interest in this topic continues to grow, with 25 and 23 publications recorded in 2022 and 2023, respectively. However, there was a significant decline in 2025 with only 15 publications recorded, which may be due to incomplete data or changes in research interests. Fluctuations in research interest in understanding this concept also occur in science education (Oya et al., 2024). Overall, the number of publications in recent years is higher than in the early stages of research, indicating that CUPA remains a relevant and important focus in the scientific community. In addition, research trends in a particular area can also be seen from the number of citations obtained (Zafar et al., 2024). As shown in Figure 4, the mean citations per article and the mean citations per year are quite volatile. This indicates that there are rapid shifts in research topics. However, CUPA research trends based on mean citations obtained indicate considerable interest.



(*Source: The results of data analysis using Biblioshiny were redrawn using Microsoft Excel*)

Figure 3. Dynamics of Publications Each Year

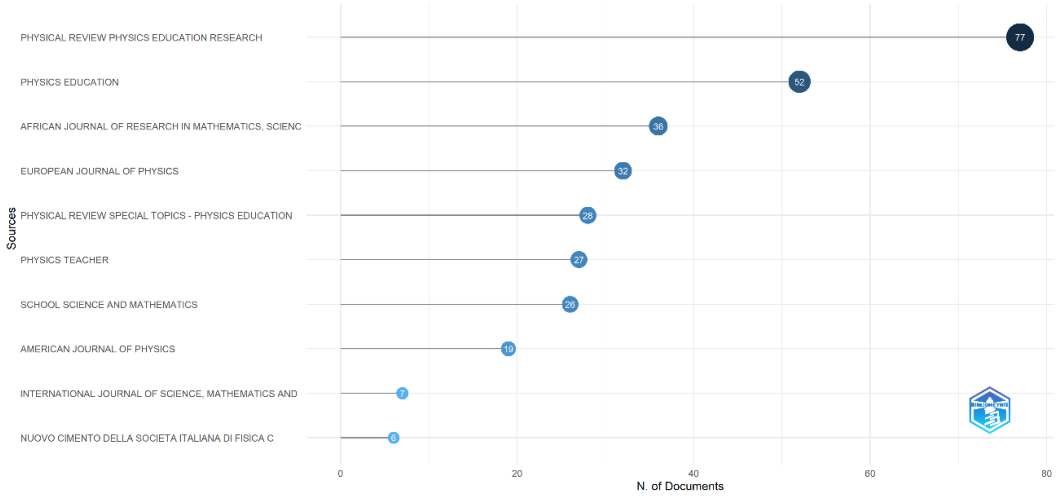


(*Source: The results of data analysis using Biblioshiny were redrawn using Origin*)

Figure 4. Mean Total Citation per Article and Year

The Most Significant Contributors to CUPA

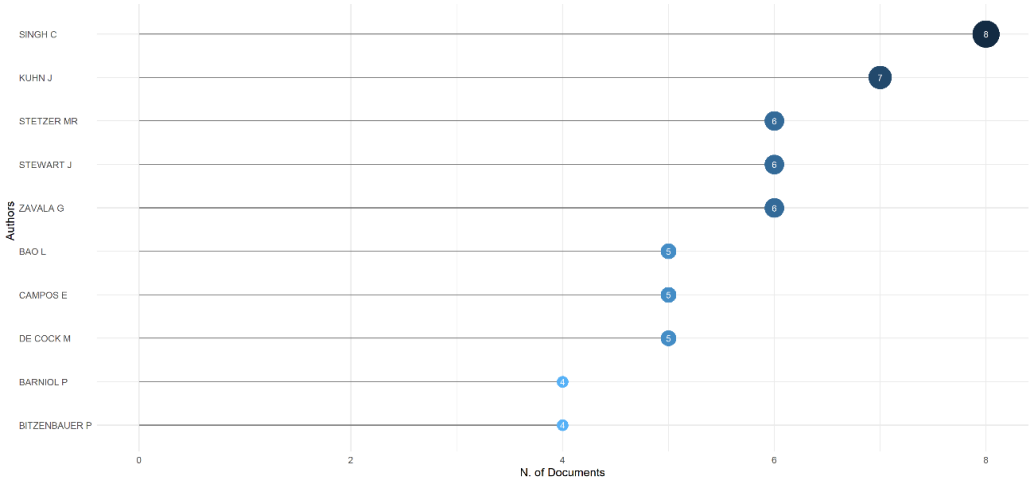
The most significant contributors in a research area are identified based on source, author, affiliation, and the most productive country. According to the information in Figure 5, Physical Review Physics Education Research is the most relevant journal with the highest number of publications, namely 77 documents. This was followed by Physics Education (52 documents), African Journal of Mathematics, Science, and Technology Research (36 documents), European Journal of Physics (32 documents), and so on (see Figure 5). Research source information, such as journals, is crucial because it helps assess the quality and impact of publications within a field (Abrar et al., 2023; Haghani, 2023). Journals with high impact factors and strong reputations often publish influential research articles, reflecting the quality of the ideas developed in those articles. Additionally, knowing the most productive research sources helps identify trends and research focuses published in specific journals. This also enables analysis of the influence of certain sources on the development of science and technology. This data can serve as important information for researchers in the CUPA field to identify the best reference sources for their ongoing research.



(*Source: The results of data analysis using Biblioshiny*)

Figure 5. The Most Relevant Sources

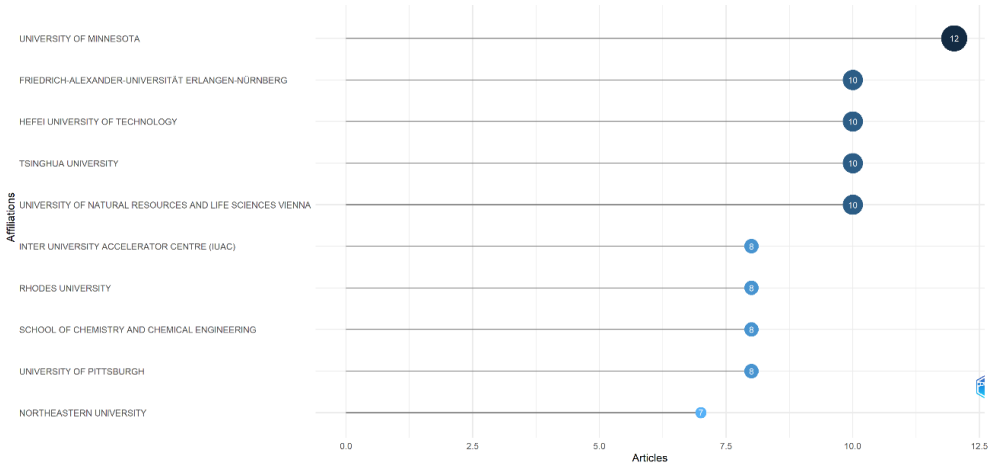
The next important piece of information is data on the most productive authors in a field. The 10 most relevant authors are shown in Figure 6. These authors include Singh C (University of Pittsburgh, USA), Kuhn J (Ludwig-Maximilians-Universität, Germany), Stetzer MR (University of Maine, USA), Stewart J (University of Illinois, USA), Zavala G (Tecnologico de Monterrey, North America), Bao L (Ohio State University, USA), Campos E (University of Vienna, Austria), De Cock M (KU Leuven, Belgium), Barniol P (Tecnológico de Monterrey, North America), and Bitzenbauer P (Leipzig University, Germany). This information is very important for identifying thought leaders or innovators in the field of CUPA. Authors with many publications and citations typically demonstrate their deep expertise in a particular topic (Harvey et al., 2021; Oladinrin et al., 2023). By analyzing author data, we can also see patterns of collaboration between authors, which can indicate strong research networks and partnerships. These collaborations often improve the quality and productivity of research, accelerate scientific progress, and open up new opportunities for further research. Recognizing author profiles also helps new researchers identify relevant mentors or collaborators.



(*Source: The results of data analysis using Biblioshiny*)

Figure 6. The Most Relevant Authors

Affiliation data is very important in bibliometric analysis because it provides an overview of the institutions or research organizations that contribute significantly to publications in a particular field. Knowing the authors' affiliations is useful for identifying leading institutions that are active in research, which can be centres of excellence or valuable resources in a particular discipline or research topic. In addition, this data also helps in understanding patterns of collaboration between institutions, both locally and internationally. The data in Figure 7 shows that the most relevant affiliation is the University of Minnesota in the United States (12 documents), followed by several other affiliations from different countries, such as Germany, China, Austria, India, and South Africa. By mapping affiliations, we can assess the strength of institutions in producing high-quality research and understand the extent of each institution's contribution to the advancement of science.



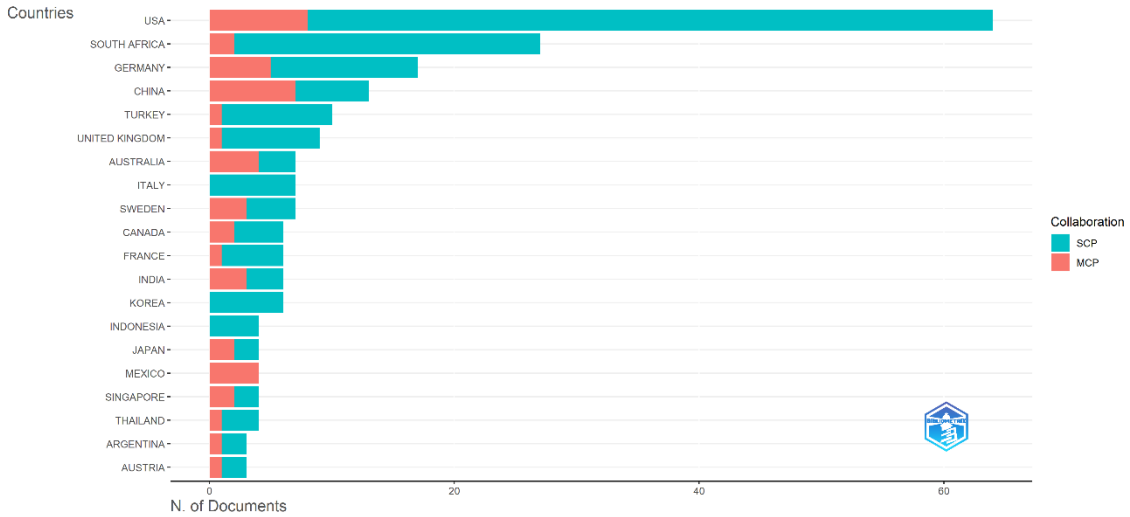
(*Source: The results of data analysis using Biblioshiny*)

Figure 7. The Most Relevant Affiliations

Figure 8 shows data on the most productive countries in research based on the number of documents published. In this graph, the most dominant country in research is the United States (USA), followed by South Africa and Germany. Other countries that contribute significantly to research are China, Turkey, the United Kingdom, Australia, Italy, and several other European countries.

The data in this graph is also differentiated based on two types of collaboration: Single Country Publications (SCP) and Multiple Country Publications (MCP). SCP refers to publications produced by researchers from a single country, while MCP reflects publications involving collaboration between researchers from various countries. Some countries, such as the USA, are more dominant in SCP, while other countries, such as South Africa, show a balance between the two types of collaboration. This illustrates the importance of international collaboration in increasing scientific productivity. Describing data on the most productive countries in research provides global insights into who is leading the way in scientific development at the international level. Countries that produce many publications demonstrate their research capacity, which is often influenced by government policy, financial support, and good research infrastructure. In addition, country data also reveals research gaps between developed and developing countries, which can serve as a basis for policymakers to formulate more effective strategies. Collaboration

between countries in this research is also very important in providing new perspectives according to their respective expertise (Luthfiyah, 2025). Mapping country contributions also highlights important patterns of international collaboration in promoting cross-border research and enhancing global scientific productivity.



(*Source: The results of data analysis using Biblioshiny*)

Figure 8. The Most Relevant Corresponding Author's Countries

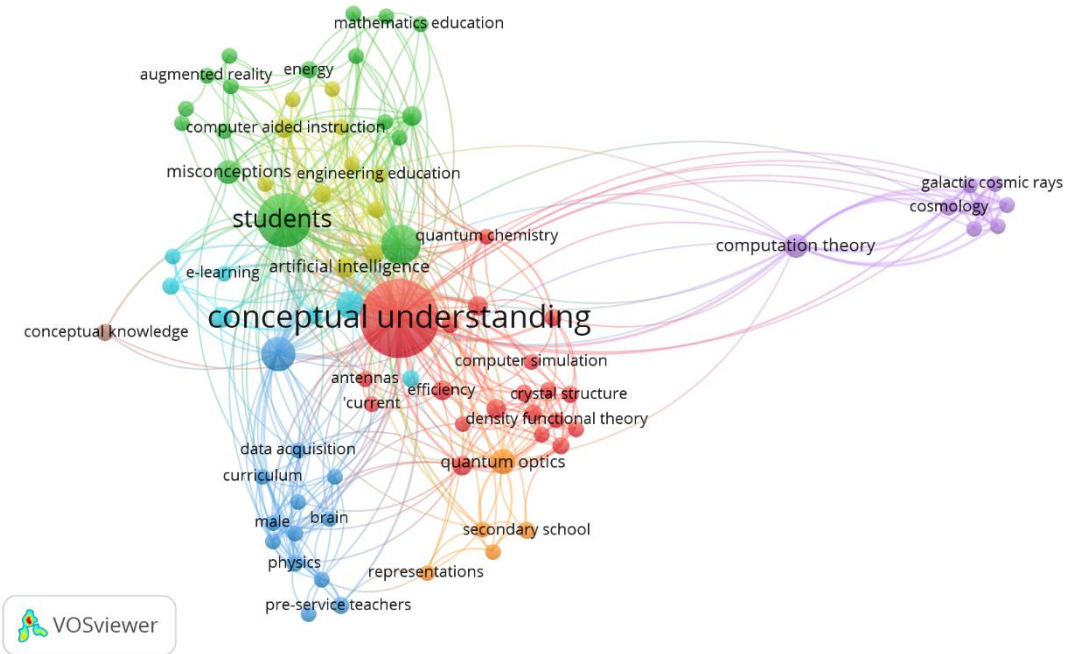
The Most Relevant Words about CUPA

The results of the VOSviewer analysis for network visualisation in the Context of CUPA are shown in Figure 9, which illustrates the relationships between various topics or concepts related to conceptual understanding in physics and astronomy. This visualization shows how these topics are interconnected, with "conceptual understanding" at the center, forming the core of the research discussed. This concept is the main focus of various studies exploring how knowledge in physics and astronomy is understood by students and implemented in teaching. Related keywords such as "students," "misconceptions," and "curriculum" indicate that conceptual understanding is greatly influenced by the educational context, particularly in terms of how material is presented to students, as well as common misconceptions that arise in physics learning. This is in line with numerous studies, in which researchers focus on designing learning and restructuring the curriculum as efforts to improve student learning outcomes and solve learning problems in the classroom (Atarah et al., 2025; Nicholus et al., 2024; Yates & and Millar, 2016).

In addition, several color clusters were identified that reflect groups of related topics (Khan et al., 2024; Sajovic & Boh Podgornik, 2022). One of the main clusters focuses on education, with keywords such as "e-learning," "computer-aided instruction," and "mathematics education," indicating that teaching methods and the use of technology have a significant influence on the understanding of concepts in physics. This cluster highlights the importance of innovative pedagogical approaches in helping students grasp complex physics concepts. On the other hand, there is also a cluster that focuses on physics and astronomy, with keywords such as "quantum optics," "quantum chemistry," and "crystal structure," which indicate the relationship between conceptual understanding and more advanced scientific topics in physics and their application in astronomical research.

Another important aspect is the close relationship between physics and astronomy, where keywords such as “cosmology” and “galactic cosmic rays” indicate a strong connection between the understanding of basic physics concepts and their application in astronomical studies. This demonstrates that research in both fields is not solely focused on scientific theory but also on how these theories are translated into practice and understood by students. Additionally, there is a clear connection between technology and education, as seen in the cluster linking “artificial intelligence” and “computer simulation,” which highlights the significant potential of technology in enhancing students' learning experiences and understanding of physics and astronomy concepts.

Overall, Figure 9 provides important information that conceptual understanding in physics and astronomy is highly dependent on various factors, including pedagogical approaches, learning technologies, and the connection between scientific theory and its application in an educational context. In addition, this visualization also highlights how research in both fields continues to evolve, with an increasing focus on the use of technology to help students build a deeper and more comprehensive understanding of complex scientific concepts. In the research focus, it is also apparent that the image does not show any network between “conceptual understanding” and 21st-century skills, such as critical thinking skills, creative thinking skills, communication skills, and collaboration skills. This is certainly an important finding that points to the need for research on the development of these skills in physics and astronomy, not just conceptual understanding alone. Nevertheless, many studies have shown that conceptual understanding is correlated with other thinking skills (Abaniel, 2021; Binkley et al., 2012).



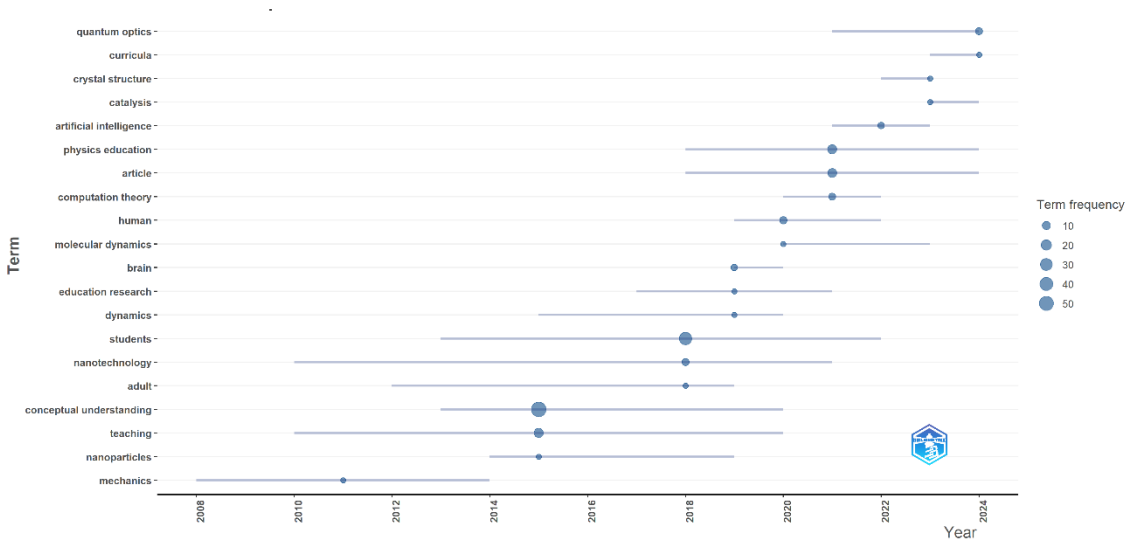
(*Source: The results of data analysis using VOSviewer*)

Figure 9. Network Visualization in The Context of CUPA

The Focus of Future Research on CUPA Based on Trend Topics

The future research direction on the topic of CUPA can be seen based on the results of the Trend Topics analysis generated by Bibioshiny in Figure 10. Several terms, such as "quantum optics," "curricula," "crystal structure," and "catalysis", appear at the beginning of the period (around 2008-2012), but their frequency tends to be lower than that of other terms. This suggests that while these topics are relevant in physics literature, their application in research related to conceptual understanding may not have been as popular as other topics at that time. Over time, several other terms, such as "artificial intelligence," "physics education," and "computation theory," began to show a significant increase in frequency from 2017 to 2020, with an even greater peak. This reflects a growing interest in the integration of advanced technologies such as artificial intelligence and computational theory in physics education and their application in physics and astronomy research. Terms like "conceptual understanding" and "teaching" began showing a clear upward trend around 2015 to 2024, with increasingly larger peaks, indicating that research on conceptual understanding and teaching methods is gaining more attention in this field. Topics related to "students," "nanotechnology," and "dynamics" also show a significant increase in frequency, reflecting a greater focus on student education and applied research involving new technologies.

Overall, the information in the image provides insights into how the field of conceptual understanding in physics and astronomy has evolved, with an increasing interest in teaching and the application of advanced technologies over time. Newer terms, such as "artificial intelligence" and "conceptual understanding," have become more prominent in the last decade, illustrating a shift in focus toward more modern approaches to education and scientific research. Currently, AI is also one of the research focuses in education that will continue to grow (Pham & Sampson, 2022; Schiff, 2022; Selwyn, 2022). Therefore, in the fields of physics and astronomy, there is a need for research that explores the use of AI in learning and assessment.

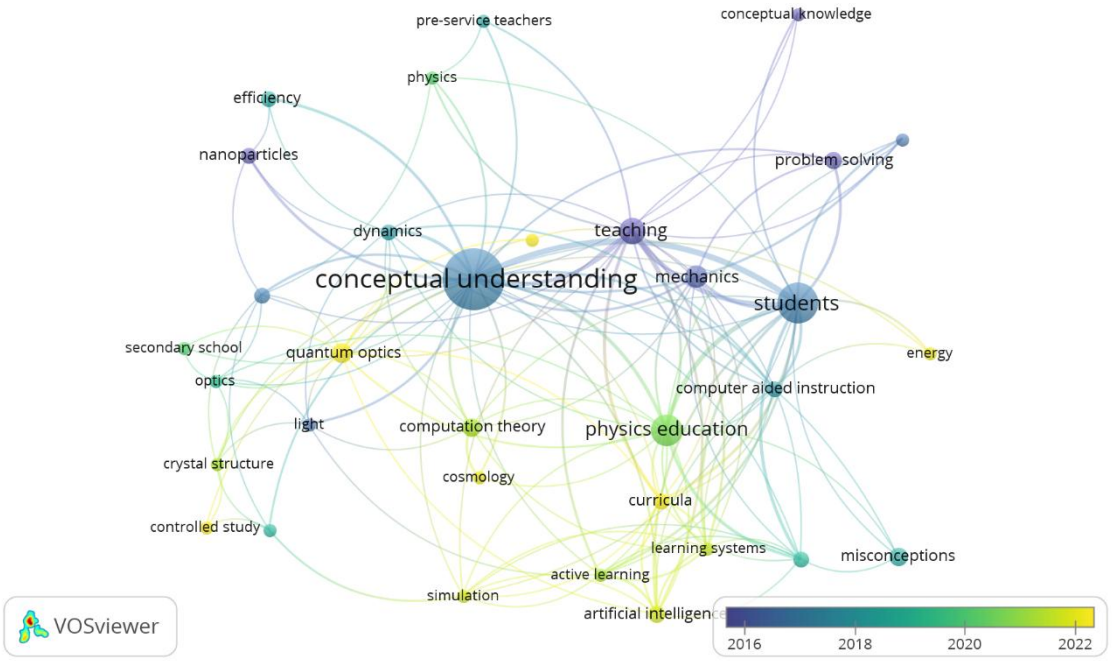


(*Source: The results of data analysis using Biblioshiny*)

Figure 10. Trend Topics in The Context of CUPA

The results of the Biblioshiny analysis in Figure 10 are consistent with the output of the VOSviewer analysis in Figure 11. The time trends indicated by color changes show that newer

terms, such as “artificial intelligence” and “problem solving,” have begun to appear more clearly in recent years, reflecting a growing interest in the use of advanced technology and problem-solving approaches in physics education. Overall, the data indicates a shift in focus within physics education toward the integration of technology and active learning techniques to enhance conceptual understanding among students.



(*Source: The results of data analysis using VOSviewer*)

Figure 11. Overlay Visualization in The Context of CUPA

Research Limitations

Although this article provides comprehensive insights into the development of research on conceptual understanding in physics and astronomy (CUPA), there are several limitations that need to be noted. Although the data used comes from the Scopus database, which is one of the leading sources of data in bibliometric analysis, limited access to articles in languages other than English may limit the scope of the research. This may overlook important contributions from countries that publish more works in local languages. Furthermore, although this article uses bibliometric analysis to explore publication trends, this analysis does not provide in-depth insights into the methodologies or specific results of the existing research. Therefore, despite the large number of articles recorded, a deeper understanding of how the research was conducted or the results found is not explained in detail in this analysis. Another limitation is the limited analysis period up to mid-2025. The decline in the number of publications in 2025, as seen in the data, may be due to incomplete data or changes in research focus that have not yet been fully recorded.

Recommendations for Future Research

Future research should address several limitations of this study. One is the need to expand the scope by considering publications in various languages, including non-English languages, to

provide a more complete picture of global contributions to the understanding of concepts in physics and astronomy. In addition, further research could expand the focus to explore not only conceptual understanding, but also how these concepts can be integrated into critical thinking, creative thinking, and problem solving skills, which are highly relevant 21st-century skills in the context of physics and astronomy education.

One key suggestion is to further explore the role of artificial intelligence (AI) in helping to improve conceptual understanding in physics and astronomy. While the trend toward using AI in education has shown significant growth in recent years, much remains to be learned about how AI can be used for more personalized and adaptive assessment and learning interventions. Future research could explore various ways in which AI can be applied to support contextual learning in physics and astronomy. On the other hand, more research could be conducted to identify gaps in understanding among students in different countries or regions. This research could examine factors that influence differences in conceptual understanding across education systems, including the influence of different curricula and teaching approaches used at the global level. This research could also expand the use of computer simulations and technology-based learning in improving scientific concept understanding, as well as measure its effectiveness compared to traditional learning methods.

Finally, although this article has identified the important contributions of countries and lead authors, further research should examine in greater depth the international collaboration that has taken place in CUPA research. Understanding how international cooperation can accelerate the development of physics and astronomy education and conceptual understanding is crucial. Further research could also consider the influence of culture and educational policies in shaping the direction and quality of research in this field.

CONCLUSION

Research on concept understanding in physics and astronomy (CUPA) shows steady and collaborative development between 2006 and 2025, with the number of publications continuing to increase, especially during the period from 2017 to 2021. Despite fluctuations in the number of publications each year, this topic remains a key focus for the scientific community, reflecting its relevance and contribution to the advancement of knowledge. This research also highlights the importance of international collaboration, with approximately 23% of the documents involving cross-national collaboration, demonstrating the global dimension of this topic. Some of the main contributors in this field include authors, affiliations, and highly productive countries, such as the United States and South Africa, which play an important role in driving research progress. Additionally, this research identifies that conceptual understanding is significantly influenced by educational factors such as curriculum, teaching methods, and technology, with increasing attention being paid to artificial intelligence (AI) in enhancing scientific conceptual understanding.

Moving forward, further research should expand its scope by considering publications in languages other than English to explore more diverse global contributions. Subsequent research should also explore in greater depth the integration of conceptual understanding with critical thinking, creativity, and problem-solving skills, which are increasingly important in 21st-century education. Additionally, the use of AI in physics and astronomy education warrants further

investigation, particularly in the context of personalized and adaptive assessment and learning interventions. Finally, it is important to explore further international collaboration in CUPA research and understand how such collaboration can accelerate the development of physics and astronomy education globally.

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