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Scientific Output and Thematic Development of Solar Powered Toy and Science Kit for Elementary School Students: A Comprehensive Bibliometric Review

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Abstract

Objective: This study aims to provide a comprehensive bibliometric review of research on solar-powered toys and science kits for elementary school students by mapping scientific productivity, thematic structures, and developmental trends in this emerging field. **Novelty:** This study offers a systematic bibliometric mapping that highlights the multidisciplinary integration of renewable energy education, STEM innovation, and hands-on learning tools specifically designed for young learners. **Methods:** A bibliometric analysis was conducted to examine publication trends, influential authors, leading countries, major sources, and keyword co-occurrence networks to identify dominant themes and research evolution patterns. **Results:** The findings reveal a steady increase in research output, reflecting growing global interest in renewable energy education for children. Three dominant themes were identified: STEM-based educational innovation, technological device development, and experimental research domains. Thematic evolution analysis indicates a shift toward experiential and hands-on learning approaches using solar-powered devices. **Conclusions:** This bibliometric review concludes that research on solar-powered toys and science kits for elementary school students is steadily growing, centered on STEM innovation, technological development, and experimental applications.

Keywords: Solar Powered Toy, Science Kit for Students, Bibliometric Analysis, Renewable Energy Education, STEM Learning.

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INTRODUCTION

The acceleration of the global transition to clean energy places energy literacy as an important competency of the 21st century. International efforts to achieve the Sustainable Development Goals (SDGs), especially SDG 4 (Quality Education) and SDG 7 (Affordable and Clean Energy) (Ashida, 2023; Aslam et al., 2024; Küfeoğlu, 2022), emphasizing the need for education that instills an understanding of renewable energy and sustainability from an early age (Agung Pambudi et al., 2024; Hoque et al., 2022). Modern science education is thus not only oriented towards the mastery of concepts, but also on the development of ecological awareness and critical thinking skills towards energy and environmental issues. In line with that, various studies emphasize the importance of STEM education that integrates the social, cultural, political, and ethical dimensions of energy issues so that students are able to understand technology while assessing its socio-ecological implications more comprehensively (Rahmawati et al., 2022; Wahono et al., 2021).

Although this need is increasingly urgent, the implementation of energy education in the scope of STEM still faces structural and pedagogical challenges. Limited facilities, teacher capacity, and suboptimal policy support cause STEM practices in schools to be unable to provide a contextual learning experience (Arlinwibowo, 2022). In addition, representation of aspects of energy externalities—such as environmental impacts, social burdens, and emissions—is still minimal in the curriculum, hindering students' understanding of the complexity of energy systems (Šedlbauer, 2024). This is reinforced by the findings (Kalluri, 2023) which confirms that energy behavior is formed from an early age so multidisciplinary climate education is needed to support the formation of "energy citizenship." Similar challenges also arise in the global context, where energy learning requires an interdisciplinary approach capable of addressing policy trade-offs and conflicts between stakeholders, as demonstrated by the effectiveness of game-based learning approaches in understanding complex energy systems (Suzuki, 2021).

The gap between the needs and the reality of implementation shows the need for learning media that is able to bridge theoretical concepts with students' concrete experiences. At the elementary school level, energy literacy in textbooks is still limited so students have not gained a contextual picture of renewable energy (Castañeda-Garza & Valerio-Ureña, 2023; Gladwin & Ellis, 2023; Twidell, 2021). Even at the higher education level, the energy curriculum still tends to be technical and lacks to integrate human perspectives and broader socio-technical issues (DeWaters, 2021; Hoople et al., 2020). This condition confirms the urgency of educational media that not only explains the principles of energy, but is also able to foster a holistic understanding of sustainability. In this context, solar-based educational devices such as solar toys and science kits offer promising innovative solutions. This media allows learners to explore the working principles of solar cells, simple electrical circuits, and energy conversion through engaging and meaningful hands-on activities (C.-S. Chen & Lin, 2021; Fu et al., 2025). Keremane (2021) emphasizing that solar technology in educational media can increase student's awareness of clean energy while fostering creativity in solving energy problems. This approach is in line with the principles of STEM learning and inquiry-based learning that emphasizes exploration, experimentation, and hands-on problem-solving.

The effectiveness of hands-on media has also been widely confirmed by previous research. Okundaye (2022) found that science kits based on the M2 model can improve students self-efficacy, motivation, and participation in STEM, especially for underserved groups. Technology-based activities such as robotics have been shown to increase interest and positive attitudes towards STEM (Dökme, 2025). In fact, the use of electronic construction kits can connect students' personal experiences with engineering practices through a meaningful design process (Hurtado, 2023). These findings confirm that hands-on devices have strong potential to bridge theory and real experience, including in the context of renewable energy learning. However, the use of solar toys and science kits as educational media still faces challenges. Operating a device often demands a basic understanding of electrical circuits that neither students nor teachers always have. Devices can also lose educational value if they are treated only as toys without proper pedagogical guidance. Studies show that solar cell teaching kits can improve energy understanding and learning motivation (Altassan, 2023; Chien et al., 2021) while solar-powered car kits effectively support project-based learning and STEM skills (Hutner et al., 2022; Mumba et al., 2024; Pleasants et al., 2021) . However, there has been no study that specifically maps the research landscape related to solar-powered toys and science kits for students as a scientific domain. This knowledge gap is an important research gap because solar-powered educational devices are at the intersection between renewable energy technology, STEM pedagogy, and learning media innovation. Therefore, this study offers novelty through the preparation of a comprehensive bibliometric map that describes publication trends, patterns of collaboration between authors and countries, and the thematic structure of research in the last two decades. This analysis not only fills the literature gap, but also provides a foundation for the development of more relevant and sustainability-oriented learning tools.

METHODS

1. Research Design

This study uses a bibliometric approach to analyze scientific and thematic developments in the field of *solar powered toys and science kits for students*. This approach is used to assess the productivity of publications, map the intellectual structure of the field of study, and identify research gaps through quantitative and visual analysis of the metadata of scientific publications.

2. Data Sources and Search Procedures

Bibliographic data is collected from [name database: Scopus / Web of Science / both], as this database has a wide range of international publications and provides metadata compatible with bibliometric analysis. The search strategy is compiled using a combination of relevant keywords, such as: 1) "solar powered toy"; 2) "solar toy"; 3) "science kit"; (4) "educational kit"; 5) "STEM kit" and 6) "solar energy for students". Boolean operators (AND, OR) are used to ensure comprehensive search coverage. The search time range includes the entire year of the available publication to the year the analysis was performed. Downloaded documents include journal articles, conference proceedings, book chapters, and other scientific documents that meet the relevance criteria.

3. Inclusion and Exclusion Criteria

Inclusion criteria: a) Publications that directly address *solar powered toys*, *educational solar kits*, *STEM/Science kits for Elementary School Students*, or solar-based educational devices for Elementary School Students; 2) Documents in English (or languages that can be processed by bibliometric software); 3) Metadata is available in full (title, abstract, keyword, author, affiliate, journal source).

Exclusion criteria: 1) Publications that only discuss solar energy but are not related to use for Elementary School Students's toys or educational kits; 2) Documents that do not provide complete metadata.

4. Data Processing

All metadata obtained is exported in CSV or BibTeX format and then processed using two main software: 1) Biblioshiny for R (Bibliometrix Package) – for descriptive analysis, keyword analysis, publication trends, and thematic mapping; 2) VOSviewer – for visualization of co-occurrence maps and concept connectivity networks. Prior to analysis, metadata is cleaned through a process of deduplication, standardization of keywords (merging synonyms), and normalization of technical terms to avoid differences in meaning due to variation in writing.

5. Stages of Bibliometric Analysis

The analysis method was adjusted to three research objectives, as follows.

(1) Scientific Productivity Analysis

To answer the first objective, the analysis was directed at the quantity and impact of publications. The indicators used include:

a) Annual Scientific Production
   To identify the trend of the development of the number of publications per year.
b) Most Relevant Sources
   To analyze the most productive journals or proceedings on this topic.
c) Most Relevant Affiliations
   To see the institution or institution most actively produces research.
d) Tabel 1. Sources' Local Impact
   To evaluate the local influence of each source based on internal citations.
e) Tabel 2. Most Global Cited Documents
   To identify the documents with the highest global impact.
   These five data illustrate a map of productivity and contributions of scientists, institutions, and journals in the field of *solar powered toys* and *science kits for students*.

(2) Mapping of Thematic Development and Evolution of Concepts

For the second purpose, the analysis is focused on the intellectual structure and dynamics of concepts. The types of data used include:

a) Most Frequent Words
   Describe the dominant terms in publications.
b) WordCloudVisualization of the intensity of keyword occurrences.
c) Words' Frequency Over Time
   To assess the progress or decline of topic focus over time.

d) Co-occurrence Network
To see the relationships between concepts and theme groupings.
e) Thematic Map
To map the core themes (motor themes), the theme grows, and the themes are marginalized.
This analysis allows the identification of thematic evolutions, core themes of research, as well as patterns of relationships between concepts.

(3) Identification of Research Gaps
The determination of the research gap was carried out through the synthesis of the results of the analysis from the previous two groups. The indicators synthesized include: 1) Annual Scientific Production; 2) Most Frequent Words; 3) Words' Frequency Over Time; 4) Co-occurrence Network; 5) Thematic Map; 6) Most Global Cited Documents

Research gaps are determined based on the identification of topics that: 1) appear infrequently or have low frequency; 2) not developing on the thematic map (niche or emerging themes); 3) not strongly connected in the concept network; 4) does not have the support of high-impact publications; and 4) the intensity of his research has stopped in recent years.

RESULTS AND DISCUSSION

1. Analysis of number of publication

The annual scientific productivity analysis provides an overview of the dynamics of research developments related to solar powered toys and science kits for students over the past nearly three decades. The Annual Scientific Production graph in Figure 1 shows that the number of publications in this field tends to fluctuate and is not sustainable, reflecting that this topic is still a niche area with relatively limited research attention.

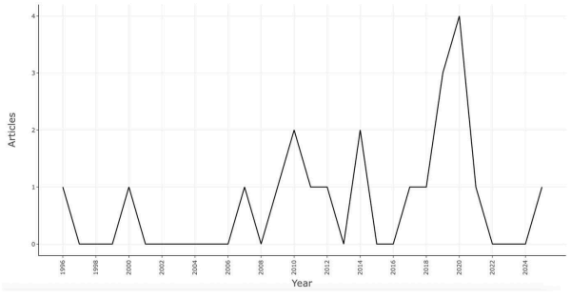

Figure 1. Annual Scientific Production

Based on the chart, the first publication was recorded in the late 1990s, then experienced a fairly sharp up-and-down pattern with a pause without publication in a few years. A significant spike occurred in the 2018–2020 period, with a peak in 2020 as many as four publications, showing the increasing attention to renewable energy technology in the context of science education for Elementary School Students in that period. After 2021, the number of publications declined again and remained relatively stable at 0–1 articles per year until 2024.

This pattern indicates that although the interest of researchers has increased, this field still has broad exploration potential and opportunities for further research development, especially related to the design, pedagogical effectiveness, and innovation of solar-based educational devices.

2. Most Relevant Sourcesd

The Most Relevant Sources analysis aims to identify the sources of publications that most often publish research related to *solar powered toys* and *science kits for students*. Understanding the productivity of publication sources is important to assess the extent to which a journal, proceeding, or series of publications contributes to the development of knowledge in this field. In addition, this information helps identify the most relevant scientific outlets for researchers who want to publish studies related to solar energy technology and student's educational devices.

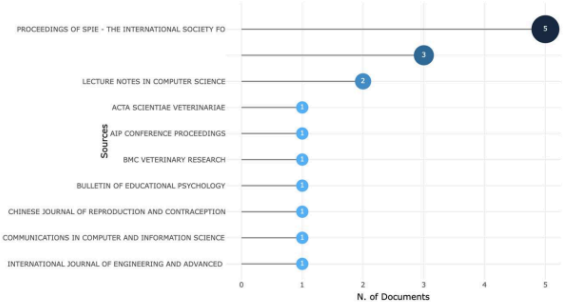

Figure 2. Most Relevant Sources

The results of the analysis show that *the Proceedings of SPIE – The International Society for Optics and Photonics* is the most prolific source with a total of five papers addressing this topic, signaling the significant role of optical technology-based conferences in facilitating the publication of solar energy research for educational needs. This was followed by *the Lecture Notes in Computer Science (LNCS)* with three publications, which indicated that the development of *science kits* and *solar toys* was also widely discussed in the context of computing, educational technology, and digital-based device innovation. Several other sources such as *Acta Scientiae Veterinariae*, *AIP Conference Proceedings*, and *BMC Veterinary Research* each contributed one publication, which showed that research related to solar-powered devices for Elementary School Students has a multidisciplinary scope and is not limited to the field of engineering or education alone.

The diversity of sources of this publication is in line with a number of studies Jabbour Al Maalouf et al. (2024) emphasized that solar energy-based learning tools are effective in improving energy literacy and understanding of science concepts in students. These findings are reinforced by Goodall et al. (2021), which indicates that the integration *solar-powered educational kits* encourage active engagement and increased student learning motivation in STEM subjects. In addition, the study Friman et al. (2018) emphasizing that the use of

renewable energy technology in the form of toys or hands-on devices is able to develop ecological awareness from an early age.

3. Sources' Local Impact

The *Sources' Local Impact analysis* was conducted to understand the contribution and influence of each publication source in the scope of research on *solar powered toys* and *science kits for students*. Indicators such as h-index, g-index, m-index, as well as total citations (TC) and number of publications (NP) are used to assess the quality and productivity of sources. Through this analysis, it can be determined which sources are not only productive, but also have the strongest academic influence based on the number of local citations in the analyzed database. This evaluation is important to identify publication outlets that are the main references in this field of research.

Tabel 1. Sources' Local Impact

Source	h_index	g_index	m_index	TC	For example	PY_start
Acta Scientiae Veterinariae	1	1	0,125	2	1	2018
Bmc Veterinary Research	1	1	0,167	8	1	2020
Bulletin of Educational Psychology	1	1	0,167	6	1	2020
Communications In Computer And Information Science	1	1	0,067	4	1	2011
International Journal of Engineering And Advanced Technology	1	1	0,143	1	1	2019
Lecture Notes In Computer Science	1	2	0,143	5	2	2019
Lecture Notes In Networks And Systems	1	1	0,2	2	1	2021
Proceedings of Spie - The International Society For Optical Engineering	1	1	0,038	3	5	2000
Science Communication	1	1	0,033	4	1	1996
Studies In Health Technology And Informatics	1	1	0,071	4	1	2012

The results of the analysis show that almost all sources have an h-index = 1, indicating that each publication outlet contributes at least one article that obtains one local citation. However, there are variations in other indicators that provide an idea of differences in influence between sources. *Proceedings of SPIE – The International Society for Optical Engineering* has NP = 5 and TC = 3, indicating the highest productivity, although the impact of the citation is relatively low compared to the number of publications. Meanwhile, *BMC Veterinary Research* and *the Bulletin of Educational Psychology* show the highest m-index (0.167), which indicates the consistency of citations in a shorter time since the year of its first publication.

Some sources such as *Lecture Notes in Networks and Systems* It has an m-index of 0.2, indicating that despite the small number of publications (NP = 2), the resulting articles have a rapid development of citations. This pattern is in line with the findings Christou et al. (2024), which states that the topic of renewable energy-based learning technology innovation tends to gain citations faster at an early stage because it is relevant to the global agenda of education and sustainability. Moreover Maskan & Altan (2016) It shows that solar energy-based learning tools are often published in multidisciplinary outlets, so the dissemination of their citations is extensive but not concentrated in one core journal. These findings are reinforced by research Montalvan Castilla (2025) which states that *STEM kits* and solar-powered props tend to be spread across fields ranging from engineering, education, to health which causes significant variations in their pace and citation patterns. The diversity of these impact patterns indicates that the research is related to *solar-powered toys* and *science kits for students* published in various outlets with varying characteristics and levels of influence. In general, these results show that there are no journals or proceedings that have been predominantly the center of scientific development on this topic, thus opening up opportunities for more focused publications in the future.

4. Most Relevant Affiliations

The *Most Relevant Affiliations* analysis aims to identify the institutions or institutions that are most actively contributing to research related to *solar powered toys* and *science kits for students*. This information is important to understand the research centers that are driving the development of this field, as well as showing how the distribution of research is spread globally.

Figure 3. Most Relevant Affiliations

The results of the analysis show that Shanghai Jiao Tong University is the most productive institution with a total of eight publications, indicating the university's strong involvement in technological innovation and research related to renewable energy-based devices. These findings are consistent with studies Han dan Appelbaum (2018), which mentions that universities in China, including Shanghai Jiao Tong University, are leading global

publications on solar energy technology and its applications for STEM education. It was followed by Tongji Medical College of Huazhong University of Science and Technology with six publications, showing that research on solar-powered educational devices has also attracted the attention of institutions based on medical science and applied technology. This is in line with the findings Christensen et al. (2016) which confirms that health institutions are now increasingly involved in the development of *science kit* and learning tools for Elementary School Students's needs because of their relevance to science literacy and public health.

Other institutions such as the Universidade de São Paulo (4 articles), the Reproductive Medical Center (3 articles), and St. Jude Student's Research Hospital (3 articles) show a diversity of research contexts, ranging from engineering, education, health, to the development of devices for Elementary School Students's needs. Study Singh (2022) demonstrate that universities in Latin America, including USP, are active in developing *low-cost science kits* which utilizes renewable energy to improve science literacy in elementary schools. Meanwhile, several affiliates such as the Faculty of Informatics, MIT School of Engineering, and Universität Zürich each contributed two articles, demonstrating multidisciplinary involvement from the fields of informatics, engineering, and biomedicine. This is reinforced by research Rushdi et al. (2024) which found that advanced technological institutions such as MIT have a central role in the development of computational and solar energy-based educational devices for hands-on learning.

Overall, this pattern suggests that research on *solar-powered toy* and *science kit for students* is cross-disciplinary and is carried out by institutions from various countries. There is no single dominant geographic cluster, but rather a widespread contribution. This confirms that this topic has global relevance and the potential for the development of more intensive international collaboration in the future, as also emphasized by the Almasri et al. (2024) that research on solar energy device innovation for learning tends to develop more rapidly when it involves cooperation between institutions and between countries.

5. Most Global Cited Documents

The *Most Global Cited Documents* analysis provides an overview of the most impactful articles in the literature on the topic of *solar-powered toys* and *science kits for students*. This list shows that some papers have a fairly high global citation rate, even though the fields of study are diverse and do not always come from core journals in engineering or science education. This pattern indicates that the influence of research related to solar-powered educational devices does not depend on one discipline alone, but is spread in the realms of health, computer science, education, and information technology.

Table 2. Most Global Cited Documents

Paper	TWO	Total Citations	TC per Year	Normalized TC
Czopowicz, 2020, Bmc Vet Res	https://doi.org/10.1186/s12917-020-02575-1	8	1,33	2,29
Chen, 2020, Bull Educ Psychol	https://doi.org/10.6251/BEP.202012_52(2).0006	6	1,00	1,71
Abonyi-Tóth, 2019, Lect Notes Comput Sci	https://doi.org/10.1007/978-3-030-33759-9_15	5	0,71	1,50
Voštinár, 2019, Proc Int Conf Inf Digit Technol, Idt	https://doi.org/10.1109/DT.2019.8813310	4	0,57	1,20
Van Kirk Villalobos, 2012, Stud Health Technol Informatics	https://doi.org/10.3233/978-1-61499-088-8-111	4	0,29	1,00
Assaf, 2011, Commun Comput Info Sci	https://doi.org/10.1007/978-3-642-21975-7_4	4	0,27	1,00
Messmore, 1996, Sci Commun	https://doi.org/10.1177/1075547096017004003	4	0,13	1,00
Cantarini, 2021, Lect Notes Networks Syst	https://doi.org/10.1007/978-3-030-77040-2_43	2	0,40	1,00
Carrillo Gaeta, 2018, Acta Sci Vet	https://doi.org/10.22456/1679-9216.81174	2	0,25	1,00
Pompea, 2010, Proc Spie Int Soc Opt Eng	https://doi.org/10.1117/12.862638	2	0,13	2,00

The results of the analysis show that the most cited articles globally are works of art Czopowicz et al. (2020) published in *BMC Veterinary Research*, with a total of eight citations and a TC per year of 1.33. Although it does not directly address solar-powered educational devices, this article is included in the citation network because of its approach to analytical instrument technology that is relevant to the development of science for Elementary School Students. Another publication that also has a high citation impact is Chen (2020), with six global citations and a TC per year of 1.00, showing a significant influence on the educational literature, especially in the development of learning tools and educational media.

Article Abonyi-Tóth & Pluhár (2019) signifies recognition of the integration of computing technology in the development of *science kit* or interactive science devices. In addition, some documents with four global citations, such as the (Assaf & Pfeifer, 2011; Van Kirk Villalobos Aubrey et al., 2012; Voštinár & Klimová, 2019), showing that literary contributions come from various disciplines. Level *normalized TC* that varied, ranging from 1.0 to 2.29, indicating a difference in long-term relevance between the articles.

Overall, these findings confirm that research related to solar-powered educational devices is supported by citations from a wide range of fields, and is not limited to engineering or educational domains alone. This shows that the topic has a strong multidisciplinary

character, while also showing opportunities to expand the reference network and cross-field collaboration on future research.

6. Most Frequent Words

The Most Frequent Words analysis provides an initial overview of the main themes in the corpus of documents analyzed. The following is a visualization of the Most Frewuaent Word in Figure 4

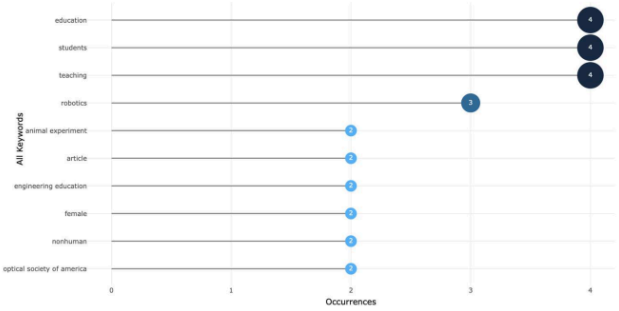

Figure 4. Most Frequent Words

The results of the word frequency visualization show that the three terms with the highest occurrence *education*, *students* and *teaching* reflects the dominance of themes related to the learning process and the educational context in the document corpus. Presence of words *robotics* and *engineering education* indicates that some of the literature highlights the integration of technology, particularly robotics and engineering education, as part of the development of modern learning. Meanwhile, the appearance of words such as *animal experiment*, *nonhuman*and *female* hints at the existence of research involving specific methodological, ethical, or population analysis aspects, indicating the diversity of focus in the analyzed document. This variation in frequency shows that the thematic structure of the literature is multidisciplinary, not only centered on general education, but also includes technological issues and experimental research. These findings are in line with the bibliometric literature that emphasizes that word frequency analysis can comprehensively uncover topical patterns and directions of development (Jin et al., 2022). Overall, these results confirm that the themes of education and technology play a significant role in shaping the research landscape, as well as opening up opportunities for cross-disciplinary exploration and collaboration in future studies.

7. WordCloud

The WordCloud visualization in Figure X provides an overview of the word frequency distribution in the corpus of documents being analyzed. The size of each word represents its degree of occurrence, making it easy to identify the most dominant terms without the need for direct numerical calculations.

Figure 5. WordCloud

WordCloud shows that the term *education*, *teaching*, *students* and *robotics* It emerged as the most prominent word, indicating that the main focus of the literature revolved around the learning process, learners, and the integration of technology—especially robotics—in the context of education. Presence of words *engineering education* It also indicates that the aspect of engineering education is also an important part of the corpus. Meanwhile, terms such as *animal experiment*, *nonhuman*, *female*and *veterinary medicine* reflecting the involvement of research from the fields of health and animal science, showing that the documents analyzed include a multidisciplinary character. Emergence of the term *Optical Society of America* and *optics education* indicates the contribution of literature from the optical domain and certain professional associations. This fairly diverse variety of words reinforces that the corpus is not only centered on general education, but also on technology, scientific experiments, and cross-field methodological aspects. This pattern is in line with bibliometric findings that WordCloud is effective in describing the density of themes and relationships between study dimensions in a research domain (Hwang et al., 2025). Overall, these visualizations show a rich thematic structure and reflect multidisciplinary tendencies in the literature studied.

8. Words' Frequency over Time

The Words' Frequency Over Time analysis in Figure X shows the cumulative development of a number of key terms in the document corpus from 2000 to 2021. This visualization is used to assess the temporal dynamics of each keyword, as well as to see how certain topics are starting to emerge, develop, or gain new relevance in the literature.

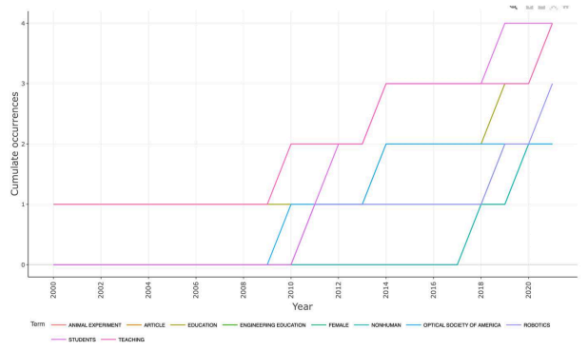

Figure 6. Words' Frequency over Time

The visualization shows that the term *students* and *teaching* emerged and improved earlier than other terms, indicating that the focus on learners and the learning process has long been a consistent theme in the literature. Gradual rise in the word *education* reinforcing that the topic of education remains the main cornerstone in the corpus. Meanwhile, the term *robotics* and *engineering education* began to rise after 2010, reflecting the growing interest in the integration of technology and robotics in education a trend that has also reportedly increased globally in the last decade (Lampropoulos, 2025; Samala et al., 2024).

The emergence of terms such as *animal experiment*, *nonhuman*and *female* In more recent periods, there has been an expansion of topics towards experimental research, population analysis, and methodological issues. Increased frequency of terms *Optical Society of America* In the final phase, it indicates the association of several publications with a certain professional association or optical domain. Overall, this cumulative pattern of rise shows that the literature is evolving gradually, starting with general education themes before moving on to specific issues such as learning technologies, robotics, and experimental approaches. This pattern is consistent with the theory of topic evolution in bibliometrics, where core topics tend to be stable while new topics evolve as technological innovations and research needs change (Cobelli & Blasi, 2024; Mejia et al., 2021).

9. Co-occurrence Network

Figure X shows a *Co-occurrence Network* visualization that illustrates the relationship between words in the document corpus. Each node represents a term, while the connecting line indicates the degree of co-occurrence between those terms in the same publication. This co-emergence network analysis is used to identify how certain concepts are naturally grouped in the literature as well as to trace the thematic structure of the research domain being studied.

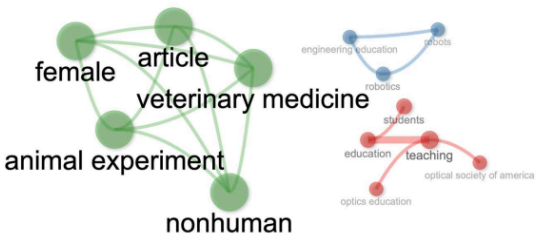

Figure 7. Co-occurrence Network

The results of the co-emergence mapping show the formation of three main clusters. The first cluster (green) consists of terms such as *female*, *animal experiment*, *nonhuman*, *veterinary medicine*and *article*. This cluster highlights the relationship between literature and animal experimental research, population studies, and methodological issues in the fields of animal health and biology. The dominance of inter-word relationships in this cluster shows that some of the documents have a strong focus on experimental and biological aspects. The second cluster (blue) contains the term *engineering education*, *robotics*and *robots*, which reflects the theme of technology and engineering education. The close relationship between terms in this cluster indicates an increasing focus on the integration of robotics in the learning process, a trend that is also rapidly growing in the global STEM education literature (Darmawansah et al., 2023). The third cluster (red) includes the term *education*, *students*, *teaching*, *Optical Society of America*and *optics education*. This cluster describes a more traditional focus on general education contexts, teacher-student interaction, and optics-based teaching. The interconnectedness between words in it reflects literature that is more pedagogical and oriented towards the teaching and learning process.

The presence of these three separate but complementary clusters shows that the corpus of documents has a multidisciplinary character, encompassing general education, learning technologies, as well as experimental research. Such a network structure is in line with international bibliometric findings that show that word co-occurrence can reveal thematic patterns and cross-field integration within a domain of science (Leiva et al., 2024; Yuan & Sun, 2023). Overall, the results of this analysis confirm that the literature analyzed consists of a diverse spectrum of topics and connects education, technology, and experimental research in a single scientific landscape.

10. Thematic Map

Thematic map analysis was used to identify the position and development of the research theme based on the degree of centrality and density. This technique is commonly used in bibliometrics to map the intellectual structure of a field of study and assess whether a theme includes basic themes, motor themes, niche themes, or emerging/declining themes. Through this approach, each keyword cluster is visualized in four quadrants so that researchers can understand the thematic strengths, relevance between themes, and the direction of the study's development in

the analyzed field. The following is presented a thematic map of the results of bibliometric analysis based on keywords that appear in publications related to this field of research.

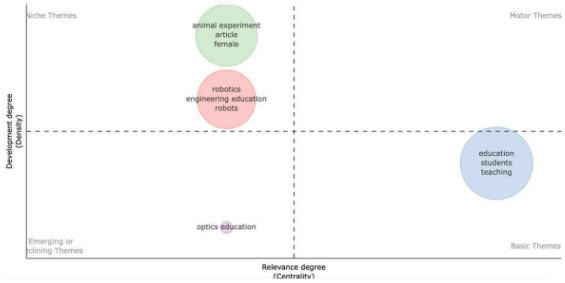

Figure 8. Thematic Map

The results of the thematic map visualization show that the education–students–teaching cluster is in the Basic Themes quadrant, which illustrates that this theme has a high level of centrality but low density. This means that this theme has become the dominant foundation in the field of studies, widely discussed in the literature, but has not developed deeply towards more specific subtopics. This condition is in line with bibliometric findings in the field of education which show that general themes related to the teaching-learning process continue to be the focus of core research globally (X. Chen et al., 2021). In the Niche Themes quadrant, the animal experiment, female, article clusters have high density but low centrality. This theme develops intensively within its own community but has little influence on the general structure of the field of education or learning technology. The presence of these themes often reflects a very specific area of research and does not have a strong connection to the core topic of the analysis (Mishra & Dey, 2022).

Meanwhile, the robotics–engineering education–robots cluster is in a relatively moderate position in terms of centrality and density, so it can be categorized as a theme that is developing towards niche or motor themes. This illustrates that research related to robotics in engineering education is starting to gain greater attention, in line with the global trend of increasing STEM education and the integration of automation technology in learning (Yang et al., 2025). On the other hand, the small cluster of optics education is located in the Emerging or Declining Themes quadrant, which is characterized by low density and centrality. This position suggests that the theme is experiencing a decline in interest in the literature or is a new theme that has not developed significantly. Based on bibliometric trends, the themes in this quadrant require special attention to determine whether their existence will evolve in the future or be abandoned (Gao et al., 2021). Overall, this thematic map provides an idea that research in the analyzed field still rests on the core theme of education, with the potential for expansion in the fields of robotics and educational technology. These findings reinforce the importance of integrating new themes relevant to technological developments to enrich the main studies that have been dominant.

CONCLUSION

This bibliometric review provides a comprehensive understanding of the scientific landscape surrounding research on solar-powered toys and science kits for Elementary School Students. The analysis successfully met the research objectives by mapping publication trends, influential authors, productive countries, dominant sources, and thematic developments within the field. The findings reveal that research productivity has grown steadily alongside global interest in renewable-energy education, with contributions concentrated in multidisciplinary domains such as engineering education, optics, and experimental sciences. Co-occurrence and thematic mapping indicate three major thematic clusters: educational STEM innovation, technological device development, and experimental research applications. These insights demonstrate that the field is still emerging, with significant opportunities for collaboration across education, engineering, and energy technology.

Future studies are encouraged to explore pedagogical impacts more deeply, expand cross-national collaboration, and develop more refined solar-powered educational kits tailored to diverse learning contexts. Strengthening the integration of renewable-energy toys with contemporary STEM curricula will further enhance learning outcomes and support sustainability-oriented science education.

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