ISSN (PRINT) : 2549-9955 ISSN (ONLINE): 2549-9963
JURNAL ILMIAH PENDIDIKAN FISIKA
https://ppjp.ulm.ac.id/journals/index.php/jipf/index

Bibliometric Analysis of STEM Robotics in Physics Education: Global Trends (2008-2024) Based on Scopus Data

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Abstract

This study aims to analyze global trends in STEM-based robotic physics education through a bibliometric analysis conducted using data obtained from the Scopus database. STEM and robotics are increasingly gaining attention as effective approaches in physics education, aligning with the 21st-century demand for technical skills, creativity, and problem-solving abilities. This research utilizes R bibliometric software to identify publication patterns, researcher collaborations, and key trends in STEM-based robotic physics education from 2008 to 2024. The methods involved searching for articles using the keywords "STEM AND robotic AND physics AND education," resulting in 53 downloaded and analyzed articles. The analysis was conducted in two main steps: data collection from Scopus and metadata analysis to identify research trends and collaboration networks among researchers. The results indicated a substantial growth in the volume of publications and international collaborations, with the United States leading in publication contributions, followed by Ukraine and Colombia. The key findings reveal that recent research trends focus on learning media and STEM. Meanwhile, topics that have received less attention include the impact of STEM on the curriculum and the development of critical thinking skills. Several topics, such as augmented reality and critical thinking, were also identified as challenging potential avenues for future research. This research offers significant guidance for future researchers in developing more effective STEM-based education strategies and suggests closer collaboration between academics and practitioners in various countries. Future research is recommended to explore alternative bibliometric analysis tools and expand the database coverage to enrich perspectives and enhance the scope of findings.

Keywords: bibliometric analysis; physics education; robotics; scopus; STEM

Received: 30 October 2024
Accepted: 4 December 2024
Published: 7 December 2024
DOI : https://doi.org/10.20527/jipf.v8i3.13894

How to cite: Windrawan, I. G., Wibowo, F. C., & Sugihartono, I. (2024). Bibliometric analysis of STEM robotics in physics education: Global trends (2008-2024) based on Scopus data. *Jurnal Ilmiah Pendidikan Fisika*, *8* (3), 462-476.

INTRODUCTION

STEM robotics has become an increasingly popular tool in physics education, providing learners with engaging opportunities in practical applications of theoretical concepts in real-world contexts (Budiyanto et al., 2020). Through engagement in robotics projects, students witness the direct impact of physics principles on the design and functionality of their creations (Dwivedi et al., 2021). This practical approach deepens their comprehension of physics concepts while promoting the growth of creativity, problem-solving skills, and collaboration among peers (Nilimaa, 2023). Overall, integrating STEM robotics into physics education has proven to enhance student engagement (Ntemngwa & Oliver, 2018) and understanding of complex scientific principles (Ching et al., 2019). As technology evolves, incorporating robotics into classrooms enables students (Haleem et al., 2022) to hone skills essential for success in an increasingly digital world (Khine, 2017). Encouraging critical thinking and collaboration in problem-solving, STEM robotics in physics education prepares students for careers in science and technology and instils a lifelong passion for learning and discovery (Khine, 2017).

Data from the World Economic Forum indicates that STEM robotics has garnered interest from academics and education practitioners. It is considered one of the most relevant skills for preparing students for the future (Morze, Strutynska, & Umryk, 2018). STEM robotics education has shown significant growth in scientific publications, as reflected in increased research and articles in databases such as Scopus (Darmawansah et al., 2023). Between 2008 and 2024, this topic has grown exponentially in the volume of publications and the breadth of disciplines involved. Governments across various countries have responded by creating policies that support the development of STEM robotics education (Brougham & Haar, 2018). Some countries, integrating robotics into STEM curricula has become a national priority, supported by initiatives such as teacher training and the provision of technological tools in schools (El-Hamamsy et al., 2021). Additionally, increasing recognition of the significance of STEM-based education has increased, as seen in various technology development programs involving students, such as robotics competitions and science projects (Wahono & Chang, 2019).

Research on STEM robotics in physics education has become a primary focus for researchers, especially in deepening students' understanding of complex physics concepts (Lin et al., 2019). STEM robotics enables students to link physics theory with real-world applications through projects involving robotics technology. For instance, robotics in physics learning has been shown to enhance students' critical thinking skills and conceptual understanding of physics (Ferrarelli & Iocchi, 2021). A detailed example of this is a study in which high school students built and programmed robots to demonstrate Newton's laws of motion (Menkhoff et al., 2022), allowing them to visualize and understand these concepts in practice (Barredo Arrieta et al., 2020). Hands-on experience with robotics reinforces theoretical knowledge (Budiyanto et al., 2020) and fosters a deeper appreciation of applying physics principles in real life (Siahaan et al., 2022).

While previous research has explored the benefits of STEM in physics education, a gap remains in more integrated approaches that bridge physics learning with relevant STEM robotics projects (Uden et al., 2023) and relevant STEM robotics projects. Many studies focus solely on one aspect, such as conceptual understanding or technical skills, without considering a holistic approach involving multidisciplinary collaboration (Nguyen & Mougenot, 2022). Proposed solutions in some studies include implementing an integrated project-based approach involving cross-disciplinary collaboration and interactive technology. Additionally, enhanced collaboration between academics, educators, and industry is needed to design a more integrated STEM robotics curriculum (Anwar et al., 2019).

To address this research gap, this study investigates the global trends in STEM-based robotic physics education from 2008 to 2024, focusing on publication patterns, active contributors, emerging topics, and the impact of international collaborations. The key research questions include: (1) What are the global publication patterns and trends in STEM-based robotic physics education during this period? (2) Which countries, researchers, and institutions are the most active contributors to the field? (3) What emerging topics and underexplored areas exist in STEM-based robotic physics education research? and (4) How do international collaborations influence the development and dissemination of research in this domain?

To answer these questions, the study posits the following hypotheses: (H1) There has been a significant increase in global publication output on STEM-based robotic physics education between 2008 and 2024. (H2) Countries with higher investments in STEM education and technology, such as the United States, contribute disproportionately more to the field than developing nations. (H3) Emerging topics, including augmented reality and critical thinking, still need to be explored and hold substantial potential for advancing STEM-based robotic physics education. (H4) International collaborations enhance the diversity and quality of research in this area.

Further research is imperative to develop learning models integrating theoretical physics with advanced robotics applications (Willard et al., 2022). Future research could also focus on utilizing cutting-edge technologies, including artificial intelligence and machine learning, to enhance the impact and efficacy of using STEM-based robotics in the teaching and learning process of physics (Ameen et al., 2021).

This study's use of bibliometric analysis aligns with previous research that has effectively employed similar methods to identify and guide significant research directions in STEM and physics education. For example, a study by Natalia et al. (2024) highlights steady growth in robotics science education (RSE) research between 2012 and 2024, utilizing bibliometric analysis of 50 articles. This study identified a peak in publication growth in 2021, with the United States leading in contributions and notable international collaborations involving institutions such as Aristotle University of Thessaloniki and NYU Tandon School of Engineering. These findings emphasize RSE's transformative potential in STEM education through innovative applications, including enhancing student engagement, understanding scientific concepts, fostering computational thinking, and supporting special education (Aleksandrova et al., 2024). Similarly, Athiyah et al. (2023) provide an overview of STEM-based physics education research in Indonesia from 2018 to 2022, applying descriptive qualitative methods and bibliometric analysis using Publish or Perish software and VOS viewer. Their study revealed increasing interest in STEM education despite challenges such as student anxiety and low interest, with 45 articles identified and mapped using the keywords "STEM Education" and "Physics" to outline future research opportunities. These complementary findings demonstrate the critical role of bibliometric analysis in uncovering trends, addressing educational challenges, and identifying potential research directions in STEM and physics education globally (Sari & Ardianto, 2023). The analysis aims to identify research patterns, researcher collaborations, and future research directions in this field. Utilizing data from Scopus, this research offers an in-depth analysis of the development and impact of

STEM robotics in the global context of physics education. Accordingly, the problem design in this literature review study addresses how to advance research findings on STEM robotics approaches to physics learning bibliometrically, along with the trend challenges in physics learning research integrating STEM. By examining trends and collaborations in STEM robotics research in physics education, this study will offer insights into the current state of the field and potential areas for further exploration. This analysis also seeks to address the challenges and opportunities in integrating STEM principles into physics learning, especially through the use of robotics. Educators and researchers can better inform their practices and contribute to advancing STEM education in physics by understanding the research patterns and directions in this area. Several specific issues and gaps in the existing literature underline the urgency of this study. Firstly, research integrating local contexts, such as the implementation of STEM approaches within specific educational curricula like Indonesia's Merdeka curriculum, must be improved, hindering a deeper understanding of how cultural and policy factors influence STEM adoption. Additionally, while global STEM research highlights the benefits of international collaboration, there needs to be more documentation on cross-country partnerships, particularly in developing regions, which could provide valuable insights for scaling and diversifying STEM education. Furthermore, persistent challenges such as low student interest in physics, driven by perceptions of difficulty and irrelevance, need to be addressed in empirical studies offering practical solutions. Another significant gap lies in the integration of innovative practices, such as robotics and virtual laboratories, into physics education through STEM approaches, with few studies providing comprehensive frameworks for their effective implementation. Finally, previous bibliometric analyses often fail to offer a holistic view of STEM physics education research over extensive periods or across diverse geographic regions. Addressing these gaps is essential to better understanding research patterns and directions, enabling educators and researchers to inform their practices and contribute meaningfully to advancing STEM education in physics.

METHOD

The search for keywords related to STEM robotics trends in physics education was conducted using the Scopus database, which provides broader coverage in the sciences and social sciences compared to WoS (Darmawansah et al., 2023). The article search was performed on October 5, 2024, using the keywords "STEM AND robotic AND physics AND education" from 2008 to 2024. To ensure the relevance and quality of the results, inclusion criteria were applied, such as peer-reviewed articles, publications in English, and studies focusing on the intersection of STEM, robotics, and physics education. Conversely, exclusion criteria involved articles unrelated to the education domain, non-peer-reviewed publications, and those focusing solely on robotics without any educational or STEM integration context. Including these criteria enhances the validity and precision of the bibliometric analysis.

The collected data consists of metadata from articles relevant to this topic. The search yielded 53 articles, downloaded with their metadata and saved in CSV format. The data was subsequently reviewed to ensure all articles matched the keywords used and were relevant to the theme of STEM robotics in physics education (Yiğit, 2019). This research utilizes bibliometric analysis with the assistance of R software to examine data retrieved from the Scopus database. The research procedure was structured into two primary stages: data acquisition and analysis.

Data collection was conducted through the Scopus database, while data analysis involved processing the collected metadata to identify research patterns (L. Zhang & Eichmann-Kalwara, 2019) and collaboration trends in STEM robotics-based physics education. This analysis process is illustrated in Figure 1, which shows specific activities at each research step (Wibowo et al., 2024).

The two main areas in bibliometric measurement are dynamic analysis and structural analysis (Chen et al., 2017). Dynamic analysis considers the development and distribution of publications, keyword trends, keyword Frequency, citation metrics, distribution patterns, and impact measures like the h-index (Lu et al., 2021).

x.php/download. The analysis procedure begins with the following steps: Step 1, install R software, then install the Bibliometrix package by entering the command *install.packages("bibliometrix")*, followed by *library(bibliometrix)* and *biblioshiny()* to launch the application (Büyükkidik, 2022). Step 2: once the application is running, click the Data menu, select Import file, and upload the metadata file downloaded from the Scopus database in CSV format (Pallath & Zhang, 2022).

Step 3: Select the Scopus database, search for the desired file, and click *Start* to initiate the data analysis. The final step, Step 4, is to choose the *Documents* menu, then proceed to *Conceptual Structure*, *Social Structure*, and *Word Cloud* to visualize the analysis results, such as natic
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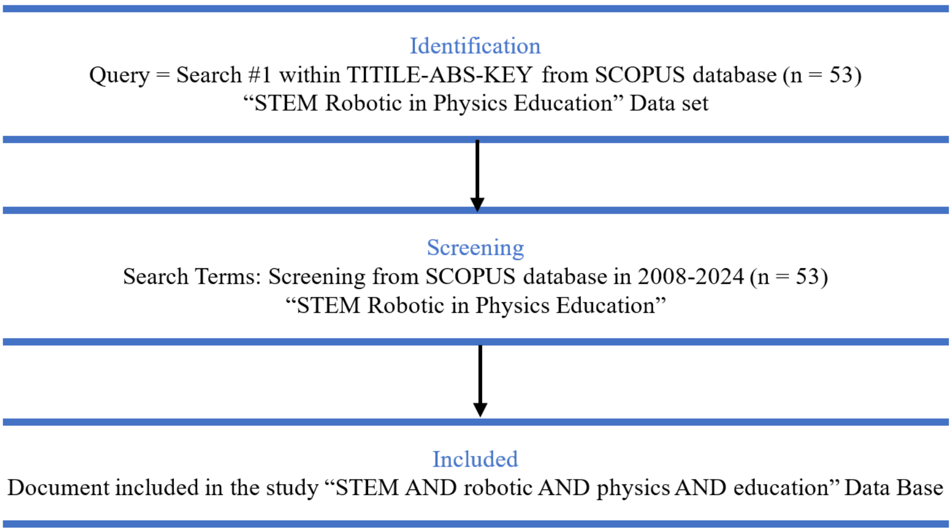

Figure 1 Stages of bibliometric analysis

On the other hand, structural analysis includes creating word dendrograms, co-occurrence networks, thematic representations, collaborative networks, and co-citation structures (Thin et al., 2018).

This study explores dynamic and structural analyses using the Bibliometrix software on R, accessible at https://www.bibliometrix.org/home/inde

RESULT AND DISCUSSION

Global Trends in Bibliometric Analysis of STEM Robotics in Physics Education, based on Scopus information gathered as shown in Table 1, compile descriptive statistical findings from the Scopus database using the keywords "STEM AND robotics AND physics AND education," focusing on the period from January 2008 to October 2024. This data is broken down into dynamic features, including sources (books, journals, etc.) with up to 37 documents, a total of 53 documents, an average of 20.28 citations per document, Keywords Plus (ID) with up to 377 documents, and Author's Keywords (DE) with up to 144 documents.

Table 1 Bibliometric statistical data on STEM robotics and physics education descriptions

Dynamics		Structure	
Timespan	2008 – 2024	Authors	167
Source (Journal, Books, etc.)	37	Author of single-authored docs	9
Documents	53	Single-authored documents	9
Average citation per document	20.28	Co-Authors per Documents	3.17
Keyword Plus (ID)	377	International co-authorships %	3.774
Author's Keyword (DE)	144	Reference	0

Table 1 also describes the research product structure, including author specifications and references. Among the document categories, nine single-author documents are authored by 167 different authors. Each document has an average of 3.17 co-authors. Every document includes at least one reference, and 3.774% of authors collaborate internationally. Thus, future researchers studying "STEM robotics and Physics Education" should pay close attention to the sources they cite in their research.

The year 2020 saw a significant increase in annual scientific production, with four articles published; in 2021, five articles were published; in 2022 and 2023, each produced four articles; and in 2024, six articles were published, as shown in Figure 2.

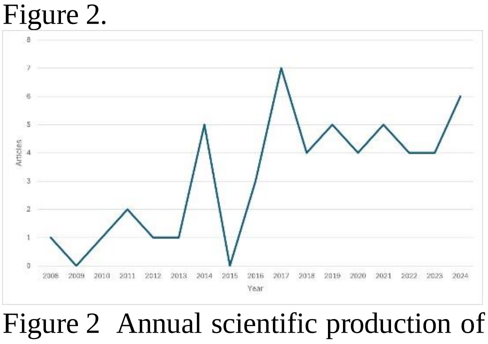

Figure 2 Annual scientific production of "STEM robotics and physics education"

As shown in the data, the significant increase in publications between 2015 and 2017 warrants a deeper analysis. This surge could be attributed to several factors. Firstly, new policies or initiatives during this period, such as increased research funding, national priorities in advancing specific scientific fields, or targeted support for international collaborations, played a pivotal role in boosting productivity. Secondly, major academic events such as international conferences, workshops, or collaborative research programs may have provided a platform for researchers to publish their findings more actively. Additionally, this period may reflect the culmination of advancements in relevant technologies or methodologies, which facilitated higher research output. Understanding these factors is essential, as this spike in publications likely had broader implications, such as increased visibility of the research community, greater adoption of new approaches, and potential influence on related policies in physics education or technology. The analysis offers valuable insights into the dynamics driving scientific productivity during this period by contextualizing these findings.

The title of the first study related to STEM robotics and physics education in 2008 was *"Impact of Undergraduate Robotics Research on Recruiting Freshman Students to Major in Engineering Physics and Computer Science Fields."* (Anwar et al., 2019). The study found that robotics significantly boosted students' confidence and enthusiasm, leading to an increased interest in pursuing education in

Engineering, Physics, and Computer Science. The results showed that students displayed enthusiasm for these study programs, successfully collaborated in teams, and developed prototypes during the research activities. However, the study faced some limitations, such as students' need for more skills in using computer-aided design software and initial difficulties in maintaining engineering journals. Nevertheless, the main findings indicate that robotics research can enhance student interest in STEM (Science, Technology, Engineering, and Mathematics) programs. Students' enthusiasm for continuing education in STEM fields was also reflected in the qualitative results obtained. On the other hand, this research needs more of an in-depth analysis of long-term student retention and limited exploration of students' diverse backgrounds and experiences (Anwar et al., 2019).

A ranking has been made for the top twenty countries regarding scientific output publishing articles on STEM robotics in physics education. Table 2 presents the publications from these countries. Countries considered active in this context have published ten or more publications during the designated period and have significantly contributed to the STEM robotics literature in physics education. These countries are regarded as having significantly advanced research in this field, demonstrating a high level of engagement and output in STEM robotics in physics education research. The United States, with 59 publications, is the most active country. Ukraine ranks second with 13 publications, although still far behind the U.S. Colombia, the third country, has eight publications.

Table 2 Countries' scientific production

Rank	Country	Freq
1	USA	59
2	Ukraine	13
3	Colombia	8
4	Italy	8
5	Spain	8
6	Canada	7
7	Chile	5
8	Romania	5
9	China	4
10	Qatar	4
11	Australia	3
12	Brazil	3
13	Costa Rica	3
14	France	3
15	Greece	3
16	Serbia	3
17	UK	3
18	Czech Republic	2
19	Azerbaijan	1
20	Egypt	1

A comparative analysis highlights significant disparities between high-contributing and low-contributing countries. According to Kayan et al. (2022), high-contributing countries such as the United States demonstrate extensive research activity due to well-established STEM initiatives, robust funding for educational research, and access to advanced technologies and resources. Institutions in these countries often collaborate internationally, further amplifying their impact. For example, the United States has a long-standing emphasis on integrating robotics into educational curricula, supported by government grants and industry partnerships (Kayan-Fadlelmula et al., 2022). In contrast, according to Manuel's research (2022), low-contributing countries may face challenges such as limited funding for STEM education, insufficient infrastructure for robotics and technological experimentation, and a need for trained educators proficient in implementing STEM robotics. Additionally, varying educational priorities and policies can hinder the development of such specialized research areas. For example, despite being ranked third, Colombia's relatively lower output might stem from its emerging research capacity in the field and limited integration of STEM robotics into the national educational framework. These disparities underscore the importance of global collaboration and capacity-building efforts to enable less-represented countries to contribute more significantly to this evolving field. Investments in educator training, infrastructure, and international partnerships could help bridge the gap, ensuring more equitable advancements in STEM robotics in physics education worldwide (Manuel, 2022).

The contribution level to scientific research related to STEM robotics in physics education is shown in blue in Figure 3, which displays a distribution map of countries that have made substantial contributions. Countries with the highest contributions are marked in darker blue on the map. Countries highlighted in dark blue have a high rate of publication production in STEM robotics in physics education and intense research activity. This map illustrates global trends and opportunities for international collaboration in STEM-based physics education research, particularly in robotics technology, and shows the geographic distribution of scientific contributions. The map can serve as a visual aid to identify key research facilities and assess cross-border collaboration opportunities in this field.

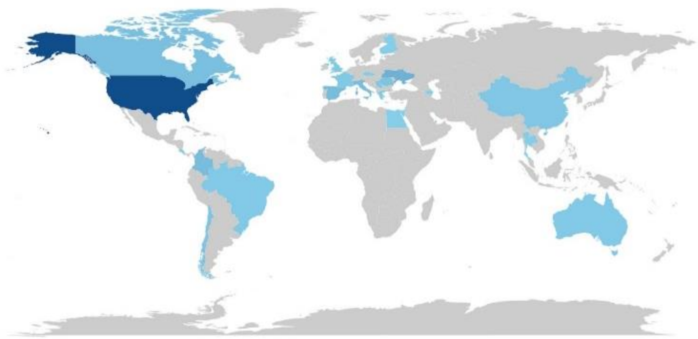

Figure 3 Countries' scientific production

The bibliometric analysis results identified 14 countries with the highest citation counts, making notable advancements in STEM robotics within physics education. Table 3 presents the top 10 countries ranked by citation counts. Europe is home to the most influential countries in STEM robotics in physics education research, especially Spain and Macedonia. Publications from Europe are also trending. However, other key countries include Greece, Brazil, Egypt, Ukraine, Australia, and Italy.

Table 3 Most cited countries

Rank	Country	Total Citations
1	Macedonia	612
2	Spain	49
3	Greece	35
4	Brazil	19
5	USA	13
6	Czech Republic	5
7	Egypt	4
8	Ukraine	3
9	Australia	2
10	Italy	2

Meanwhile, four countries not listed in the ranking order include Colombia, Canada, China, and Israel. There is significant global competition in STEM research, specifically in physics education robotics, as evidenced by the growing number of high-quality papers on this topic from countries worldwide. The discrepancy between Macedonia's position as the most cited country (Table 3) and its absence from the top 10 publishing countries (Table 2) can be attributed to several factors. First, while Macedonia produces fewer publications, the quality or impact of its research may be significantly higher, leading to more frequent citations. Macedonian studies may address niche or innovative topics, filling critical gaps in the field and garnering substantial attention from the global research community. Second, the relationship between publication frequency and citations is sometimes linear; countries with higher publication counts, such as the USA, may have their citations dispersed across numerous subfields, whereas Macedonia's focused contributions might attract concentrated recognition. Third, collaborative efforts may play a role—Macedonian research could involve partnerships with prominent international institutions, enhancing its visibility and credibility. Additionally, disseminating Macedonian research through highly regarded journals or global conferences might amplify its accessibility and influence. These factors underscore the importance of considering quantity and quality in evaluating scientific impact.

Researchers in related fields are drawn to frequently cited publications, as these works present high-quality material on the latest research topics in STEM robotics for physics education. A document's overall citation count reflects its value to the scientific community. Using R software and the bibliometric tool Biblioshiny, ten published papers were ranked by citation count based on available data. Table 4 lists the papers with the highest global citation counts. The top three journal articles garnered the highest citation counts during the specified period.

Table 4 Most global cited documents

Rank	Paper	Total Citation
1	"Virtual laboratories for education in science, technology, and engineering: A review", 2016, Computers and Education	612
2	"Robotic construction kits as computational manipulatives for learning in the STEM disciplines", 2016, Journal of Research on Technology in Education	98
3	"An Arduino investigation of simple harmonic motion", 2014, Physics Teacher	54
4	"Formation of design and research competencies in future teachers in the framework of STEAM education", 2020, International Journal of Emerging Technologies in Learning	48
5	"Application in augmented reality for learning mathematical functions: A study for the development of spatial intelligence in secondary education students", 2021, Mathematics	47
6	"Europa: A case study for teaching sensors, data acquisition and robotics via a ROS-based educational robot", 2020, Sensors (Switzerland)	35
7	"A review: Can robots reshape K-12 STEM education?", 2016, Proceedings of IEEE Workshop on Advanced Robotics and its Social Impacts, ARSO	33
8	"Technological structure for technology integration in the classroom, inspired by the maker culture", 2020, Journal of Information Technology Education: Research	19
9	"Situation of organizing STEM activities in Vietnamese Schools", 2019, Journal of Physics: Conference Series	19
10	"Activity plan template for supporting study science with robotics and programming", 2019, CEUR Workshop Proceedings	10

Based on the analysis in this study, Figure 4 presents a comprehensive word cloud that maps the structure of a bibliometric research network, integrating STEM, robotics, and physics education into three main clusters. The bibliometric grouping is displayed in clusters, with colours indicating each cluster. The proximity of terms on the map reflects the strength of the relationships between these themes. The closer the keywords are to each other, the more closely related the topics are. Larger text size in the mapping represents the intensity of issues or the frequency of topic appearances in the literature, indicating these topics are research focal points. This figure shows the frequency of specific keyword usage and helps identify major themes within integrated physics education, robotics, and STEM. Researchers can use this information to understand current research trends, explore emerging fields, and identify potential collaboration opportunities based on clusters formed by relationships among research topics. This mapping is a powerful tool for analyzing the direction and focus of research in STEM robotics for physics education.

Based on Scopus data, the word cloud for “STEM Robotics and Physics Education” highlights research trends, from the most frequently discussed topics to those less commonly explored. Prominent terms include engineering education, students, robotics, curricula, robot programming, education, educational robots, educational computing, teaching, professional aspects, STEM education, and robots. Research trends for 2024 indicate that learning media and STEM subjects are key priorities, while the impact of STEM on curriculum and creative thinking skill development receives comparatively less attention. Additionally, terms like STEM robotics, creative thinking, and high school students present research challenges, as all are linked to STEM robotics and physics education.

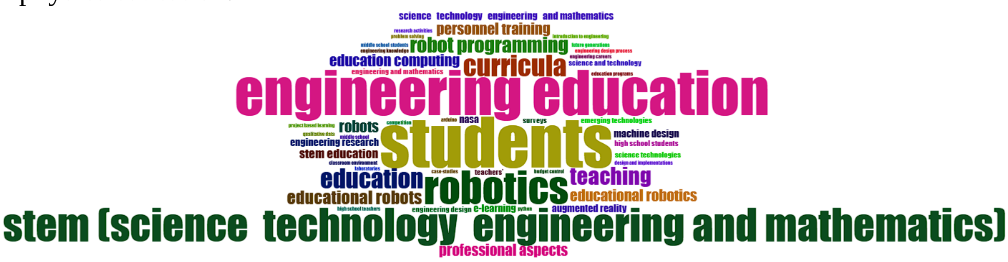

Figure 4 Wordcloud “STEM robotic and physics education” from data base Scopus

This field of study holds significant potential to develop more effective learning methods, particularly those involving technology such as robotics and creative thinking strategies within high school education (Ioannou & Makridou, 2018). These findings are further supported by related studies highlighting the impact of technology-driven approaches on student engagement and learning outcomes (Rashid & Asghar, 2016). For instance, research has shown that integrating robotics into physics education enhances students' understanding of abstract concepts, such as motion and force, through hands-on experimentation (Ferrarelli & Iocchi, 2021). Similarly, studies on creativity-based learning emphasize the importance of fostering innovative thinking by allowing students to design and build technological solutions to real-world problems (Behnamnia et al., 2020). Such evidence underscores the transformative potential of combining robotics and creative thinking in high school curricula, contributing to a more interactive and future-ready education system (Thomas, 2016).

Specific recommendations include enhancing creativity and physics understanding of concepts like motion, energy, and waves. For instance, robotics can be used to teach dynamics by programming robots to visualize trajectories or acceleration.

Additionally, learning about energy can be enriched through interactive experiments where robots demonstrate mechanical-to-electrical energy conversion. Meanwhile, wave concepts can be better understood through simulations and experiments with robot sensors to detect wave frequency and amplitude. Thus, integrating robotics technology and creative thinking strategies not only boosts students' interest in learning but also deepens their comprehension of abstract physic concepts. This is consistent with the findings reported in the study by Deyu Zhang, Jiawen Wang, and Yanting Jing (2024), which highlights that robotics not only enhances cognitive abilities and problem-solving skills but also fosters interdisciplinary learning and the practical application of knowledge (D. Zhang et al., 2024). Similarly, a study by Mwangi Peter Ngugi, Muriithi Christopher Maina, and Agufana Peace Byrne (2023), found that integrating robotics into learning significantly boosted students' interest and participation in physics. Furthermore, the study concluded that robotic activities enhanced students' conceptual understanding of physics concepts and positively shifted their attitudes toward the subject (Ngugi et al., 2023).

CONCLUSION

This study, which conducted a comprehensive literature review on STEM robotics and physics education, provides in-depth insights and essential recommendations for future researchers in the field. The bibliometric analysis results indicate an upward trend in research over recent years; the United States emerged as the primary contributor, followed by Ukraine and Colombia. Although this study thoroughly summarises global scientific achievements, certain limitations should be noted. The analysis relies solely on papers indexed in the Scopus database, potentially overlooking significant contributions from other sources such as WoS and PubMed. Furthermore, while the analysis employed the Biblioshiny tool based on Rstudio, other bibliometric applications like VOSviewer and CiteSpace could offer additional relevant perspectives.

Despite the limitations of the analysis program, the data scope collected between 2008 and October 2024 holds potential for future enhancement by incorporating data beyond October 2024. This study also indicates that less-researched topics, such as the impact of STEM on curricula and creative thinking skills, offer substantial opportunities for further investigation. Future research in this field could concentrate on implementing new technologies and more relevant learning strategies, in line with emerging trends in technology, such as robotics and creativity-based learning approaches. Several strategic measures are essential to enhance physics education through STEM-focused robotics integration. First, integrating robotics into the physics curriculum can create engaging learning experiences, such as using sensors in robotic systems to measure motion parameters like speed, acceleration, or energy changes. These activities can be designed as problem-based learning (PBL) projects to help students apply theoretical knowledge to real-world scenarios. Second, schools must be equipped with adequate infrastructure, including robotics labs and simulation tools like TinkerCAD or MATLAB, which support hands-on experimentation. Moreover, teacher capacity building is crucial, necessitating regular workshops and certifications to prepare educators to utilize robotics effectively in physics lessons. Collaboration with industries and higher education institutions can further enhance the learning process, offering students access to mentorship and authentic robotics projects aligned with physics principles. Encouraging creativity through robot design and gamified learning experiences also allows students to explore physics concepts innovatively. Finally, these initiatives should be supported by ongoing evaluation and feedback mechanisms to ensure the policies remain adaptive and impactful. By adopting these measures, physics education can be transformed into an engaging, technology-rich domain that equips students with the skills needed for the future.

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