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Exploring the frontiers: A comprehensive bibliometric analysis of robotics in science education

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Abstract

The present bibliometric review focuses on the 50 research articles indexed in Scopus Database in robotics science education (RSE) between the years 2012 and 2024. The analysis of publications shows the steady growth rates which is especially notable for 2021 thereby specifying the growing demand in the field. These are researchers from universities named The Aristotle University of Thessaloniki, The Kaunas University of Technology, and the NYU Tandon School of Engineering. The funding bodies that have greatly supported research work include National Science Foundation, CAS-TWAS Scholarships, and EPF Lausanne. The current study emphasizes that the topic of robotics in the learning process involves tendencies of the social sciences, engineering, computer science, psychology and other sciences. The United States leads in publication output, followed by countries like Greece, Turkey, and Lithuania, highlighting a global interest in leveraging robotics for educational innovation geographically. The location of the research studies points to the fact that, there is a need to reach out to various countries as a way of encouraging the use of robotics in the STEM curriculum. The following analysis offers insights into the current trends, risks, and opportunities of robotic innovations in education study and underlined the need for a continuous stakeholders' discourse on the best use of robots in enhancing science learning. This bibliometric analysis emphasizes the dynamic growth, disciplinary integration, and international collaboration characterizing RSE, underscoring the importance of ongoing dialogue and cooperation to realize its transformative potential in STEM education.

Keywords: robotics, science education, bibliometric analysis

INTRODUCTION

Educational robotics is an implementation in the education process which could improve student involvement, and their degree of understanding of scientific principles. Through involving students' requirements and their attitude in the design process, the platforms of educational robotics can build a place of inspiration that influences learners to take part in STEM courses more eagerly and achieve better skills (Kyprianou et al., 2023). Educational robots working in combination with hypermedia has helped students to acquire a lot of scientific concepts well (Ajlouni & Jaradat, 2021). Thus, the impressions received from observing educational robots and hypermedia could be used in the process of the students' studying of certain subjects, particularly the science subjects. By using robots in class, students will be more entertained hence learn more while hypermedia can extend a students' knowledge and opportunities to gain more knowledge.

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Contribution to the literature

- This paper aims to constitute a bibliographic review as the eligibility statement based on which the editorialization of the form can be developed, and the significant trends, authors, and journals in the field of robotics in science education are identified.
- Thus, identifying the gaps and promising fields in the given field of study, the systematic literature review helps scholars to orient to possible topics of further research.
- The result presents research connects and affiliations that represent the chord for improving academic engagement as well as cross-disciplinary research in robotics and science education fields.

These tools' combination can assist students in attaining a better understanding of science. Students, who learn through participation technologies, for example, robot educational programs, are involved in and interestedly attracted to the learning process with a positive outcome as the result (Mukh, 2021). Robotics teaching with instructional scaffolded approach illustrates efficacy in the development of science concepts and in-confidence with teaching robotics-based activities among pre-service teachers (Jaipal-Jamani, 2023). Different research studies that appeal to learning robotics and cooperative learning reveal that these strategies help in learning more and stimulate the interest of students.

Students can gain a lot of skills from robotics in science that will improve demonstration and the implementation of science concepts. Educational robotics might be a great example of an innovative learning tool in computational thinking (CT), coding and engineering, which we can use to implement into the STEM program (Drakatos & Stavridis, 2023). It provides students not only with new and fresh knowledge but also makes learning more exciting and stimulating, particularly for those who get bored during class or might not be fond of the conventional style of teaching. Besides, robotics might be a fantastic supplement to the education of students who have special educational needs to sustain their focus as well as favor their playful involvement in the learning process (Vouglanis, 2023). The advantage of incorporating robotics tasks in physical science, such as physics, is the creation for practical sessions and the engagement students in them (Joventino et al., 2023). In addition, robotics will develop students' skills of both methodological thinking and cognitive flexibility with regard to algorithms (Ngugi et al., 2023). Generally, including robots in science classroom is a key element in the students' learning environment, fueling curiosity, and introducing the students to the fourth industrial revolution.

Today, trends in robotics integration in science education are distinguished by the emphasis on STEM education at the levels of lower schools, by the use of robotics as learning tools, and by the popularity of robots during pre-university and higher education (Chiu et al., 2022; Darmawansah et al., 2023). Robotics is regarded as a useful approach to ensure a high level of multi-disciplinary competencies that allow learners to apply their knowledge in solving different issues (Chatzichristofis, 2023). Open software and open hardware that are accessible for the price that many people are able to afford also contribute to the demand of robots in colleges and universities as well as the new programming software attuned for people of different age groups and skills level (Chiu et al., 2022). According to the prognosis, there will be a massive increase in educational robotics market, which likely will facilitate independent funding for smaller companies for equipment prototyping and realizing their own projects (Hwang & Chu, 2023). This research focused mainly on various aspects of student and their teacher's view, they use of LEGO as a resource, and project-based learning (PBL) as their strategy, and how they can be assessed properly (Marulcu & Barnett, 2015). To sum up, the facilitation of robotic technology is treated synonymously as a major revolution, which can improve learning and teaching (de Souza et al., 2021).

This bibliometric analysis singles out the kind of study that falls under the rubric of domain science as well as robotics in teaching with particular emphasis toward the research presented. The published articles' review was done from the view of regions, funding sponsors and collaboration, keywords and subjects, the general trend of the publication, famous and influential authors, and the year-to-year distribution. Thus, analyzing these diverse features of the matter, this review provides a complex and syncretic vision of the current state of affordances to introduce robotics in science education (RSE) research.

LITERATURE REVIEW

Integrating literature review into robotics technology can also affect science courses positively aimed at improving the outcomes of education. Empirical evidence established that educational robotics may be used for producing enriching education by improving learning as well as teaching concepts in STEM and mathematics (Benitti, 2012; Wardat et al., 2023). Of course, while some studies have demonstrated the enhancement of performance in learning processes through the robotics (Belmonte et al., 2021) not all of them have, therefore, it is very vital to research more on this. Robotics, in recent times has shown its clear potential, as it helped in training surgeons of the future

and improved their perception of the outcome of learning (Vieyra & Edwards, 2021). As a result of the PBL approach, which integrates robotics, the efficiency of children's creative expressivity in science has grown together with their scientific thinking skills (Putri, 2022). Similarly, conferring the opportunity of using models such as problem-solving, project-based and inquiry-based learning ones can reinforce independent thinking and better student learning's results (Kapucu, 2023).

RSE makes innovations in in learning and teaching. Over the past years, education technology has settled in computer science, especially in RSE (James et al., 1997). In the same manner, many articles have been issued on multidisciplinary areas related to RSE. These are just a couple of fields where RSE is critically important (Ficker, 1997). According to these studies, it is crucial to develop as well as sharpen the science education graduate`s technical skills to respond to technology movements in the market (Dyer & Smith, 2021). The consideration of integrating digital media in education was also made by considering students improve media skills and self-regulation skills (Skamp, 2020). This integration has the capability to revamp the entire learning environment and improve the final quality of the education provided. To sum up, these experiments on the other hand show that it is possible for innovation to influence RSE in addition to become crucial factor in the process of the educational development.

Science education will be best conveyed if robotics is made a part of the learning process with a literature review as the conductor (Younis et al., 2023). It generates interest, enhances skills of learning, critical thinking and ultimate engagement in class activities. The merging of CT with adversarial thinking (AT) in robotics teaching is causing the transformation of educational methodologies and readying the teachers for critical thinking ability (Adnan et al., 2023). The especially prominent application of the information and communication technology-based discovery inquiry learning models to education of students is linked with an increase in comprehension of such concepts as affective skills, psychomotor skills as well as knowledge (Alake-Tuenter et al., 2012; Fannakhosrow et al., 2022; Khairullina et al., 2023). Also, PBL model is good for science education by improving its effectiveness and for example increasing student's imagination and science skills (Warr & West, 2020). These data imply the need for teacher's attention to literature review in robotics program and the whole purpose is to promote good learning and academic achievement in science education (Alneyadi et al., 2023).

Through a literature review, science education related to robotics will be improved substantially since the contributions of findings from various studies will be consolidated and a more thorough explanation of the present will be provided. Thus, they point out the knowledge gap, stress new trends and interests, and make the relevant future decision about the further research. As a case in point, Tselegkaridis and Sapounidis (2022) conducted a comprehensive review of literature to discuss the settings of primary STEM education research as well as the element of study design, sample characteristics, samples and tools used (Çetin & Demircan, 2018). On the other hand, Camargo et al. (2021) conducted a systematic review on this theme that aimed to identify the simulators with realistic characteristics for educational robotics featuring visualizing and physics engines. Literature review also assists to reveal the pitfalls in the ascriptive arguments and preemptions by the way of Gordon and Pasvenskiene's (2021) review on the moral and legal status of intelligent robots. To summarize, literature review is one of the chief aspects that steers the robotics education research and guides the teachers toward the evidence-based technique.

Students will get to grasp more through a literature review when studying robotics than in an ordinary science class. Studies show that the development of NLP in information systems may pass the access barrier of information and bring intelligent information-system services (Bramastia & Trisnawati, 2023). In addition, as a result of the systemic study in the field of CT and AT in robotics learning revealed that the integration of these skills can assess the robotics activity and make students participate in critical thinking (Younis et al., 2023). Next, the use of PBL in science education specially made students more creative and also enhanced their science skills in cognitive, affective and motor domains (Chiu et al., 2022). The fact that developing robotics can be a host vehicle for literature review of information shows how this learning tool has become more and more popular among science education.

METHOD

The Scopus Database was chosen for the bibliometric analysis of the overall topic of RSE due to the wide coverage of scientific resources of various research areas.

Data Collection

It was also easy to identify a number of keywords and phrases that were related to robotics in the field of teaching and learning of science. These included "robotics", "science education" and "bibliometric review". The choice of these keywords was made after a reference was made to the related literatures and advice from experts in the fields. We did an extensive search on Scopus using the selected keywords. The search was limited to articles from 2010-2024 to ensure that the trends being discussed are current. The search terms used were title, abstract and index to access relevant articles. My initial search produced 2,500 articles. We applied the following inclusion and exclusion criteria to achieve inclusion and exclusion criteria. Peer-reviewed

journal articles were considered only. We excluded all abstracts that were in other languages, conference proceedings, editorials, book reviews and papers that were not focused on robotics in the context of science education. This filtering process resulted in 50 articles from the original dataset.

Data Analysis

Bibliometric analysis was performed using a series of quantitative methods and tools to gain insights into the research situation in this field.

Descriptive Analysis

We did a descriptive analysis to determine the frequency of publications over time and the most prolific journals besides the geographical dispersion of research. This analysis comprised of the annual growth of publications, contribution of nations, and prominent institutions.

Co-Authorship Analysis

To visualize collaboration structures among researchers we performed a co-authorship network analysis. This entailed finding patterns on the links between authors based on the number of publications they co-authored. The research collaboration network was modeled using degree centrality, betweenness centrality and clustering coefficient to understand the structure and dynamics of the network.

Co-Occurrence Analysis

Keyword co-occurrence was used to identify distinct research themes. The main task of this analysis was to create a co-occurrence network based on the frequency of particular keywords and their relationships. For this purpose, the VOSviewer was used to visualize related keywords and identify prominent themes emerging in the literature.

Scopus was used to carry out data retrieval and preliminary dataset cleaning. Bibliometric networks, using the VOSviewer to construct and visualize co-authorship and co-occurrence networks. MS Excel was used to analyze and make graph the collected data set. We used these methodologies to address the research landscape of the RSE with a clear focus on its main directions, popular studies, and collaboration trends.

FINDINGS

Publication Trends

The number of articles published about RSE has been increasing faster than other areas. The number of publications grew from four in 2012 to six in 2014. Following falling by the end of 2016 into three, the number of publications increased to four in both 2017 and 2018. There was a drop from three in 2019, and in the following year only two were issued. Secondly a few top increasing publications happened in 2021 with ten robotics publications in science education. The end happened to be five publications in 2022 and three in 2023, respectively. In March 2024 the only publication out has thus far. This is the trend where a curve slopes upwards and hence reflects the increasing popularity of RSE (**Figure 1**).

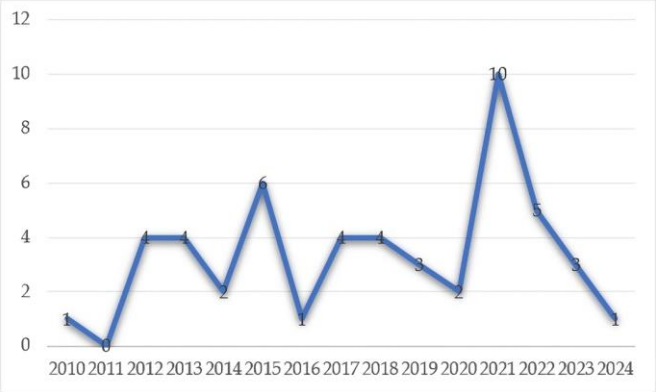

Figure 1. Number of publications over years (2010-2024) (Source: Authors' own elaboration)

Exploring the Contributions of Most Influential Authors

Authors Demetriadis, S., Phamduy, P., Porfiri, M., and Sapounidis, T. with publications such as Bespalova, K., Bruno, B., and Burbaite, R. followed by El-Hamamsy, L. are some of the most recognized experts in robotics as science educators who have made various contributions. As we review their contribution, we notice it is also a factor to the growth in publications as it was in recent years. A gradual growth in publication from 2012's number of 4 to 2015's I six was seen. Following a downward trend in 2016, the figures recovered in the two succeeding years, 2017 and 2018, and recorded as many as four issues in total. It decreased from three to three in 2019 and then an epoch of two births in 2020. Contrary to all the above mentioned, there was a rise in the number of publications in 2021 concerning RSE reaching to ten. Five publications in 2022 and three in 2023 then came next which was followed by 2023. There exists a single issue in 2024 at press time. The increase in this trend demonstrates an expanding curiosity in RSE which means there is now an interest in the subject (**Figure 2**). Besides that, this section explores collaboration patterns among authors utilizing techniques such as co-authorship network analysis between prolific authors and collaboration strength metrics (**Figure 3**). The given figure describes the co-authorship network visualization, which makes it possible to identify the relations between important authors in the given field. In these figures, each node is the author, and the relative size of the node is the productivity or the impact of the corresponding author.

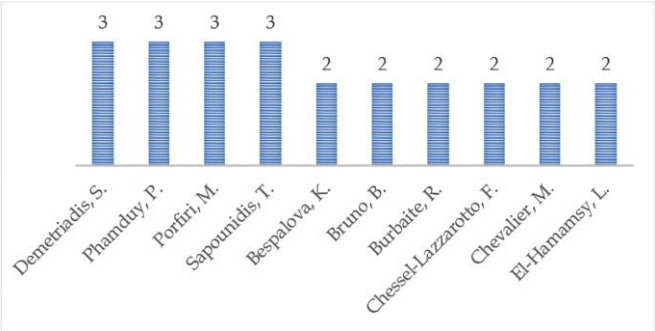

Figure 2. Number of articles per author names (Source: Authors' own elaboration)

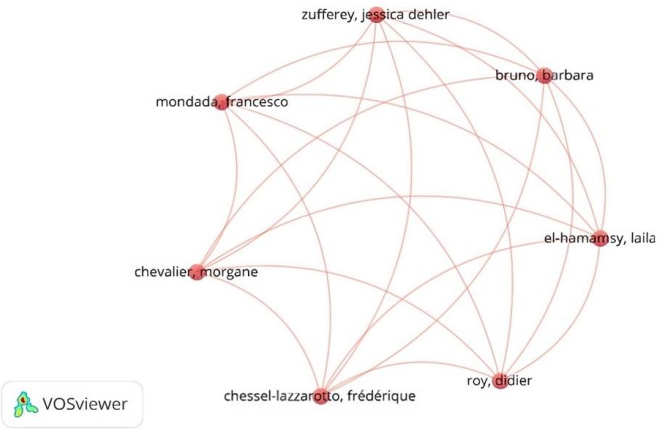

Figure 3. Co-authorship networks between prolific authors (Source: Authors' own elaboration)

The link between the nodes is the co-authorship relationship, suggesting that the authors have published the papers together. The thickness of the border depends on the number and intensity of the authors' activities together, which indicates the nature of their collaboration. Moreover, it highlights several groups of closely connected authors, collaborative groups or research teams. These clusters might be based on research focused on similar topics, specialties or the representatives of a single institution. The network also displays individual authors who function as major bridging nodes for the different clusters so as to enhance the flow of knowledge and cooperation between separate research communities. All in all, the co-authorship network analysis offers useful recommendations regarding the collaborative processes and the general context of a certain scientific discipline. It can be used for recognition of productive authors, the observation of the dynamics of the collaboration networks, as well as for understanding the relationships between different groups of researchers.

Year-wise Analysis of Articles in Different Science Education Journals

IEEE Transactions on Education, International Journal of Engineering Education, Advances in Intelligent Systems & Computing, Education & Information Technologies, Education Sciences, IEEE Robotics & Automation Magazine, Instructional Science, and Journal of Science Education & Technology were included in this study. In this list, three articles from IEEE Transactions on Education made the most impact by contributing five discussions on using RSE, which reveal the need of integrating robotics to science studies. Just behind these are International Journal of Engineering Education and Advances in Intelligent Systems & Computing, which both have 3 articles and 2 articles, respectively, the fact showing a shared agreement of how robotics have become a standard tool in improving engineering education. Education & Information Technologies and Education Sciences also occupy sounder scholar area concerning robotics with 2 articles each of them dedicates to studying on the role of robotics in education. And future issues will include two articles, both on the cross-domain aspect and necessity of robotics in education, for publication in the IEEE Robotics & Automation Magazine, Instructional Science, and Journal of Science Education & Technology. Thus, the bibliometric investigations, on the one hand, give an idea of the current framework about RSE and while on the other hand they shed light on the fact that there is still gap which needs further investigation and study. Thus, robotics in education that people are educators and researchers are trying to make the robots do that which was not possible. At the same time, robotics in education mingles with many challenges but they get the opportunities for innovations and to change the learning experience for future's students (**Figure 4**).

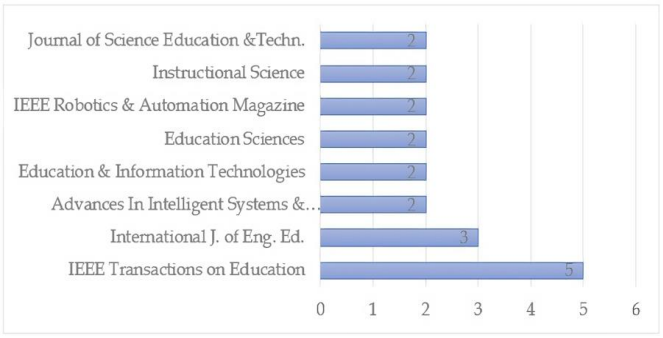

Figure 4. Number of articles by journal names (Source: Authors' own elaboration)

Distribution of Number of Articles published by Countries

Our bibliometric analysis would unfold the "robotic jigsaw puzzle" as it puts the elements in its proper places, starting with the global scale and down to nations' specificities. Out of all these, the United States steal the show, with 14 articles about industrialization in learning science, which brings to light the American dominance in the area of learning innovations and technologies. Closely behind Greece and Turkey with 5 articles each, it has become evident that these two

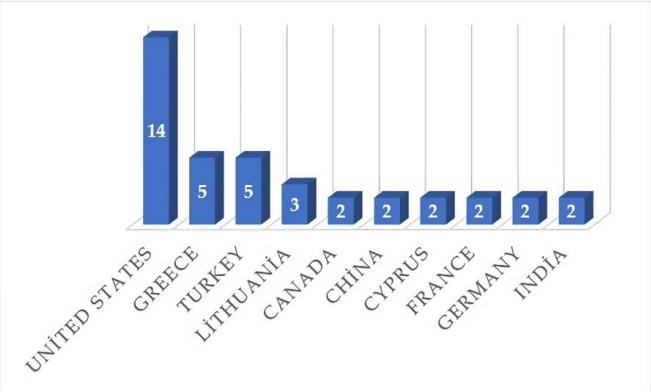

Figure 5. Number of articles published by countries (Source: Authors' own elaboration)

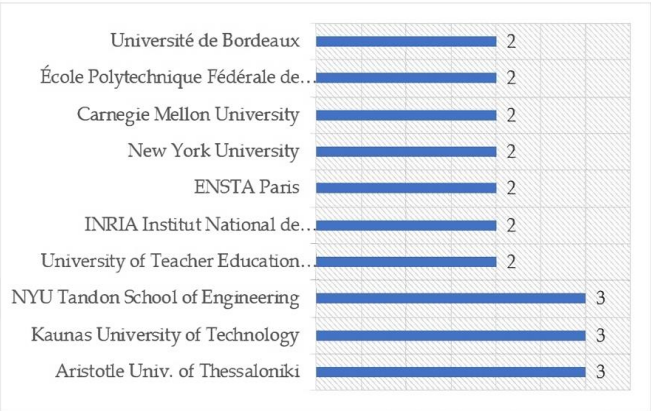

Figure 6. Number of articles by affiliations (Source: Authors' own elaboration)

countries are also adopting an attitude that is aimed at incorporating robotics in their educational systems. Also, Lithuania has three entries that reveal country's desire to increase education opportunities in this field of study. Like this, Canada, China, Cyprus, France, Germany, and India each provide 2 articles as well. This demonstrates global widespread support in studying robots as a tool which is adding quality to science education delivery (**Figure 5**). This information emphasizes how big of a countrywide trend robotics in education is, that intense collaboration of educators, policymakers, and expertise all around the world is highly needed to shape STEM education, worldwide.

Most Funding Sponsors and Affiliations

In the midst of the dynamic setting of science education of robotics, an in-depth analysis of links and funding sources sheds light to the tangled web of institutions and organizations that are guiding discoveries and innovations in the edges of the said field. Besides, the three key featured institutions with three articles shared each are, Aristotle University of Thessaloniki, Kaunas University of Technology, and NYU Tandon School of Engineering that showcased their unflagging commitment to push forward the robotics education (**Figure 6**). The funding ecosystem

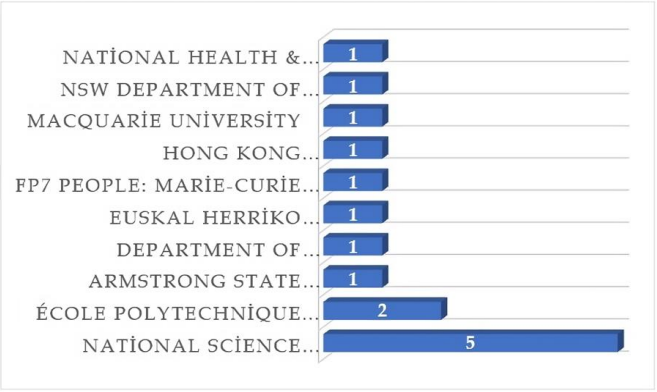

Figure 7. Number of articles by funding sponsors (Source: Authors' own elaboration)

also mirrors the diversity in which the National Science Foundation sponsors the highest domain field with 5 articles showing that this organization plays a great role in sponsoring in the R&D initiatives. Besides EPF Lausanne, Armstrong State University, and the Department of IIST, a Unit under Ministry of Science and Technology–Government of Australia, these are the sponsors from whom we can observe that there is a close to global cooperation on robotics education (**Figure 7**). Such data, however, is not only evidence of the encouraging joint efforts of academia and funding organizations but also shows the need of the funding to continue and grow beyond the present. It is the inspiration of the successful scientists of tomorrow within science and technology sector.

Distribution of Articles According to Keywords and Subject Areas

It is the RSE that essentially denotes interdisciplinary nature of the subject, bringing scholars from diverse areas together to contemplate and investigate impacts of robots on education. Through bibliometric approach, we get a chance to discover the wide-ranging disciplines, which paves way for better understanding of the multidimensional nature of educational applications in the field of robotics. Social sciences are the top spot holder with 33 articles that investigate socio-emotional aspects of teaching with robots, the educational processes, and the ubiquitous impact of robots on education. Following engineering by 24 titles the section reveals the technical qualifications and new product developments of educational robotics. Moreover, computer science becomes also an important member of the team with 21 articles focusing on such areas as programing, artificial intelligence and human-computer interaction implication in robotics education. Psychology is of special interest with 6 articles, as the cognitive and behavioral aspects of the learning from robotic, and thus, the interdisciplinary nature of education research is shown. Additionally, chemistry, decision sciences, health professions, and materials science each contribute 2 papers, thus the robotics not

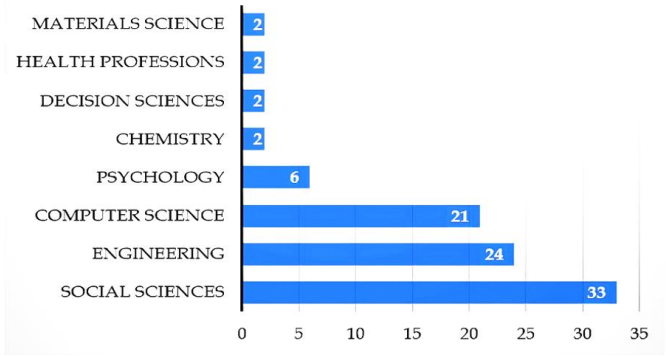

Figure 8. Distribution of articles according to subject areas (Source: Authors' own elaboration)

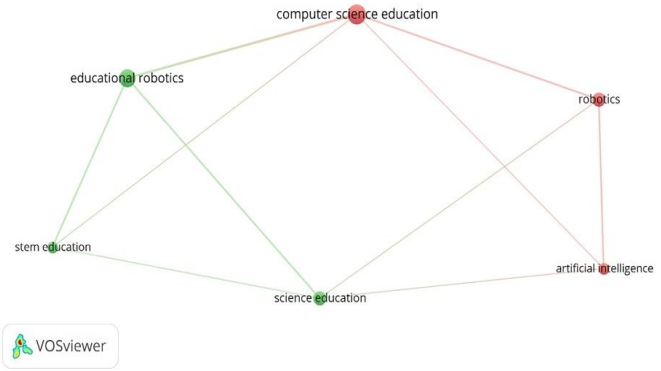

Figure 9. Keywords co-occurrence network (Source: Authors' own elaboration)

only adds to the subjects but also to the many ways of viewing them (**Figure 8**). It is not only this data that confirm the breadth of research in robotics in education but also create a call upon educators and scientists across disciplines to make collaborations, which will result in the innovations and the complex educational problems through robotics technology.

It was examined the frequency and distribution of keywords within the analyzed literature can provide insights into prevalent themes, emerging topics, and shifts in research focus over time. In addition, keyword co-occurrence network was shown in **Figure 9**. The keyword co-occurrence network shows the relationship between various keywords concerning RSE. The size of each node quantifies the use of the term and the thickness of the link between the two nodes shows the extent of shared use. It also features focal topics in RSE including educational robotics, artificial intelligence, stem education, and science education. These themes are connected as RSE is a very multifaceted subject, which is connected with other fields of knowledge. The network reveals how RSE is connected with the other domains, namely STEM education and science education domains. This underlines the need to coordinate RSE concepts and practice them with other strategies in STEM education.

DISCUSSION AND CONCLUSION

The examination of RSE is discussed as an active and developing area with the outlook of the shifts but overall increase of the number of publications during 2012-2024. The literature in the field started with four articles in the year 2012 and grew to six in 2014, but there was a decline to three articles in 2016; however, the number slightly improved to four in both 2017 and 2018. The number of publications decreased to three in 2019 and two in 2020; however, the year 2021 witnessed an encouraging increase of ten publications. Despite, the numbers got scaled down to five in 2022 as well as three in 2023, yet the single publication that was published by March 2024 depicts a continuous participation of the student. Other notable scholars which have contributed widely to the filed include Demetriadis, S., Phamduy, P., Porfiri, M., and Sapounidis, T., Bespalova, K., Bruno, B., and Burbaite, R., and El-Hamamsy, L. Specifically, such scholarly publications as IEEE Transactions on Education, the International Journal of Engineering Education, and Advances in Intelligent Systems & Computing play essential roles in the sharing of valuable knowledge and the identification of the need to include robotics in science and engineering curriculum.

The findings also stress the importance of this essay and the attempt at achieving research in robotics education, by pointing out the role that both collaboration and funding have to play. As for this regard, some of the institutions that have demonstrated a strong commitment to the development of the sector comprise the Aristotle University of Thessaloniki–Greece, Kaunas University of Technology–Lithuania and NYU Tandon School of Engineering–the United States, whose sample has contributed a lot in the current literature and the practice that are being used. An additional and valuable typification that helps to boost the offered typification of the key studies is the fact of existence of the significant funding sources, namely, the National Science Foundation which finances a number of the essential initiatives pointed in the present paper. In addition, CAS-TWAS Scholarships, EPF Lausane, Armstrong State University and the department of IIST under Ministry of Science and Technology, Government of Australia also show the fact that it has become a concern of completely international level which is evident from the attempts made by all the countries of the world to implement the benefits of Robotics in the systems of education al quality of different countries.

The future of science education is integrative and nowhere more manifest than in Robotics. Social sciences have been prominent in creating more contribution hence researchers have extended their focus on the socio-emotional aspect of teaching with robotics with particular concentration in the effects of the technologies on the teaching process as well as the social relations within the learning environment. This breakdown exemplifies engineering's great contribution in stating the technical developments and creations of educational robotics as well as computer science research in programming, artificial intelligence, and human-

computer interaction as the important domains for creating education robotic systems. The engagement of psychology in the leaning process highlights the cognitive and behavioral changes as facilitated by robots in learning and an insight into how the use of these tools can be enhanced to fit the learning process. New submissions from the areas of chemistry, decision sciences, health professions, and materials science can assert to the interdisciplinary inclination of robotics and provide insights on the applicability of robotics and automation in every existing field concerning education.

The distribution of research studies also shows that scholars from different parts of the world are aware of the role of robotics in enhancing the teaching and learning process. The United States is also mentioned to be the most populous regarding publication which speaks of its prominence in the leadership of educational change and technology. In this regard, the contingent from Greece, Turkey, Lithuania, Canada, China, Cyprus, France, Germany, and India that contributed massively to the success of this festival also responds positively to the utilization of robotics in improving science learning. This is so because the many issues and opportunities that robotics poses and offers in education can only be effectively faced and embraced through a cross national cooperation. This unity of purpose regarding further development of this field by promoting cooperation within and between countries as well as by common knowledge sharing and co-operation contributes to the growth of the more extensive range of improvements in the educational process.

Therefore, from this bibliometric analysis of the RSE in the period of 2012 to 2024 it can be argued that the field is characterized by growth as well as disciplinary and international integration. Therefore, it is possible to observe an increase in the number of published materials as well as the growth of research fields interested in this area. Scholars and organizations have an important place in developing the field's knowledge by receiving sufficient funds from many sources. Thus, the matters and ideas arising from social sciences, engineering, computer science, psychology, and more disciplines demonstrate how an extensive influence of robotics appears in the sphere of education. The further research in the direction put forward in this paper will remain viable due to the consistent dialogue between key stakeholders, including researchers, educators, policymakers, and funding bodies that will ensure the optimal use of robotics in the context of STEM education in the future. This analysis offers not only the state of affairs of robotics in education research at the present stage but also suggests further research directions highlighting the continuous nature of the efforts that should be provided to examine the potential and encounter the issues in this active area.

Research Gaps and Future Directions

Trends and gaps of robotics in science and education are reflected through bibliometric analysis. Current research points out the United States as one of the most developed countries in the field of robotics (Akgun & Atici, 2023; Fernandez et al., 2023), with the popular topics like CT, STEM, and programming (Abdullah et al., 2023). Still, stroke survivors are the population in need for robotic interactions in rehabilitation, an area that is, however not frequently addressed (Uivarosan et al., 2022). Moreover, although educational robotics and cyclone separator research reveal tendencies of growth, further cooperation between researchers is still insignificant in the latter area (Alex et al., 2022).

Although studies on the integration of robotics in science has gained a lot of research in recent years, few gaps that need to be filled as seen as follows. Where this body of literature could be considered lacking is the insufficiency in various bibliometric assessments to map out the research area in this multidisciplinary field. While previous research does offer useful information about the overall trends, patterns, and factors preferring RSE as a subfield, there is still little bibliometric research complemented to this specific area. Perhaps, the future studies should attempt to solve this problem by using latest bibliometric methods to conduct an objective and integrated analysis and visualization of the existing scholarly literature to find out major topics, authors, journals, and trends. Furthermore, there should be more studies with assessment of changes in research topics throughout the years, since such assessment would help to understand the further development of the field and indicated the topics to be researched further. Also, the assessment of the effects of robotics integration in teaching and learning, being familiar with the emerging theories and approaches as well as considering new and advanced technologies in science education might enhance the findings of the present study in identifying the potentials and actual effectiveness of using robotics in teaching science.

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REFERENCES

Abdullah, K. H., Roslan, M. F., Ishak, N. S., Ilias, M., & Dani, R. (2023). Unearthing hidden research

opportunities through bibliometric analysis: A review. *Asian Journal of Research in Education and Social Sciences, 5*(1), 251-262. https://doi.org/10.55057/ajress.2023.5.1.23

Adnan, N., Abdullah, S. N. H. S., Yusof, R. J. R., Zainal, N. F. A., Qamar, F., & Yadegaridehkordi, E. (2023). A systematic literature review in robotics experiential learning with computational and adversarial thinking. *IEEE Access, 11*, 44806-44827. https://doi.org/10.1109/access.2023.3249761

Ajlouni, A. O., & Jaradat, S. A. (2021). The effect of integrating an educational robot with hypermedia on students' acquisition of scientific concepts: The case of fifth-grade students. *International Journal of Interactive Mobile Technologies, 15*(11), Article 113. https://doi.org/10.3991/ijim.v15i11.18537

Akgun, M., & Atici, B. (2023). Bibliometric map of educational robotics studies. *International Journal of Technology in Education, 6*(2), 283-309. https://doi.org/10.46328/ijte.402

Alake-Tuenter, E., Biemans, H. J., Tobi, H., Wals, A. E., Oosterheert, I., & Mulder, M. (2012). Inquiry-based science education competencies of primary school teachers: A literature study and critical review of the American national science education standards. *International Journal of Science Education, 34*(17), 2609-2640. https://doi.org/10.1080/09500693.2012.669076

Alex, F. J., Tan, G., Agyeman, P. K., Ansah, P. O., Olayode, I. O., Fayzullayevich, J. V., & Liang, S. (2022). Bibliometric network analysis of trends in cyclone separator research: Research gaps and future direction. *Sustainability, 14*(22), Article 14753. https://doi.org/10.3390/su142214753

Alneyadi, S., Wardat, Y., Alshannag, Q., & Abu-Al-Aish, A. (2023). The effect of using smart e-learning app on the academic achievement of eighth-grade students. *EURASIA Journal of Mathematics Science and Technology Education, 19*(4), Article em2248. https://doi.org/10.29333/ejmste/13067

Belmonte, J. L., Robles, A. S., Moreno-Guerrero, A., & González, M. E. P. (2021). Robotics in education: A scientific mapping of the literature in Web of Science. *Electronics, 10*(3), Article 291. https://doi.org/10.3390/electronics10030291

Benitti, F. B. V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education, 58*(3), 978-988. https://doi.org/10.1016/j.compedu.2011.10.006

Bramastia, N., & Trisnawati, I. A. (2023). Literature review: Pembelajaran discovery inquiry berbasis tik [Literature review: Tik-based discovery inquiry learning]. *Kwangsan, 11*(1), Article 486. https://doi.org/10.31800/jtp.kw.v11n1.p486--496

Camargo, C., Gonçalves, J., Conde-González, M. Á., Rodríguez-Sedano, F. J., Costa, P., & García-Peñalvo, F. J. (2021). Systematic literature review of realistic simulators applied in educational robotics context. *Sensors, 21*(12), Article 4031. https://doi.org/10.3390/s21124031

Çetin, M., & Demircan, H. Ö. (2018). Empowering technology and engineering for STEM education through programming robots: A systematic literature review. *Early Child Development and Care, 190*(9), 1323-1335. https://doi.org/10.1080/03004430.2018.1534844

Chatzichristofis, S. A. (2023). Recent advances in educational robotics. *Electronics, 12*(4), Article 925. https://doi.org/10.3390/electronics12040925

Chiu, M., Hwang, G., & Tu, Y. (2022). Roles, applications, and research designs of robots in science education: A systematic review and bibliometric analysis of journal publications from 1996 to 2020. *Interactive Learning Environments*. https://doi.org/10.1080/10494820.2022.2129392

Darmawansah, D., Hwang, G., Chen, M. A., & Liang, J. (2023). Trends and research foci of robotics-based STEM education: A systematic review from diverse angles based on the technology-based learning model. *International Journal of STEM Education, 10*, Article 12. https://doi.org/10.1186/s40594-023-00400-3

de Souza, V. F., Mânica, E., Lavarda, R. L. H., & Da Rocha, T. R. (2021). Educational robotics in science teaching. *International Journal for Innovation Education and Research, 9*(9), 262-273. https://doi.org/10.31686/ijier.vol9.iss9.3337

Drakatos, N., & Stavridis, S. (2023). The perspective of STEM education through the usage of robotics. *World Journal of Advanced Research and Reviews, 18*(3), 901-913. https://doi.org/10.30574/wjarr.2023.18.3.1146

Dyer, J. S., & Smith, J. E. (2021). Innovations in the science and practice of decision analysis: The role of management science. *Management Science, 67*(9), 5364-5378. https://doi.org/10.1287/mnsc.2020.3652

Fannakhosrow, M., Nourabadi, S., Huy, D. T. N., Trung, N. D., & Tashtoush, M. A. (2022). A comparative study of information and communication technology (ICT)-based and conventional methods of instruction on learners' academic enthusiasm for L2 learning. *Education Research International*. https://doi.org/10.1155/2022/5478088

Fernandez, D., Dastane, O., Zaki, H. O., & Aman, A. (2023). Robotic process automation: Bibliometric reflection and future opportunities. *European Journal of Innovation Management, 27*(2), 692-712. https://doi.org/10.1108/ejim-10-2022-0570

Ficker, T. (1997). Innovations in science and technology education. *Physics Education, 32*(5), Article 023. https://doi.org/10.1088/0031-9120/32/5/023

Gordon, J. S., & Pasvenskiene, A. (2021). Human rights for robots? A literature review. *AI and Ethics, 1*(4),

579-591. https://doi.org/10.1007/s43681-021-00050-7

Hwang, G. J., & Chu, S. T. (2023). Roles and research issues of robots in education: A review of the 2011-2021 publications. *International Journal of Mobile Learning and Organisation, 17*(3), 426-442. https://doi.org/10.1504/ijmlo.2023.131879

Jaipal-Jamani, K. (2023). Preservice teachers' science learning and self-efficacy to teach with robotics-based activities: Investigating a scaffolded and a self-guided approach. *Frontiers in Education, 8*. https://doi.org/10.3389/feduc.2023.979709

James, E. J., Eijkelhof, H., Gaskell, J., Olson, J., Raizen, S. A., & Verdecho, M. (1997). Innovations in science, mathematics and technology education. *Journal of Curriculum Studies, 29*(4), 471-484. https://doi.org/10.1080/002202797184008

Joventino, C. F., De Abreu Alves E Silva, R., Pereira, J. H. M., Yabarrena, J. M. S. C., & Oliveira, A. (2023). A sim-to-real practical approach to teach robotics into K-12: A case study of simulators, educational and DIY robotics in competition-based learning. *Journal of Intelligent and Robotic Systems, 107*, Article 14. https://doi.org/10.1007/s10846-022-01790-2

Kapucu, M. S. (2023). Studies on robotic coding education in science education: A systematic literature review. *Journal of Education in Science, Environment and Health, 9,* 74-84. https://doi.org/10.55549/jeseh.1239093

Khairullina, E. R., Kosarenko, N. N., Chistyakov, A. A., Erkiada, G., Vaskova, L. B., & Kotina, V. P. (2023). A comprehensive bibliometric analysis of information and communication technologies in science education. *EURASIA Journal of Mathematics Science and Technology Education, 19*(10), Article em2343. https://doi.org/10.29333/ejmste/13652

Kyprianou, G., Καρούσου, A., Makris, N., Sarafis, I. T., Amanatiadis, A., & Chatzichristofis, S. A. (2023). Engaging learners in educational robotics: Uncovering students' expectations for an ideal robotic platform. *Electronics, 12*(13), Article 2865. https://doi.org/10.3390/electronics12132865

Marulcu, İ., & Barnett, M. (2015). Impact of an engineering design-based curriculum compared to an inquiry-based curriculum on fifth graders' content learning of simple machines. *Research in Science & Technological Education, 34*(1), 85-104. https://doi.org/10.1080/02635143.2015.1077327

Mukh, Y. N. A. (2021). Educational robotics as an effective use of technology to enhance learning. *International Journal of Online and Biomedical Engineering, 17*(06), Article 122. https://doi.org/10.3991/ijoe.v17i06.22401

Ngugi, M. P., Maina, M. C., & Byrne, A. P. (2023). The impact of robotic activities on secondary school students' interest in physics in Kenya. *International Journal of Computer Applications Technology and Research, 12*(01), 53-59. https://doi.org/10.7753/ijcatr1201.1008

Putri, I. P., & Sari, M. P. (2022). Literature review: The effect of project-based learning models on student learning outcomes in science learning. *Universe, 3*(2), 168-175. https://doi.org/10.24036/universe.v3i2.213

Skamp, K. R. (2020). Research in science education (RISE): A review (and story) of research in RISE articles (1994-2018). *Research in Science Education, 52*(1), 205-237. https://doi.org/10.1007/s11165-020-09934-w

Tselegkaridis, S., & Sapounidis, T. (2022). Exploring the features of educational robotics and STEM research in primary education: A systematic literature review. *Education Sciences, 12*(5), Article 305. https://doi.org/10.3390/educsci12050305

Uivarosan, D., Bungau, S. G., Nistor-Cseppento, C. D., Negru, P. A., Bungau, A. F., Sabau, A. M., Tit, D. M., Uivaraseanu, B., & Radu, A. (2022). Application of robotic recovery techniques to stroke survivors–Bibliometric analysis. *Journal of Personalized Medicine, 12*(12), Article 2066. https://doi.org/10.3390/jpm12122066

Vieyra, R. E., & Edwards, S. (2021). Peace in science education: A literature review. *Journal of Peace Education, 18*(2), 121-142. https://doi.org/10.1080/17400201.2021.1919866

Vouglanis, T. (2023). The use of robotics in the education of students with special educational needs. *World Journal of Advanced Research and Reviews, 19*(1), 464-471. https://doi.org/10.30574/wjarr.2023.19.1.1331

Wardat, Y., Tashtoush, M. A., AlAli, R., & Jarrah, A. M. (2023). ChatGPT: A revolutionary tool for teaching and learning mathematics. *EURASIA Journal of Mathematics Science and Technology Education, 19*(7), Article em2286. https://doi.org/10.29333/ejmste/13272

Warr, M., & West, R. E. (2020). Bridging academic disciplines with interdisciplinary project-based learning. *Interdisciplinary Journal of Problem-based Learning, 14*(1). https://doi.org/10.14434/ijpbl.v14i1.28590

Younis, H. A., Ruhaiyem, N. I. R., Ghaban, W., Gazem, N. A., & Nasser, M. (2023). A systematic literature review on the applications of robots and natural language processing in education. *Electronics, 12*(13), Article 2864. https://doi.org/10.3390/electronics12132864