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Inquiry Models STEM in Physics Education for Innovative Learning Paradigm: Bibliometric Analysis Research

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ABSTRACT

The aim of this research was to investigate research trends on Inquiry STEM topic in the context of physics education and conduct a bibliometric analysis to understand the development of research in this domain. Data were collected from the Scopus database using keywords relevant to Inquiry STEM and physics. The approach used in the analysis was the bibliometric method by utilising the Scopus database and VOSviewer, which resulted in 62 relevant documents. The results showed that the use of Inquiry STEM in physics education has become an increasingly popular topic over the past ten years, despite fluctuations in publication rates. This indicates potential challenges that need to be further explored in the future. Further research of Inquiry STEM in physics education could be helpful in improving students' critical thinking skills and motivation, given the evidence that this instructional model has demonstrated effectiveness in improving students' problem-solving abilities, critical thinking, and motivation. However, it's worth noting that this research has limitations due to its sole reliance on one database, namely Scopus, for data collection. Therefore, it is advisable for future research on Inquiry STEM in physics education to incorporate the utilization of other databases besides Scopus to ensure a broader range of data is considered.

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INTRODUCTION

In an era that continues to develop rapidly in the fields of technology and science, the education paradigm must also continue to adapt to meet the demands of the times (Goh & Abdul-Wahab, 2020). Physics education, as an integrated part of STEM, plays an important role in preparing future generations with the skills and understanding needed in science, technology and innovation. The inquiry model in physics learning offers an approach that encourages students to be active in the learning process, triggers curiosity, and develops critical, analytical, and creative thinking skills (Abaniel, 2021). Through inquiry, students are encouraged to explore physics concepts directly, solve problems, and conduct experiments, which in turn builds a deeper understanding (Brookes et al., 2020).

The STEM-integrated inquiry approach in physics education has become a very important focus in developing the quality of physical science learning in the modern era (Nurwahyunani, 2021). In this case, STEM represents a holistic approach that integrates the four aspects of science, technology, engineering and maths as a whole. This approach emphasizes learning through projects, experiments, and discoveries, which support student activities to be actively involved in the process of learning activities (Kartini et al., 2021). The main advantage of the inquiry approach in physics education lies in its main driver: deep understanding through active exploration (Zhai, 2019). Students not only learn physics concepts theoretically, but they are also directly involved in experiments, observations, and practical physics problem solving (Brookes et al., 2020; Herayanti et al., 2020). In the current era of self-directed learning curricula, there is a focus on cultivating 21st-century skills, including communication, collaboration, critical thinking and problem solving, and creativity (often referred to as the 4C) (Tohani & Aulia, 2022), STEM-integrated inquiry in physics education has significant advantages. By allowing students to explore physics concepts through collaborative projects, practical experiments, and problem solving, the inquiry approach promotes these 4C skills naturally.

The application of inquiry in the 21st-century physics curriculum is a progressive step that is in keeping with the demands of the times. It not only teaches students about physics concepts but also equips them with skills that are indispensable in the real world. By understanding physics concepts through STEM inquiry, students not only become knowledge but also become knowledge makers who are able to adapt to technological changes (Deák et al., 2021). The presence of STEM-integrated inquiry in physics education is also in line with the evolution of education in responding to dynamic changes in future professional demands. Physics education in the 21st century must be able to prepare students to adapt to rapid changes, which require skills that go beyond concept understanding (Bao & Koenig, 2019; Meyer & Norman, 2020). Inquiry can emphasize problem-solving and critical thinking, providing a strong foundation to enable students to innovate, collaborate, and communicate effectively (Chen, 2021), solve complex problems, and contribute to future innovation (Matthee & Turpin, 2019).

Through the STEM inquiry model in physics education, students not only gain an understanding of physics theory but also learn how to apply it in real situations (Ellermeijer & Tran, 2021). This makes the STEM approach very relevant in the context of a curriculum that emphasizes the advantages of critical, creative, collaborative, and communicative thinking (Falloon et al., 2020). Developing students' ability to solve physics problems through STEM inquiry will not only strengthen their scientific foundation, but also equip learners with the skills they need to become real-world problem solvers, respond to complex challenges, and become future leaders in science and technology.

Over time, there has been a significant increase in inquiry-related research in physics education. It is important to conduct research related to inquiry learning because the learning model in schools can affect students' abilities. Therefore, it is essential to explore research trends related to inquiry learning, especially in the context of physics education, by conducting a bibliometric analysis. This aims to gain a deeper understanding of the evolution of research on this topic. The benefits will be felt by academics, researchers, and teachers, who can use these insights to develop more effective strategies and applications of the inquiry learning model in the school.

Bibliometric analysis methods are used to identify research directions, researcher contributions, and dominant research foci in a discipline (Lin et al., 2022). In the context of the Inquiry learning model, the bibliometric approach is a useful tool to explore publication trends, journals that are frequently published, the most prolific authors, and the most pursued research topics (Gao et al., 2021). However, currently there are still not many research trends on STEM inquiry models in schools, especially in physics education. Therefore, research on the utilization of STEM inquiry is an important novelty to be researched.

The research of bibliometric analysis of STEM inquiry models in physics education is relevant because it provides a clear picture of the development, trends, and focus of research in keywords. Bibliometric analysis is able to identify scientific publications, recent research, author contributions, as well as trends in topics that are receiving attention in physics education with this innovative approach. By mining bibliometric data, this research is expected to provide an in-depth understanding of the extent to which STEM inquiry models have been applied in physics education, providing a solid view of the successes, challenges and opportunities for further development. As such, this article has the potential to provide insights for practitioners, academics, and policymakers in the field of physics education to continuously improve the quality of STEM learning and education. Through bibliometric analysis, we can gain a better understanding of the direction of future research. This allows researchers and educators to recognize areas where knowledge is lacking and needs to be further researched in the future (Tlili et al., 2022).

By conducting a bibliometric analysis, this article aims to analyze research trends related to Inquiry STEM learning in physics education. The bibliometric analysis will provide a deep insight into the extent to which Inquiry STEM concepts have been applied, studied and adopted in the realm of physics education. In addition, this article also aims to evaluate the impact and implications of these research trends on the future of physics education, including potential improvements and adjustments that can be made in the learning process.

The implication of these research trends is that it is important to shape a future view of physics education that is more adaptive, responsive and effective. By considering the future direction of physics education, the integration of the Inquiry model with STEM in the curriculum can provide a strong foundation for creating a generation that not only understands physics, but is also able to apply it in various life contexts. This will help create learners who are ready to face the challenges of an ever-changing and evolving era.

RESEARCH METHOD

In this research, bibliometric analysis was conducted using a quantitative approach that mainly focused on international journal publications. The Scopus database was used as a source of indexed literature from various leading publishers internationally. This bibliometric analysis aims to provide a comprehensive understanding of the entire discipline, including describing or visualizing publication trends as well as the amount of contribution of articles to the development of science and the relationship between relevant topics (Guo et al., 2019; Karakus et al., 2019; Yulianingsih et al., 2020).

In a search conducted in the Scopus database using the keywords "(inquiry AND STEM AND in physics AND learning)," 62 articles were found, which became the data source for this research. The data collected was then analyzed using MS. Excel and VOSviewer to get a clearer bibliometric mapping. The hope is that this bibliometric analysis can provide in-depth insight into progress and trends in research so that it can help and provide insight for researchers in identifying areas where knowledge is still lacking and requires further research in the future (Dwikoranto et al., 2023).

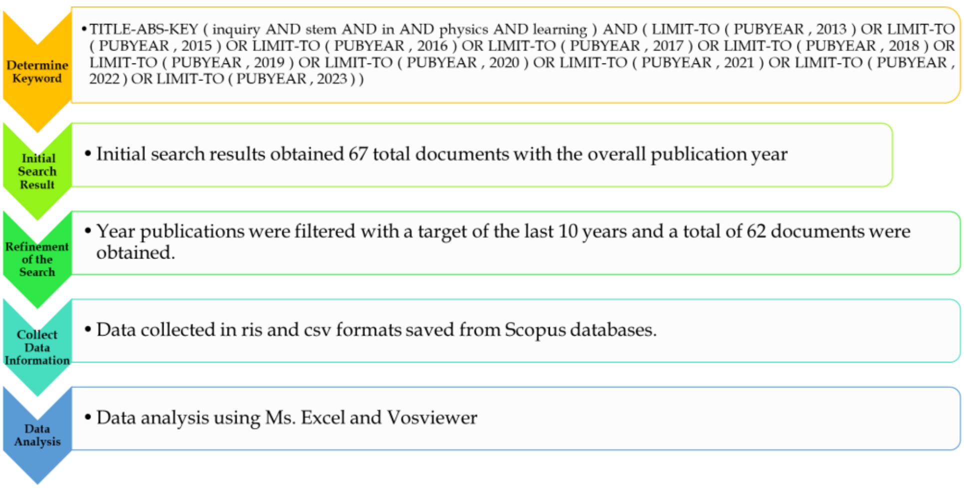


Figure 1. Research flow in carrying out bibliometric analysis
(Dawana et al., 2022a; Dawana et al., 2022b)

Figure 2 above is a step in the data analysis process through the application of the bibliometric analysis method. This method uses VosViewer software to produce visualizations regarding research trends, including Co-Occurrence interactions between authors, documents, and keywords relevant to the research topic (Dawana, Setyarsih, et al., 2022). This analysis focused on network visualization and overlay, which was then examined to explore the relationship between STEM inquiry models in Physics education. Through this approach, the main objective of the research is to understand how the STEM inquiry model can be applied in the scope of learning in the school environment. It is hoped that the results of this research can provide significant information in the development of future learning models, especially in the world of education.

RESULTS AND DISCUSSION

After searching using the keywords "Inquiry and STEM and Physics" in the Scopus database, a total of 62 relevant documents were found. The documents were then downloaded in .csv and .ris formats, and further analysed using MS Excel and VOSviewer software. Through a structured analysis process, the most relevant keywords with the highest level of relevance were placed at the top, as illustrated in Table 1.

Table 1. Top 10 documents with the highest relevance in the Scopus database

Result Number	Authors	Year	Source	Cited	Ref
1	Aprilia A.; Kuswanto H.; Dwandaru W.S.B.	2023	Revista Mexicana de Fisica E	0	(Aprilia et al., 2023)
2	Solomon F.; Champion D.; Steele M.; Wright T.	2022	Journal of the Learning Sciences	6	(Solomon et al., 2022)
3	Sokolowski A.	2021	Understanding Physics Using Mathematical Reasoning: A Modeling Approach for Practitioners and Researchers	2	(Sokolowski, 2021)
4	Yuliati L.; Parno P.; Hapsari A.A.; Nurhidayah F.; Halim L.	2018	Journal of Physics: Conference Series	15	(Yuliati, Hapsari, et al., 2018)
5	Yuliati L.; Parno; Yogismawati F.; Nisa I.K.	2018	Journal of Physics: Conference Series	6	(Yuliati, Yogismawati, et al., 2018)
6	Yuliati L.; Yogismawati F.; Purwaningsih E.; Affriyenni Y.	2021	Journal of Physics: Conference Series	1	(Yuliati et al., 2021)
7	Thongsri P.; Prasongsap B.; Panjaburee P.; Srisawasdi N.	2020	ICCE 2020 - 28th International Conference on Computers in Education, Proceedings	1	(Thongsri et al., 2020)
8	Paolucci P.; Scianitti F.; Galati G.	2021	Proceedings of Science	1	(Paolucci et al., 2021)
9	Ait Si Ahmad H.; Alarcon M.; Berrada K.	2022	Lecture Notes in Educational Technology	0	(Ait Si Ahmad et al., 2022)
10	Saregar A.; Latifah S.; Hudha M.N.; Susanti F.; Susilowati N.E.	2020	Periodico Tche Quimica	1	(Saregar & Susanti, 2020)

Table 1 displays the outcomes of the search for the top ten noteworthy articles associated with the exploration of "Inquiry STEM" within the Scopus database. The ranking places the most pertinent article in the first position among the ten selected articles. These ten main articles are important reference sources in analyzing the application of Inquiry STEM in the context of Physics education.

The results of ten articles of research show that the integration of inquiry learning with STEM can strengthen scientific literacy abilities and problem-solving skills. The use of Inquiry STEM has also been proven to be able to increase understanding of concepts and trigger creative thinking. This is in accordance with research from (Uğur et al., 2020) inquiry learning integrated in STEM has many significant benefits. It will provide students with opportunities to actively participate in the learning process, investigate science concepts in a real-world context, and develop problem-solving skills (Ješková et al., 2022; Uğur et al., 2020). Through inquiry STEM, students not only recognize physics concepts but also learn how to apply that knowledge in real situations and think creatively to find the best solution. The application of the inquiry STEM model can create a stronger connection between theory and practice, which supports a deeper understanding (de Jong, 2019). In addition, the inquiry STEM approach encourages students to question, investigate, and explore further. This promotes curiosity and interest in science, which are important aspects of science literacy. Therefore, the integration of this approach creates a dynamic learning environment and encourages a deeper understanding of physics as well as the development of rational thinking. Thus, this approach not only supports effective learning but also creates a solid foundation for the continued development of science literacy and problem-solving skills.

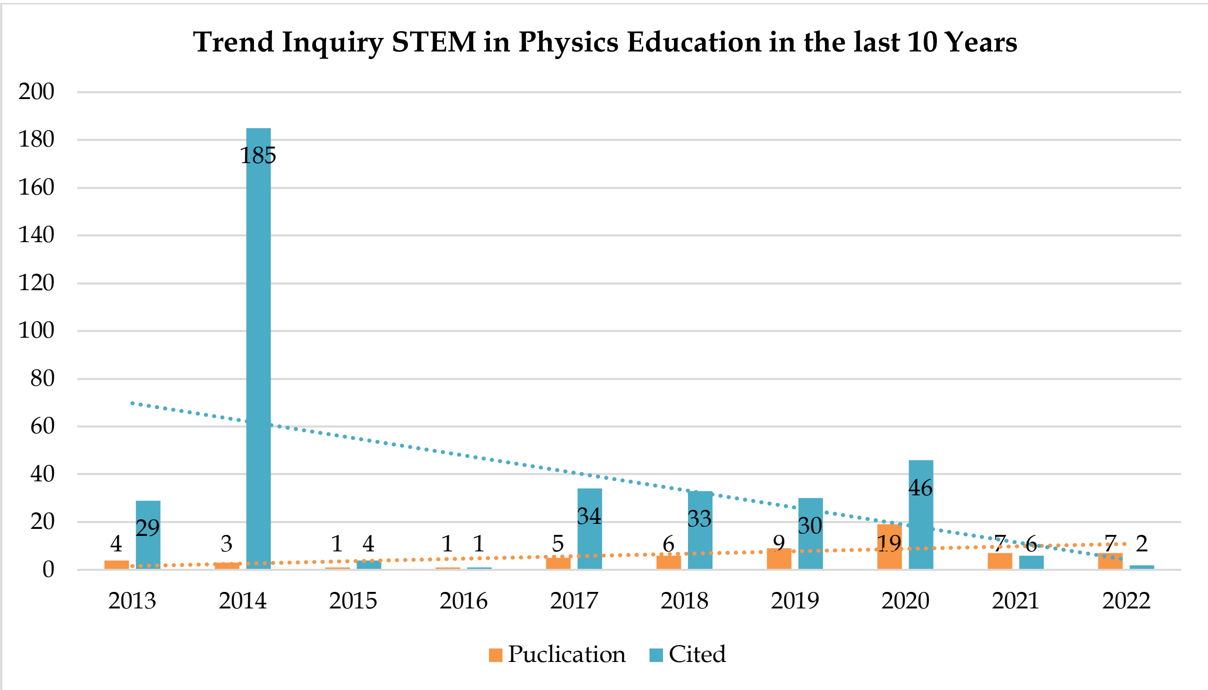


Figure 2. Number of publications and citations to STEM physics education inquiry in the last 10 years in the Scopus database

Figure 2 shows the trend of Inquiry STEM research publications in physics education on the Scopus database which is an important indicator in identifying developments and challenges in physics learning. Based on the graph, it is known that overall, there are fluctuations in the number of publications and citations on Inquiry STEM research in physics education. There is a significant upward trend in the number of publications from 2018 to 2020, followed by a sharp decline in 2021 and 2022. Citations also fluctuated, with one year having very high citations (2014) and the last two years (2021 and 2022) showing a significant decrease in the number of citations. This is a challenge for future research to contribute to Inquiry STEM research in Physics learning.

The application of Inquiry STEM in physics learning has very important implications. Through this approach, students are given the opportunity to develop a range of skills that are essential for the 21st century. Learners not only understand physics concepts, but also learn to question, investigate, and apply their knowledge in real situations (Sutaphan & Yuenyong, 2019). Thus, they foster critical and creative thinking. In addition, this approach strengthens students' problem-solving skills, as they are faced with complex problems that require the application of physics concepts to find solutions. Through STEM Inquiry, students also see how physics relates to other STEM disciplines, strengthening cross-disciplinary understanding. Notably, these skills are highly relevant in the ever-evolving world of work and prepare students for the challenges and situations that arise in the 21st century.

Subsequently, bibliometric analysis was conducted utilizing VOSviewer software, and the outcomes were represented through network analysis, specifically emphasizing the keyword "Inquiry STEM" in the domain of physics education. The mapping derived from this network analysis is depicted in Figure 3.

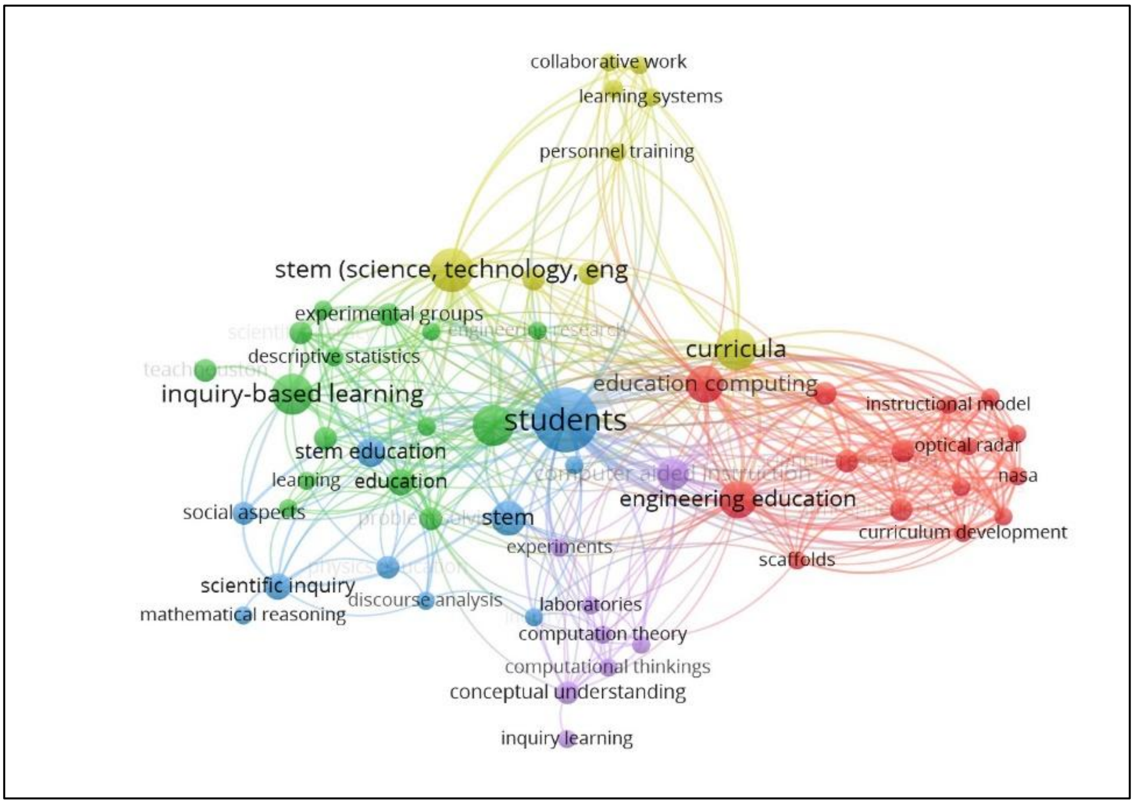


Figure 3. Mapping STEM inquiry in physics education on the Scopus database

Figure 3 shows of mapping Inquiry STEM research trends in the context of physics education. The objective was to pinpoint ongoing research based on the identified trends. The mapping outcomes revealed five clusters pertaining to STEM inquiry in physics education. The initial cluster, highlighted in red (n = 15), centers on curriculum development and technical education. The next cluster, colored green (n = 15), places more emphasis on developing learners' skills, such as problem-solving and scientific literacy. Next, the dark blue cluster (n = 10), focuses on integrating learning such as the implementation of STEM education. The purple cluster (n = 8) highlights the outcomes of the learning curriculum, as well as the learning system. Finally, the brown cluster (n = 3) focuses on computational theory and computational thinking, characterized by keywords and a more specific research focus.

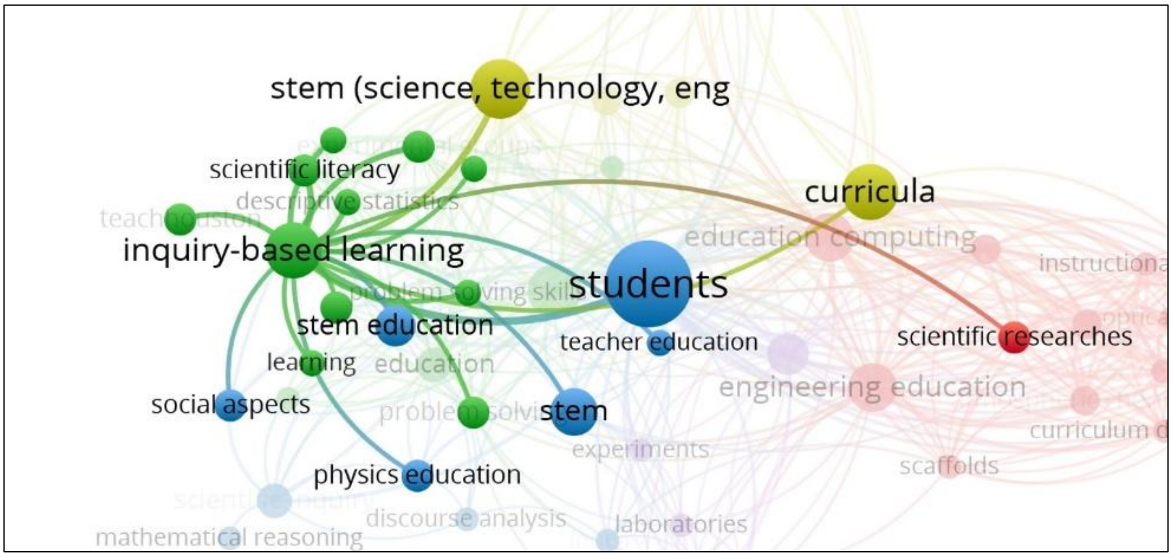


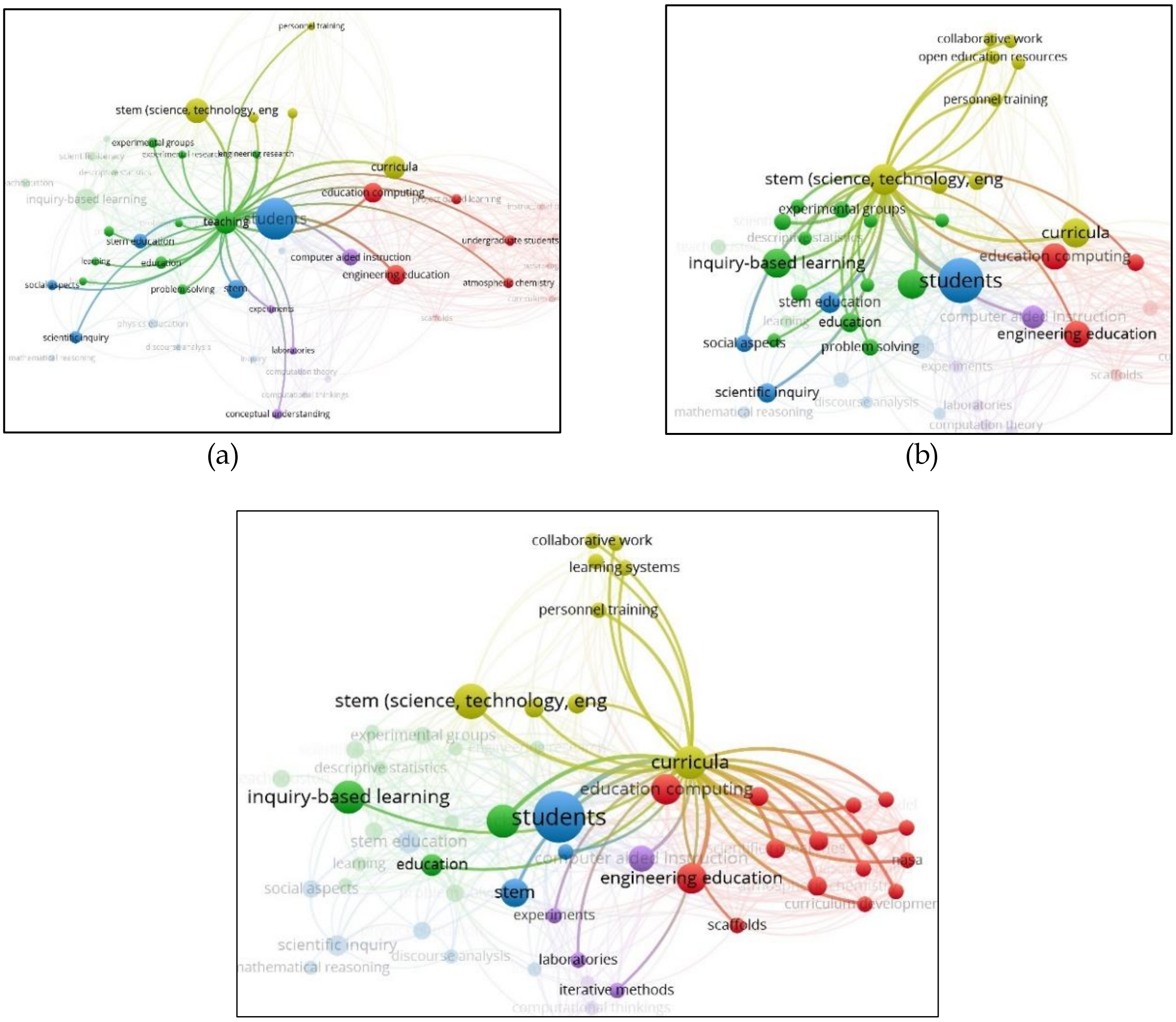
Figure 4. Visualization results of keyword mapping with inquiry-based learning topics

Figure 4 shows an example of more specific keyword mapping results on Inquiry in Physics Education. From Figure 4, it can be seen that the potential for further exploration of the Inquiry trend in physics education is very large, considering its broad topic coverage and flexibility in application. Inquiry correlates with curriculum, scientific literacy, social aspect, teacher education, scientific researches and STEM learning.

In the curriculum, Inquiry provides students with opportunities to actively participate, learn science concepts in depth, and develop essential skills needed in the 21st century (Bao & Koenig, 2019; Chu et al., 2021). This enables the development of science literacy, where students not only understand facts but can also apply that knowledge in a real-world context (Peffer & Ramezani, 2019). Inquiry engages students in collaborative learning, strengthening communication skills and cooperation (Chen, 2021). Teacher education related to Inquiry emphasizes the role of educators as facilitators in the learning process, encouraging students' creativity, exploration, and questioning. The link between Inquiry and STEM learning is strong because Inquiry STEM combines the four disciplines where Science, Technology, Engineering, and Mathematics in exploratory and integrated learning. By integrating the STEM Inquiry Model in physics learning, teachers build an innovative learning paradigm that raises students who are more active, creative, and able to think critically (Abdurrahman et al., 2019). Learners not only understand physics as a collection of facts but also see it as a skill and understanding that can be applied in the context of everyday life. Thus, the STEM Inquiry model in physics education truly realizes innovative learning that is relevant to the demands of the times. By engaging students in experimentation, problem-solving, and exploration of physics concepts, this model enables active, collaborative, and interactive learning.

Figure 5(a) shows that the Inquiry STEM research trend is very supportive of the learning conducted by teachers. Figure 5 (b) shows that STEM can be interrelated with the Inquiry model and learner learning outcomes such as scientific, problem-solving, and social aspects. This means that the Inquiry STEM model has great potential to be further explored because the topic has a broad scope and is flexible in its application. Figure 5(c) shows that the learning curriculum also correlates with engineering education, experimentation, scaffolding, and STEM. So, between these three images, there is a relationship between curriculum, learning, and STEM in accordance with previous expert research (Sutaphan & Yuenyong, 2019).

The STEM Inquiry Model not only improves understanding of science concepts but also stimulates the development of creative, critical thinking skills and problem-solving abilities. Inquiry STEM also provides space for the development of students' science literacy, who not only understand the theory but are also able to apply it in real-world situations (Schwartz et al., 2023; Sutaphan & Yuenyong, 2019). In addition, the STEM Inquiry model provides a strong foundation for the development of students' social skills. Collaboration, communication, and cooperation are important aspects of this approach, which encourages students to work together in groups, share ideas, and solve problems together. The Inquiry STEM model encompasses a broad spectrum and offers flexibility in its implementation (Uğur et al., 2020). It allows teachers to customize learning according to student's needs and expand the exploration of science and technology, allowing different aspects of STEM to be explored thoroughly. Thus, the STEM Inquiry model has great potential to continue to be further explored and developed in the ever-evolving education.



(a) (b) (c)

Figure 5. The results of the keyword mapping visualization are specific to the research topics: a) Teaching, b) STEM, and c) Curriculum.

The application of the STEM Inquiry Model in physics education is an innovative learning paradigm because it connects science concepts with aspects of technology, engineering, and mathematics in a comprehensive manner. It allows students to engage in dynamic, collaborative and applied learning, where they not only understand physics concepts but also apply them in a real-world context. The application of this model also strengthens communication skills, as students are exposed to collaborative tasks that encourage them to convey their ideas clearly and effectively (Chu et al., 2021; Palupi & Subiyantoro, 2020). Collaboration between students in solving physics problems encourages collaboration skills that are important in real-world social and professional situations. In addition, the STEM Inquiry model encourages students' creativity, as they are given the freedom to find solutions to problems encountered in physics learning (Dewi et al., 2019). This allows students to think out of the box and find innovative solutions. Thus, the application of the STEM Inquiry Model in physics education is important because it not only strengthens the understanding of physics concepts but also prepares students with 21st-century skills that are urgently needed in this modern era.

Recommendations for future research are to further integrate the Inquiry STEM learning model so that researchers contribute to the Scopus-indexed International scale. Research is also more directed and correlated with scientific literacy and problem-solving; perhaps it can be used to increase motivation and critical thinking. Based on research from (Samadun et al., 2023) the application of inquiry can improve critical thinking skills, but in bibliometric analysis, it still does not appear that research related to this. Based on the results of bibliometric analysis, stem integration Inquiry Research has been applied, but in the bibliometric relationship cycle, it is still relatively small, and researchers still contribute less to research in the STEM field. So this will be an opportunity for further research to increase physics education publications on the Inquiry STEM learning model (Dwikoranto et al, 2023).

From Figure 6, it can be seen that there are three relevant authors out of a total of 62 identified authors in the context of the information available to relevant co-authors. Figure 6(a) shows two different clusters, the green cluster with one referrer and the red cluster with two authors. Analysis of the Scopus database shows that Bering, e.a., is the leading author with the most visual representation in the topic of STEM Inquiry in physics learning. Meanwhile, Figure 6(b) displays the visualization without the restriction of connections between entities. From the figure, it is clear that the Bering e.a cluster contributes significantly to the STEM inquiry research In physics education indexed by Scopus (Dawana & Dwikoranto, 2024).

(a) (b)

Figure 6. Visualization of top authors and visualization of all authors in the Scopus database

The limitation of this research is only the use of the Scopus database, so it is only able to visualise the data available in it. Therefore, it is recommended for future research in the domain of STEM Inquiry trends to use various other databases besides Scopus, such as Google Scholar, to obtain a more comprehensive picture of the research trends.

CONCLUSION

Based on the results of bibliometric mapping analysis, several important findings were identified. Publication trends related to Inquiry STEM in the context of physics education show fluctuations, posing a challenge for future research to explore whether there will be an increase in this topic. It was noted that the topic of Inquiry STEM in physics education has great potential for further research in the future. Analysis of the research showed that the main focus of the research trend of Inquiry STEM in physics education is the application of this model to improve science literacy and skills in problem-solving. The outcomes of this investigation hold significant implications, such as the discovery of pioneering instances of Inquiry STEM pedagogy in physics education, which can serve as guiding principles for further exploration in this field. Furthermore, this research facilitated the identification of the most pertinent articles concerning Inquiry STEM within physics education within the Scopus database. As a result, this research also delineates potential future research trends in this domain. For forthcoming inquiries pertaining to Inquiry STEM in physics education, it is advisable to explore alternative database platforms beyond Scopus to ensure a more comprehensive analysis.

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