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Bibliometric Analysis of STEAM Integration in Chemistry Learning at the Secondary Education Level

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Abstract

This study explores the integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) in secondary-level chemistry education, focusing on its impact on student engagement and learning outcomes. Specifically, the study aims to identify research trends, contributors, institutions, and prominent themes in this field. A bibliometric analysis was conducted on 53 research articles indexed in the Dimensions database from 2020 to 2024, and data visualization was performed using the VOSviewer tool. The results revealed a significant increase in publications, peaking at 23 in 2024, indicating a growing interest in STEAM methodologies. Notably, Greek authors demonstrated substantial influence, achieving a high citation count of 132 from only two publications, while Indonesia contributed the highest number of documents with 20 publications and 62 citations. Influential journals such as Applied Sciences and Sustainability were identified, alongside trending themes including augmented reality, gamification, and project-based learning. The findings highlight challenges such as students' negative perceptions of chemistry, limited teacher preparation, and the necessity for effective teaching strategies. This study concludes that interdisciplinary approaches foster critical thinking and creativity among students, ultimately preparing them for modern educational demands. Suggestions include strengthening teacher training, encouraging international collaboration, and adopting innovative pedagogical models. The study is limited to the Dimensions database and the 2020–2024 publication period, which may not capture all global research on STEAM integration.

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INTRODUCTION

Education in the 21st century increasingly emphasizes the integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) to equip students with essential skills for navigating a complex world (Pradana et al., 2025). This interdisciplinary approach fosters critical thinking, creativity, and problem-solving abilities, which are vital for future workforce demands (Inthanon & Wised, 2024; Sousa et al., 2024). Research indicates that STEAM education enhances student engagement and motivation, particularly in subjects like chemistry, by promoting meaningful learning experiences through collaborative projects and technology integration (Hashmi et al., 2024; Sousa et al., 2024).

However, challenges such as limited resources, traditional teaching methods, and insufficient teacher training hinder effective implementation, and negative student perceptions of chemistry (Abbas et al., 2024; Hashmi et al., 2024). For example, the case of Pakistan illustrates the barriers

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faced in developing countries where teacher readiness and infrastructure are limited, showing that such challenges are not confined to one context but are global issues. Addressing these barriers is crucial for maximizing the potential of STEAM education, which not only prepares students for academic success but also cultivates the adaptable skills necessary for real-world applications (Costa et al., 2023).

In secondary-level chemistry education, these challenges hinder the integration of interdisciplinary and project-based approaches that are essential for achieving STEAM's full potential (Dyachenko et al., 2024). Additionally, the development of collaborative problem-solving assessment tools highlights the importance of monitoring these skills in chemistry contexts, revealing that structured activities can significantly improve student engagement and learning outcomes (Ying & Tiemann, 2024). However, challenges persist, including insufficient teacher preparation and the need for effective assessment methods (Dyachenko et al., 2024; Ying & Tiemann, 2024). Furthermore, project-based learning, particularly micro project-based learning, has been shown to enhance conceptual understanding and essential learning skills, suggesting that innovative pedagogical strategies are crucial for effective STEAM integration in secondary chemistry education (Tian et al., 2023).

Given these challenges, bibliometric analysis offers a valuable method to map existing research, identify global trends, and highlight gaps that require further investigation. Recent studies have increasingly employed bibliometric approaches to map the development of STEM and STEAM education. For instance, (Marín-Marín et al., 2021) conducted a bibliometric analysis of STEAM research indexed in the Web of Science, highlighting global performance trends and thematic clusters. Similarly, Tupamahu et al., (2025) examined a decade of STEM and STEAM publications, showing the expansion of interdisciplinary research across countries and institutions. In the field of chemistry education, bibliometric studies have been applied to broader themes such as general chemical education (Auliah & Cahyani, 2024), green chemistry education (Irfani, 2024), and the evolution of organic chemistry education research (Hassan et al., 2022). These studies demonstrate the potential of bibliometrics to uncover patterns of collaboration, productivity, and thematic evolution in science education. However, none of them specifically focus on the integration of STEAM in secondary-level chemistry learning. At the same time, recent works such as (Milara & Orduña, 2024) emphasize the pedagogical challenges and opportunities of STEAM implementation, reinforcing the need to investigate how these issues are reflected in research outputs. Taken together, these findings underline a critical gap: while bibliometric methods have been applied to STEM, STEAM, and chemistry education separately, there is still a lack of systematic bibliometric analysis that explores STEAM integration in chemistry at the secondary education level, which this study seeks to address.

Therefore, this study aims to explore overarching trends in research on STEAM integration in chemistry learning at the secondary education level. Specifically, it addresses the following research questions: 1) What are the most published and cited articles related to STEAM in chemistry learning at the secondary education level from 2020 to 2024? ; 2) Which countries and authors have had the greatest impact on global research concerning STEAM in chemistry learning at the secondary education level? ; 3) Which journals have had the most influence on research related to STEAM in chemistry learning at the secondary education level? ; 4) What is the most cited publication in the field of STEAM in chemistry learning at the secondary education level? ; 5) What are the key keywords and themes associated with research on STEAM in chemistry learning at the secondary education level? ; 6) Which topics within the research on STEAM in chemistry learning at the secondary education level have the highest number of publications?

METHOD

This study employs bibliometric analysis to examine the integration of STEAM in secondary-level chemistry education. Bibliometric analysis, a quantitative research method, evaluates performance, influence, and trends in scientific publications and academic literature through the collection of bibliographic data, including article titles, author names, journal sources, publication years, and citation counts. This methodology examines scientific literature patterns, encompassing research topic developments, author collaborations, leading journals, and citation trends, with the primary goal of providing insights into scientific and technological advancements while supporting decision-making across education, social sciences, and natural sciences. The study utilizes the Dimensions database, recognizing the growing importance of efficient data collection and analysis tools in contemporary academic research.

Dimensions represents a transformative advancement in research data management, integrating a wide array of information, including publications, citations, grants, patents, and clinical trials, into a single, accessible platform. Launched in 2018, it offers broader journal coverage and citation consistency compared to traditional databases like Scopus and Web of Science, making it a viable alternative for bibliometric analysis (Thelwall, 2018). The platform not only simplifies the research process for librarians and researchers by consolidating diverse data sources but also enhances the ability to conduct complex analyses of scientific landscapes through tools like Google BigQuery (Hook & Porter, 2021; Porter & Hook, 2022). Despite some limitations, such as occasional gaps in affiliation data, Dimensions continues to provide valuable insights into research impacts and collaboration patterns, solidifying its role as an essential resource in the academic community (Guerrero-Bote et al., 2021; Purnell, 2022).

Data collection for the study on STEAM integration in chemistry learning at the secondary education level was conducted on Thursday, 24 December 2024, at 19:30. The methodology involved retrieving data through keyword searches using "steam," "chemistry learning," and "secondary education," focusing on abstracts and keywords relevant to the topic. The search utilized the AND operator to ensure that results included all specified terms, thereby enhancing the relevance of the collected data. The period 2020–2024 was selected to capture the most recent research developments in STEAM integration within secondary-level chemistry education, ensuring that the analysis reflects current trends and contemporary educational practices. This approach aligns with findings from various studies indicating that interdisciplinary connections in education, particularly in chemistry, can significantly enhance student engagement and understanding, as evidenced by improved learning outcomes and motivation among students (Dyachenko et al., 2024). However, challenges such as students' negative perceptions of chemistry and the need for effective teaching strategies remain critical issues that must be addressed to optimize learning experiences (Kousa et al., 2018; Pratomo et al., 2025). Figure 1 illustrates the data selection process, which is divided into four stages.

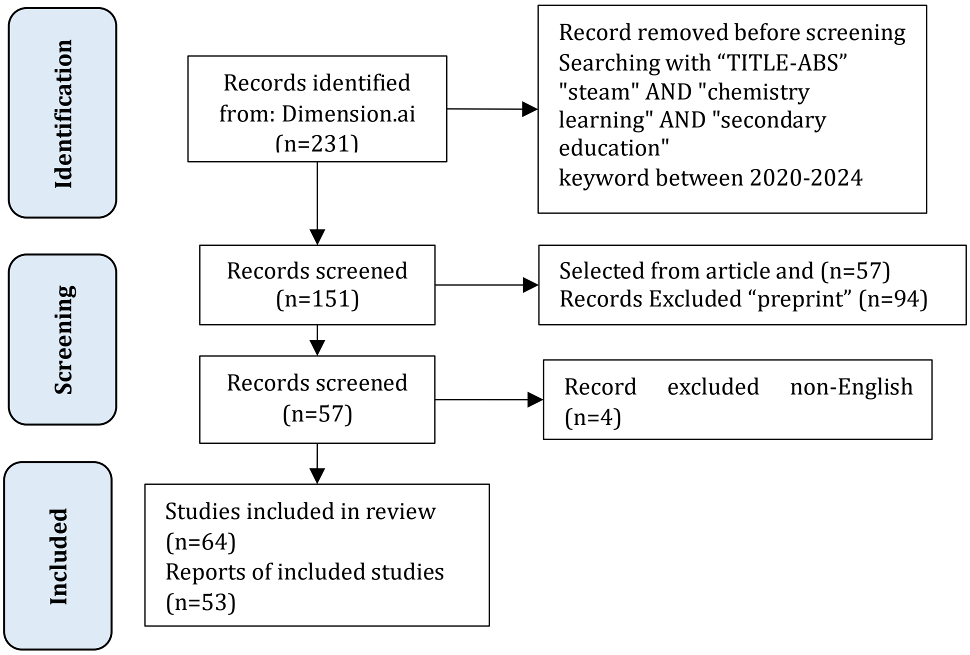

Figure 1. Flowchart of the Four-Phase Data Extraction and Filtration Process

The first stage, identification, involved conducting keyword searches in the Dimensions database, resulting in 231 documents. The second stage, screening, applied inclusion and exclusion criteria, such as filtering documents based on publication year, resulting in 151 documents.

Subsequently, the documents were filtered to retain only research articles, narrowing the selection to 57 documents. In the final stage, applying a language filter for English documents, 53 documents remained eligible for analysis. These documents were reviewed by three authors, who examined the titles and abstracts to ensure data accuracy. Articles meeting the research criteria were then exported in a (.csv) file format.

RESULTS AND DISCUSSION

Publication and Citation Trends

The trends in publications and citations related to STEAM integration in chemistry education at the secondary school level from 2020 to 2024 demonstrate a significant and consistent increase in research interest within this field. The data reveals that the number of publications rose sharply, with the highest count of 23 publications in 2024, compared to only 3 publications in 2020. This upward trend highlights the growing importance of STEAM integration in chemistry education. Figure 2: representation of this data will provide a clearer visualization of these trends.

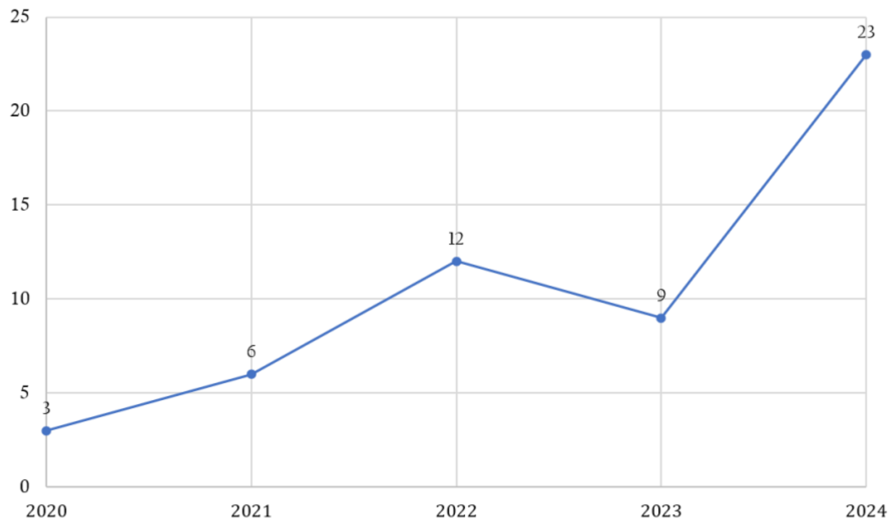

Figure 2. Trends in Publications and Citations Related to STEAM Integration in Chemistry Education at the Secondary School Level (2020–2024)

The data reveal a significant upward trend in publications related to STEAM integration in secondary-level chemistry education from 2020 to 2024. In 2020, only three publications were recorded, indicating limited research interest in this topic at the study's outset. However, from 2021 onwards, there was a notable increase, with publications doubling to six and further growing to twelve in 2022. Despite a slight decline to nine publications in 2023. This decrease may reflect delays in publication processes following the COVID-19 pandemic, a shift of research focus to broader STEM or general education issues, or funding limitations in certain countries. Despite the decline, the long-term trend remains positive, as indicated by the surge in 2024.

This pattern indicates growing attention and recognition of STEAM integration in chemistry education among researchers, particularly in recent years. Several factors may have contributed to this growth, including global emphasis on interdisciplinary learning, promotion of innovative teaching methods, and alignment with 21st-century skills. The continuous increase in publications highlights the growing significance of STEAM integration in chemistry education as a research topic, with the sharp rise in 2024 demonstrating its emerging relevance and potential impact on secondary education. These trends suggest the need for continued research in this area to enhance educational practices and outcomes.

Country Productivity

An overview of the most productive countries in research on the integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) in secondary-level chemistry education is presented in Table 1. The data highlights the number of documents published and their corresponding citation counts, providing insight into the global contributions to this area of study. The ranking of countries reflects both the volume and impact of their research output within this field. As seen in Table 1, these countries have varied levels of publication frequency and citation influence, showcasing diverse contributions to the academic landscape of STEAM integration in chemistry education at the secondary level.

Table 1. Most Productive Countries in Research on STEAM Integration in Secondary-Level Chemistry Education

Rank	Country	Number of Documents	Number of Citations
1	Greece	2	132
2	Indonesia	20	62
3	Thailand	2	55
4	Spain	1	36
5	Australia	1	30
6	Malaysia	1	26
7	Ukraine	2	19
8	Israel	2	13
9	Finland	1	10
10	Peru	1	10

Based on the data presented in Table 1, several key insights can be drawn regarding the research output on STEAM integration in secondary-level chemistry education across various countries. Firstly, Greece is the most productive country in this area, with only two publications but a notably high citation count of 132. This suggests that the research produced in Greece has had a significant impact, likely contributing important insights or findings that are widely recognized within the academic community. These studies primarily discussed the use of augmented reality and gamification in STEAM education (Lampropoulos et al., 2022), highlighting technology-driven innovations that resonated widely with international scholars. In contrast, Indonesia produced 20 publications but with 62 citations, suggesting that while output is high, global recognition remains limited, possibly due to regional scope or less international collaboration.

Other countries such as Thailand, Spain, Australia, Malaysia, Ukraine, Israel, Finland, and Peru, each contribute a smaller number of publications, typically one or two. Despite the lower number of publications, these countries demonstrate varying degrees of citation impact. For instance, Thailand and Ukraine have two documents each, with citation counts of 55 and 19, respectively, which implies that their research is being referenced more frequently compared to countries with similar publication numbers, such as Israel, which has two publications but only 13 citations.

The analysis of research productivity and citation impact across various countries reveals significant disparities in both publication volume and recognition. Greece, despite having only two publications, boasts a high citation count of 132, indicating that its research has made a substantial impact within the academic community (Koukoutsidis, 2022). In contrast, Indonesia, with 20 publications and 62 citations, demonstrates a higher output but lower recognition, suggesting that quantity does not always equate to quality or influence (Sukoco et al., 2023). Other countries, such as Thailand and Ukraine, show that even with limited publications, they can achieve notable citation impacts, with Thailand's two documents receiving 55 citations (Ridwan et al., 2021). This highlights the importance of not only the number of publications but also the quality and international collaboration, which can enhance citation impact (Wang et al., 2024). Overall, the findings underscore the complex interplay between publication metrics and academic influence across different nations.

In summary, while the number of documents published indicates the volume of research output, the citation count offers a deeper understanding of the academic influence of the research. Greece stands out in terms of citation impact, despite its relatively low number of publications, whereas Indonesia leads in volume but with a lower citation rate. This suggests that there may be regional variations in the visibility and impact of research on STEAM integration in secondary-level chemistry education.

Table 2 presents the most productive research studies on the integration of STEAM in secondary-level chemistry education. The data highlights the institutions that have published the most documents, along with the corresponding citation counts. This provides an overview of the contributions of various institutions in advancing STEAM integration in secondary chemistry education. The ranking of institutions reflects both the volume of their published work and the impact of their research, as indicated by citation counts.

Table 2. The Most Productive Research Studies on STEAM Integration in Secondary-Level Chemistry Education

Rank	Institution	Number of Documents	Number of Citations
1	International Hellenic University	2	264
2	State University of Jakarta	5	72
3	Hellenic Open University	1	132
4	University of Macedonia	1	53
5	King Mongkut's Institute of Technology Ladkrabang	3	31
6	Edith Cowan University	2	30
7	Murdoch University	1	30
8	University of Extremadura	2	25

Based on the data in Table 2, the institutions with the highest impact on STEAM integration in secondary-level chemistry education are the *International Hellenic University* and *Hellenic Open University,* each with a few publications but a remarkably high citation count of 264 and 132. This indicates that these institutions have produced highly influential research, suggesting that even a small number of publications can have a significant global impact in this field (Ridwan et al., 2021). Other institutions, such as the *University of Macedonia, King Mongkut's Institute of Technology, Ladkrabang*, and the *State University of Jakarta,* have published multiple studies. However, their citation counts are lower. This suggests that while these institutions have contributed more research output, their work may not have gained as widespread academic recognition or influence compared to the institutions with higher citation counts (Sousa et al., 2024). Furthermore, the integration of STEAM principles in chemistry education has been shown to enhance students' critical and creative thinking skills, underscoring the importance of effective pedagogical approaches in fostering meaningful learning experiences (Mahbub et al., 2024).

Table 3 provides an overview of the most prolific authors in research on the integration of STEAM in secondary-level chemistry education. The table highlights the first authors, their affiliations, the number of documents they have published, and their corresponding citation counts. This data offers insight into the individual contributions of prominent researchers in the field, reflecting both their productivity and the academic impact of their work. The ranking of authors underscores their significant influence on the development of STEAM integration in chemistry education at the secondary level.

Table 3. The Most Prolific Authors in STEAM Integration in Secondary-Level Chemistry Education

1st Author	Affiliation, Country	Documents	Citations
Georgios Evangelidis	University of Macedonia, Greece	1	132
Konstantinos I Diamantaras	International Hellenic University, Greece	1	132
Euclid A Keramopoulos	International Hellenic University, Greece	1	132
Georgios Lampropoulos	University of Macedonia, Greece	1	132
Naphong Wannapiroon	King Mongkut's Institute of Technology Ladkrabang, Thailand	1	53
Paitoon Pimdee	King Mongkut's Institute of Technology Ladkrabang, Thailand	1	53

1st Author	Affiliation, Country	Documents	Citations
Yuli Rahmawati	State University of Jakarta, Indonesia	3	42
Alin Mardiah	State University of Jakarta, Indonesia	2	38
Achmad Ridwan Ridwan	State University of Jakarta, Indonesia	2	34
Elisabeth Lily Taylor	Edith Cowan University, Australia	1	30
Peter Charles Taylor	Murdoch University, Australia	1	30

Based on the data in Table 3, several key insights can be drawn regarding the most prolific authors in the field of STEAM integration in secondary-level chemistry education. Georgios Evangelidis, Konstantinos I Diamantaras, Euclid A Keramopoulos, and Georgios Lampropoulos from Greece stand out, each having published one paper with a remarkable citation count of 132. This suggests that these authors have made a significant impact in the field, with their work being widely recognized and cited by the academic community despite the relatively low number of publications (Sousa et al., 2024)

Authors from King Mongkut's Institute of Technology, Ladkrabang, Thailand, such as Naphong Wannapiroon and Paitoon Pimdee, have published one paper each, with citation counts of 53. These researchers, although having fewer publications compared to others, still demonstrate notable academic influence, indicating that their work has contributed valuable insights into STEAM integration in secondary-level chemistry education (Sousa et al., 2024). The integration of STEAM in education has been shown to enhance critical and creative thinking skills, as evidenced by studies that emphasize project-based learning and interdisciplinary collaboration, which are essential for fostering student engagement and developing 21st-century skills (An, 2020).

Other prolific authors such as Yuli Rahmawati, Alin Mardiah, and Ridwan from the State University of Jakarta, Indonesia, have published multiple papers, with citation counts ranging from 34 to 42. Their higher publication numbers suggest a more consistent contribution to the field, with a slightly lower citation impact compared to the top authors, which may indicate that their research, while valuable, has not yet reached the same level of broad recognition. Authors from Edith Cowan University and Murdoch University, Australia, with one publication each, show a more modest citation count of 30, reflecting their more recent or specialized contributions to the field.

Productivity of Research Journals

Table 4 provides an overview of the most influential journals in the field of STEAM integration in secondary-level chemistry education. The table lists various journals along with the number of documents published and the corresponding citation counts. This data highlights the impact these journals have had in disseminating research on the integration of STEAM into chemistry education, reflecting both the volume of publications and the academic influence of their articles. The ranking of journals underscores their importance in shaping the discourse and development of STEAM integration in secondary chemistry education.

Table 4. The Most Influential Journals in Steam Integration in Secondary-Level Chemistry Education

Source	Documents	Citations
Applied Sciences	1	132
Sustainability	4	64
Education and Information Technologies	2	56
Eurasia Journal of Mathematics Science and Technology Education	2	19
CTE Workshop Proceedings	2	19
Journal of Chemical Education	2	13
Journal of Technology and Science Education	2	12
International Journal of Interactive Mobile Technologies (iJIM)	1	8
Education Sciences	1	8
Information Technologies and Learning Tools	1	6
International Journal of Language Education	1	6

The analysis of influential journals in STEAM integration within secondary-level chemistry education, as seen in Table 4, reveals significant insights into their impact and contributions. Notably, the journal *Applied Sciences*, despite having only one publication, boasts a remarkable citation count of 132, indicating that its research is highly regarded and influential in the academic community (Sousa et al., 2024). Other prominent journals include *Sustainability* and *Education and Information Technologies*, which have published four and two documents respectively, with citation counts of 64 and 56. This suggests that these journals not only maintain a consistent output of research but also play a critical role in disseminating knowledge on interdisciplinary connections in education. The research emphasizes the importance of integrating various disciplines to enhance critical thinking and student engagement, as illustrated by studies such as those by (Dyachenko et al., 2024). These findings underscore the necessity for educators to leverage these resources to foster meaningful learning experiences in STEAM education.

Journals such as the Eurasia Journal of Mathematics, Science and Technology Education, CTE Workshop Proceedings, and Journal of Chemical Education each have two publications, with citation counts ranging from 12 to 19. While these journals have a lower citation impact compared to the top journals, they still contribute valuable insights to the field. Additionally, journals like International Journal of Interactive Mobile Technologies (iJIM) and Education Sciences have one publication each with citations of 6 to 8, indicating that while their contributions are more limited, they still play a role in advancing the field of STEAM integration in secondary-level chemistry education.

Most Trending and Cited

An overview of the most trending and most cited publications on the integration of STEAM in secondary-level chemistry education is provided in Table 5. The table includes details such as the title of each publication, its authors, year of publication, source journal, and the number of citations it has received. This data offers a comprehensive perspective on the influential studies that have contributed to the academic discourse on STEAM integration in chemistry education. It highlights both emerging trends and established research that have gained significant attention within the scholarly community. The ranking of these publications reflects their substantial impact on advancing the field and underscores the increasing interest in STEAM approaches to science education.

Table 5. Most Trending and Most Cited Publications on STEAM Integration in Secondary-Level Chemistry Education

Title	Author(s)	Year	Source	Cited by
Augmented Reality and Gamification in Education: A Systematic Literature Review of Research, Applications, and Empirical Studies	Lampropoulos et al.	2022	Applied Sciences	132
Thai undergraduate science, technology, engineering, arts, and math (STEAM) creative thinking and innovation skill development: a conceptual model using a digital virtual classroom learning environment	Wannapiroon and Pimdee	2022	Education and Information Technologies	53
Students' Engagement in Education as Sustainability: Implementing an Ethical Dilemma-STEAM Teaching Model in Chemistry Learning	Rahmawati et al.	2022	Sustainability	30
Emotional Performance of a Low-Cost Eco-Friendly Project Based Learning Methodology for Science Education: An Approach in Prospective Teachers	Hernández-Barco et al.	2021	Sustainability	24
Impact of the Plugged-in and Unplugged	Chongo et al.	2021	Eurasia Journal of	18

Title	Author(s)	Year	Source	Cited by
Chemistry Computational Thinking Modules on Achievement in Chemistry			Mathematics Science and Technology Education	
Possibilities and Challenges of Using Educational Cheminformatics for STEM Education: A SWOT Analysis of a Molecular Visualization Engineering Project	Pernaa	2022	Journal of Chemical Education	13
CTE 2019 – When cloud technologies ruled the education	Kiv et al.	2020	CTE Workshop Proceedings	13
Trends in Educational Research for Sustainable Development in Postgraduate Education Programs at a University in Peru	Deroncele-Acosta et al.	2023	Sustainability	10
The integration of dilemmas stories with STEM-project-based learning: Analyzing students' thinking skills using Hess' cognitive rigor matrix	Rahmawati et al.	2021	Journal of Technology and Science Education	8
AR Module for Learning Changes of Matter in Chemistry	Mahanan et al.	2021	International Journal of Interactive Mobile Technologies (iJIM)	8

Based on the data presented in Table 5, several key observations can be made regarding the most trending and most cited publications on STEAM integration in secondary-level chemistry education. The paper Lampropoulos et al. (2022) has garnered significant attention in the academic community, evidenced by its 132 citations, which underscores its influential role in promoting augmented reality (AR) and gamification within STEAM education. This systematic literature review highlights AR's effectiveness in enhancing student engagement and understanding of complex concepts, particularly in chemistry education, where it facilitates the visualization of molecular structures and reactions (Duc & Quang, 2024). The integration of AR has been shown to improve spatial reasoning and foster a more interactive learning environment, thereby addressing the challenges of traditional educational methods (Mazzuco et al., 2022). Furthermore, the positive reception from both students and educators indicates a growing recognition of AR's potential to transform educational practices and outcomes in chemistry and beyond (Ripsam & Nerdel, 2024; Zhang et al., 2023).

Other notable works include "Thai undergraduate science, technology, engineering, arts, and math (STEAM) creative thinking and innovation skill development" by Wannapiroon & Pimdee, (2022), which has 53 citations, and "Students' Engagement in Education as Sustainability" by (Rahmawati et al., 2022), with 30 citations. These publications, though not as heavily cited as the top-ranked one, are still highly influential in promoting the application of STEAM in secondary chemistry education, particularly focusing on creative thinking and sustainability in learning models.

Additional publications such as "Emotional Performance of a Low-Cost Eco-Friendly Project-Based Learning Methodology" and "Impact of the Plugged-in and Unplugged Chemistry Computational Thinking Modules" focus on innovative, sustainable, and low-cost methods to enhance chemistry education. These studies highlight the diversity of approaches being researched, from computational thinking to project-based learning methodologies, which are seen as vital for future developments in the STEAM field.

In conclusion, the data from Table 5 illustrates the diversity of topics within the field of STEAM integration in secondary-level chemistry education, with particular emphasis on the incorporation of new technologies like augmented reality, sustainable practices, and innovative learning models. The range of citation counts shows that while some publications have had an immediate and significant impact, others are gaining recognition and contributing to shaping the field.

Keyword Analysis

An overview of the keyword frequency analysis from VOSviewer is provided. The following table summarizes the most frequently occurring keywords related to the integration of STEAM in secondary-level chemistry education, along with their relevance scores. These keywords highlight the most common terms in the field, offering insights into the primary themes and concepts within the research. They reflect the focus areas and emerging trends in academic discussions surrounding STEAM education, emphasizing key factors and areas that have gained significant attention. Figure 3 presents these keywords in order of their frequency and relevance.

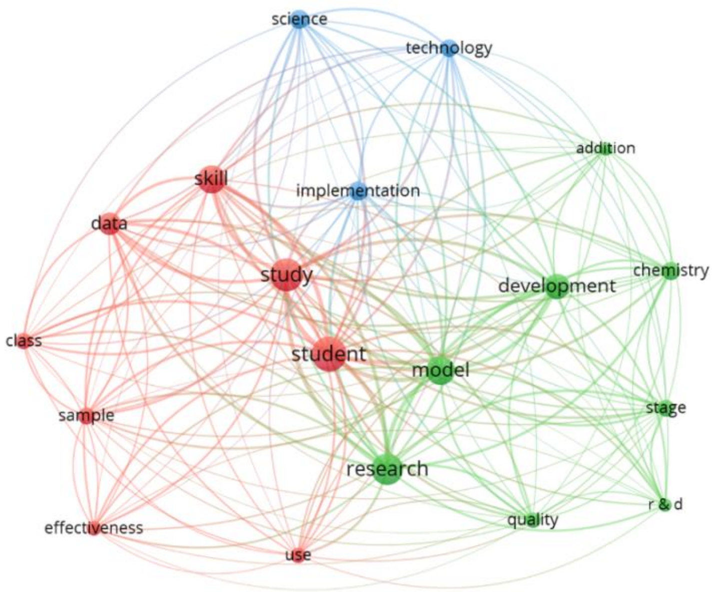

Figure 3. Shows Keyword Analysis by VOSviewer Software

Figure 3 provides a detailed overview of the most frequently used terms in research on STEAM integration in secondary-level chemistry education. The data offers insights into the central themes and key areas of focus within this field, illustrating the frequency of relevant terms that define the primary discussions and trends in this area of study.

The keyword frequency analysis in STEAM education highlights several key themes and trends within the field. The most frequent terms include "study," "skill," and "data," suggesting a strong focus on research, the development of essential skills, and the use of data to inform educational practices. Additionally, the prevalence of terms like "technology," "science," and "context" emphasizes the integration of digital tools and real-world problem-solving within the curriculum, reflecting the interdisciplinary nature of STEAM education. Another prominent theme is the integration of the arts with STEM disciplines, as seen in the frequent occurrence of terms such as "content," "implementation," and "project." These keywords point to the importance of blending creative approaches with traditional STEM subjects, fostering critical thinking and innovation in students. Furthermore, "environment" and "educator" indicate a growing recognition of the role that the learning environment and teachers play in effectively implementing STEAM education.

The keyword frequency analysis in STEAM education reveals significant themes that underscore its interdisciplinary nature and the integration of creative approaches with traditional STEM disciplines. Frequent terms such as "study," "skill," and "data" highlight a strong emphasis on research and the development of essential competencies necessary for the 21st-century workforce, as noted in the literature (Inthanon & Wised, 2024). The integration of "technology," "science," and "context" reflects the importance of real-world applications and digital tools in enhancing educational practices (Fatih et al., 2024; Inthanon & Wised, 2024). Moreover, the recurring presence of terms like "content," "implementation," and "project" indicates a focus on blending arts with STEM, fostering critical thinking and innovation among students (McLure et al., 2022). Additionally, the terms "environment" and "educator" signify the crucial role of learning contexts and teachers in effectively delivering STEAM education, which is essential for engaging students and promoting active learning (Hashmi et al., 2024; Sousa et al., 2024).

In conclusion, the keyword analysis shows that STEAM education fosters a dynamic, interdisciplinary learning experience, emphasizing creativity, innovation, and problem-solving. It highlights the importance of integrating the arts with STEM, promoting a holistic approach that develops both intellectual and practical skills.

Research Productivity by Subject Area

The data highlights the frequency of keywords related to various disciplines in STEAM education at the secondary level in chemistry. Key areas include education, curriculum, pedagogy, and specialized fields like computing sciences and language. This analysis offers insights into the prominent academic discussions surrounding STEAM integration in education, as shown in Figure 4.

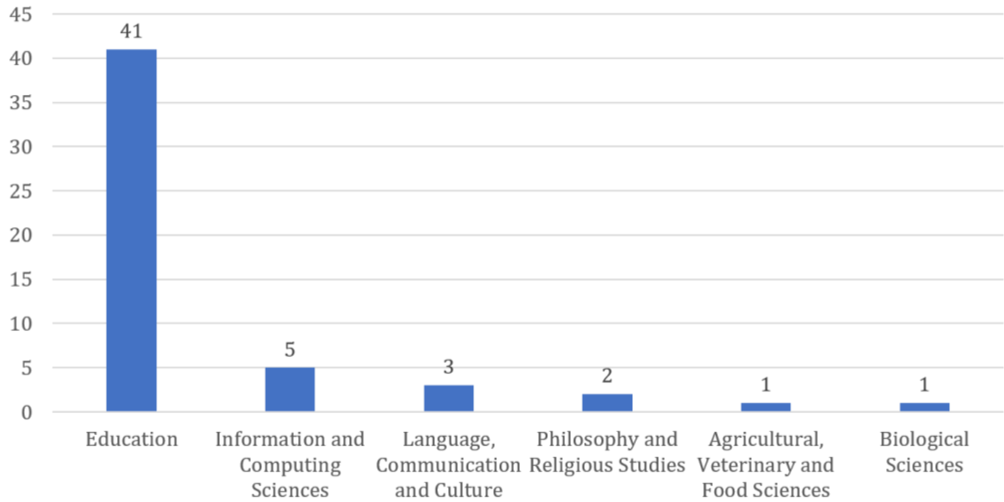

Figure 4. The Number of Documents by Subject Area.

Figure 4 shows that 53 research papers were identified using the keywords "STEAM," "chemistry learning," and "secondary education." These papers were categorized by their titles, abstracts, and keywords, though classifying them into specific fields is difficult due to their interdisciplinary nature, covering various aspects of STEAM integration in secondary chemistry education.

The data reveals that *Education* (41) is the most frequently mentioned keyword, underscoring its central role in STEAM education discussions at the secondary level. This highlights the primary focus on teaching practices, learning strategies, and the foundational importance of education in integrating interdisciplinary subjects like chemistry within the STEAM framework. Fields like *Information and Computing Sciences* (5) and *Language, Communication and Culture* (3) represent emerging areas of interest, emphasizing the growing importance of digital literacy and effective communication in a STEAM context. These fields reflect the need for modern skills and cultural adaptability in education, aligning with the interdisciplinary nature of STEAM. Less prominent but still notable are *Philosophy and Religious Studies* (2), *Agricultural, Veterinary and Food Sciences* (1), and *Biological Sciences* (1). While their presence is limited, these areas contribute unique perspectives, such as ethical considerations, sustainability, and scientific exploration, broadening the scope of STEAM education. This distribution of focus suggests prioritizing education and computing while incorporating diverse perspectives for a well-rounded approach.

The analysis of keyword frequency in STEAM education highlights the predominant emphasis on *Education*, which is crucial for fostering interdisciplinary learning and developing essential skills in students, as noted in various studies (Sousa et al., 2024). The integration of fields such as *Information and Computing Sciences* and *Language, Communication and Culture* reflects a growing recognition of digital literacy and communication skills within the STEAM framework, aligning with the need for modern competencies in education (Sousa et al., 2024). Although areas like *Philosophy and Religious Studies* and *Biological Sciences* are less frequently mentioned, they contribute valuable perspectives on ethics and sustainability, enriching the interdisciplinary nature of STEAM education (Spyropoulou & Kameas, 2023). This distribution indicates a strategic focus on core educational practices while advocating for a diverse and holistic approach to curriculum design, essential for preparing students for future challenges (Prahani et al., 2023).

LIMITATIONS

This study has several limitations that should be acknowledged. First, the dataset was limited to publications retrieved from the Dimensions database using specific keywords ("STEAM," "chemistry learning," and "secondary education"). This restriction may have excluded relevant studies indexed in other databases such as Scopus or Web of Science, potentially narrowing the scope of analysis. Second, the time frame was limited to 2020–2024. While this period captures recent developments, it does not reflect earlier contributions that might provide a more comprehensive historical overview of STEAM integration in chemistry education. Third, the bibliometric method focused on quantitative indicators such as publication counts, citations, and keyword clustering. This approach does not capture the full depth of pedagogical practices, contextual differences across countries, or qualitative insights from classroom-based implementations. Finally, the study primarily analyzed research at the global level, which may not fully reflect local or regional challenges in implementing STEAM in secondary chemistry education. Differences in educational systems, resource availability, and cultural contexts may influence how STEAM is perceived and practiced but are not addressed in this analysis. Future studies could address these limitations by employing multiple databases, extending the time frame of analysis, and combining bibliometric approaches with qualitative or mixed-method reviews to provide a richer understanding of STEAM implementation in secondary chemistry education.

CONCLUSION

This bibliometric study analyzed the trends, productivity, and impact of research on STEAM integration in chemistry education at the secondary school level from 2020 to 2024. The results indicate a growing interest in this field, with a steady increase in publications, particularly in 2024. Greece emerged as the country with the highest citation impact, primarily due to innovative studies on augmented reality and gamification, while Indonesia was the most productive in terms of publication volume. Key journals such as Applied Sciences and Sustainability served as influential sources, reflecting the interdisciplinary nature of STEAM-chemistry research. Keyword and cluster analysis revealed three dominant themes: skills development, technology integration, and project-based pedagogy, which are closely aligned with contemporary educational needs. The findings highlight the significance of bibliometric approaches in mapping global research patterns, identifying influential contributors, and uncovering thematic priorities in STEAM-chemistry education. For educators and policymakers, this study emphasizes the importance of fostering technology-driven and project-based innovations in chemistry classrooms to enhance both student engagement and learning outcomes. For researchers, the study provides an overview of emerging trends and potential gaps, particularly in underrepresented regions.

However, the study has certain limitations. It relied solely on the Dimensions database and focused on the period 2020–2024, which may have excluded earlier or non-indexed contributions. Moreover, the analysis was limited to quantitative indicators such as publication counts, citations, and keywords, without exploring qualitative insights into classroom practices. Future research should expand the scope by incorporating multiple databases, extending the time frame, and applying mixed-method reviews to complement bibliometric findings. Such efforts will provide a deeper understanding of how STEAM integration in chemistry education at the secondary school level evolves across different cultural and educational contexts.

REFERENCES

Abbas, Q., Hussain, S., Rehman, M., Tabassum, S., & Mehdi, M. (2024). 21st century skills through STEAM education: Analysis of school leaders' perspectives. *Journal of Asian Development Studies, 13*(3), 464–471. https://doi.org/10.62345/jads.2024.13.3.39

An, S. (2020). The impact of STEAM integration on preservice teachers' disposition and knowledge. *Journal of Research in Innovative Teaching & Learning, 13*(1), 27–42. https://doi.org/10.1108/JRIT-01-2020-0005

Auliah, A., & Cahyani, V. P. (2024). Exploring trends in chemical education: A bibliometric analysis (2019–2024). *Jurnal Inovasi Pembelajaran Kimia, 6*(2), 297–310. https://doi.org/10.24114/jipk.v6i2.64205

Chongo, S., Osman, K., & Nayan, N. A. (2021). Impact of the plugged-in and unplugged chemistry computational thinking modules on achievement in chemistry. *Eurasia Journal of Mathematics, Science and Technology Education, 17*(4), em1953. https://doi.org/10.29333/ejmste/10789

Costa, K., Ntsobi, M. P., & Siwahla-Madiba, N. D. (2023). The evolution of STEM as a concept in science education: A 21st century perspective. *OSF Preprints*. https://doi.org/10.31730/osf.io/5h2vn

Deroncele-Acosta, A., Jiménez-Chumacero, R. V., Gamarra-Mendoza, S., Brito-Garcías, J. G., Flores-Valdivieso, H. G., Velázquez-Tejeda, M. E., & Goñi-Cruz, F. F. (2023). *Trends in educational research for sustainable development in postgraduate education programs at a university in Peru.* Sustainability, 15(6), 5449. https://doi.org/10.3390/su15065449

Duc, N. M., & Quang, N. V. (2024). Application of augmented reality in chemistry education: A systemic review based on bibliometric analysis from 2002 to 2023. *International Journal of Education in Mathematics, Science and Technology, 12*(8), 1415–1434. https://doi.org/10.46328/ijemst.4265

Dyachenko, A., Mukanova, R., & Erkibayeva, M. (2024). Integration of interdisciplinary connections between chemistry, physics, and biology in the education of secondary school students. *International Journal of Educational Reform.* Advance online publication. https://doi.org/10.1177/10567879241290180

Fatih, M., Alfi, C., & Muqtafa, M. A. (2024). Science learning game (SLG) based on augmented reality enhances science literacy and critical thinking students' skills. *Jurnal Penelitian Pendidikan IPA, 10*(2), 973–981. https://doi.org/10.29303/jppipa.v10i2.6107

Guerrero-Bote, V. P., Chinchilla-Rodríguez, Z., Mendoza, A., & De Moya-Anegón, F. (2021). Comparative analysis of the bibliographic data sources Dimensions and Scopus: An approach at the country and institutional levels. *Frontiers in Research Metrics and Analytics, 5,* 593494. https://doi.org/10.3389/frma.2020.593494

Hashmi, K., Maqsood, S., & Noor-e-Sahar. (2024). STEAM education: A pathway to enhance critical thinking in dynamic elementary classrooms. *Sukkur IBA Journal of Educational Sciences and Technologies, 4*(1), 24–43. https://doi.org/10.30537/sjest.v4i1.1274

Hernández-Barco, M., Sánchez-Martín, J., Corbacho-Cuello, I., & Cañada-Cañada, F. (2021). Emotional performance of a low-cost eco-friendly project-based learning methodology for science education: An approach in prospective teachers. *Sustainability, 13*(6), 3385. https://doi.org/10.3390/su13063385

Hook, D. W., & Porter, S. J. (2021). Scaling scientometrics: Dimensions on Google BigQuery as an infrastructure for large-scale analysis. *Frontiers in Research Metrics and Analytics, 6,* 656233. https://doi.org/10.3389/frma.2021.656233

Inthanon, W., & Wised, S. (2024). Tailoring education: A comprehensive review of personalized learning approaches based on individual strengths, needs, skills, and interests. *Journal of Education and Learning Reviews, 1*(5), 35–46. https://doi.org/10.60027/jelr.2024.779

Irfani, F. (2024). Green chemistry in education: A bibliometric study and research trends (2002–2022). *Journal of Education for Sustainable Development Studies, 1*(1), 1–14. https://doi.org/10.70232/rq1cmx05

Kiv, A. E., Shyshkina, M. P., Semerikov, S. O., Striuk, A. M., Striuk, M. I., & Shalatska, H. M. (2020). *CTE 2019 – When cloud technologies ruled the education*. CTE Workshop Proceedings, 7, 1-59. https://doi.org/10.55056/cte.306

Koukoutsidis, I. Z. (2022). Department-level comparison of universities' scientific output: A bibliometric study of Greek universities. *arXiv Preprints.* https://doi.org/10.48550/arXiv.2212.12032

Kousa, P., Kavonius, R., & Aksela, M. (2018). Low-achieving students' attitudes towards learning chemistry and chemistry teaching methods. *Chemistry Education Research and Practice, 19*(2), 431–441. https://doi.org/10.1039/C7RP00226B

Lampropoulos, G., Keramopoulos, E., Diamantaras, K., & Evangelidis, G. (2022). Augmented reality and gamification in education: A systematic literature review of research, applications, and empirical studies. *Applied Sciences, 12*(13), 6809. https://doi.org/10.3390/app12136809

Mahanan, M. S., Ibrahim, N. H., Surif, J., & Chee, K. N. (2021). *AR Module for Learning Changes of Matter in Chemistry. International Journal of Interactive Mobile Technologies (iJIM), 15*(23), 72–88. https://doi.org/10.3991/ijim.v15i23.27343

Mahbub, S., Wafik, H. M. A., Uddin, A., & Rahman, M. (2024). Integration of technology in chemistry education at university level. *Cognizance Journal of Multidisciplinary Studies, 4*(7), 9–19. https://doi.org/10.47760/cognizance.2024.v04i07.002

Marín-Marín, J.-A., Moreno-Guerrero, A.-J., Dúo-Terrón, P., & López-Belmonte, J. (2021). STEAM in education: A bibliometric analysis of performance and co-words in Web of Science. *International Journal of STEM Education, 8*(1), 41. https://doi.org/10.1186/s40594-021-00296-x

Mazzuco, A., Krassmann, A. L., Reategui, E., & Gomes, R. S. (2022). A systematic review of augmented reality in chemistry education. *Review of Education, 10*(1), e3325. https://doi.org/10.1002/rev3.3325

McLure, F. I., Tang, K.-S., & Williams, P. J. (2022). What do integrated STEM projects look like in middle school and high school classrooms? A systematic literature review of empirical studies of iSTEM projects. *International Journal of STEM Education, 9*(1), 73. https://doi.org/10.1186/s40594-022-00390-8

Milara, I. S., & Orduña, M. C. (2024). Possibilities and challenges of STEAM pedagogies. *arXiv Preprints.* https://doi.org/10.48550/arXiv.2408.15282

Nik Hassan, N. M. H., Talib, O., Shariman, T. P., Rahman, N. A., & Zamin, A. A. M. (2022). A bibliometric analysis on how organic chemistry education research has evolved collaboratively over time. *Jurnal Pendidikan IPA Indonesia, 11*(1), 73–90. https://doi.org/10.15294/jpii.v11i1.34185

Pernaa, J. (2022). Possibilities and challenges of using educational cheminformatics for STEM education: A SWOT analysis of a molecular visualization engineering project. *Journal of Chemical Education, 99*(3), 1190-1200. https://doi.org/10.1021/acs.jchemed.1c00683

Porter, S. J., & Hook, D. W. (2022). Connecting scientometrics: Dimensions as a route to broadening context for analyses. *Frontiers in Research Metrics and Analytics, 7,* 835139. https://doi.org/10.3389/frma.2022.835139

Pradana, K. C., Noer, S. H., & Sutiarso, S. (2025). Enhancing critical thinking in mathematics through Android-based multimedia and PjBL-STEM. *Online Learning in Educational Research, 5*(1), 81–93. https://doi.org/10.58524/oler.v5i1.534

Prahani, B. K., Nisa', K., Nurdiana, M. A., Kurnianingsih, E., Amiruddin, M. Z. B., & Sya'roni, I. (2023). Analyze of STEAM education research for three decades. *Journal of Technology and Science Education, 13*(3), 837–853. https://doi.org/10.3926/jotse.1670

Pratomo, H., Fitriyana, N., Wiyarsi, A., & Marfuatun, M. (2025). Mapping chemistry learning difficulties of secondary school students: A cross-grade study. *Journal of Education and Learning (EduLearn), 19*(2), 909–920. https://doi.org/10.11591/edulearn.v19i2.21826

Purnell, P. J. (2022). The prevalence and impact of university affiliation discrepancies between four bibliographic databases—Scopus, Web of Science, Dimensions, and Microsoft Academic. *Quantitative Science Studies, 3*(1), 99–121. https://doi.org/10.1162/qss_a_00175

Rahmawati, Y., Afrizal, A., Dwi Astari, D., Mardiah, A., Budi Utami, D., & Muhab, S. (2021). *The integration of dilemmas stories with STEM-project-based learning: Analyzing students' thinking* *skills using Hess' cognitive rigor matrix. Journal of Technology and Science Education, 11*(2), 419-439. https://doi.org/10.3926/jotse.1292

Rahmawati, Y., Taylor, E., Taylor, P. C., Ridwan, A., & Mardiah, A. (2022). Students' engagement in education as sustainability: Implementing an ethical dilemma-STEAM teaching model in chemistry learning. *Sustainability, 14*(6), 3554. https://doi.org/10.3390/su14063554

Ridwan, A., Rahmawati, Y., & Hadinugrahaningsih, T. (2021). STEAM integration in chemistry learning for developing 21st century skills. *MIER Journal of Educational Studies, Trends & Practices, 11*(2), 184–194. https://doi.org/10.52634/mier/2017/v7/i2/1420

Ripsam, M., & Nerdel, C. (2024). Teachers' attitudes and self-efficacy toward augmented reality in chemistry education. *Frontiers in Education, 8,* 1293571. https://doi.org/10.3389/feduc.2023.1293571

Sousa, E. R. D., Rossi, M., & Freitas Cordeiro, L. (2024). As contribuições da abordagem STEAM na educação especial. *RECIMA21 - Revista Científica Multidisciplinar, 5*(10), e5105631. https://doi.org/10.47820/recima21.v5i10.5631

Sousa, R. R. A. D., Sanchez Júnior, S. L., Afonso, L. R., & Borges, F. D. S. (2024). A integração STEAM no currículo escolar: Desafios e benefícios. *Revista Interseção, 6*(1), 251–271. https://doi.org/10.48178/intersecao.v6i1.475

Spyropoulou, N., & Kameas, A. (2023). Augmenting the impact of STEAM education by developing a competence framework for STEAM educators for effective teaching and learning. *Education Sciences, 14*(1), 25. https://doi.org/10.3390/educsci14010025

Sukoco, B. M., Putra, R. A., Muqaffi, H. N., Lutfian, M. V., & Wicaksono, H. (2023). Comparative study of ASEAN research productivity. *Sage Open, 13*(1), 21582440221145157. https://doi.org/10.1177/21582440221145157

Thelwall, M. (2018). Dimensions: A competitor to Scopus and the Web of Science? *Journal of Informetrics, 12*(2), 430–435. https://doi.org/10.1016/j.joi.2018.03.006

Tian, P., Sun, D., Han, R., & Fan, Y. (2023). Integrating micro project-based learning to improve conceptual understanding and crucial learning skills in chemistry. *Journal of Baltic Science Education, 22*(1), 130–152. https://doi.org/10.33225/jbse/23.22.130

Tupamahu, P. Z., Dasari, D., Priatna, N., & Lethulur, N. D. (2025). STEM and STEAM education in 1st decade: A bibliometric analysis (2014–2025). *Jurnal Magister Pendidikan Matematika (JUMADIKA), 7*(1), 115–130.

Wang, J., Frietsch, R., Neuhäusler, P., & Hooi, R. (2024). International collaboration leading to high citations: Global impact or home country effect? *Journal of Informetrics, 18*(4), 101565. https://doi.org/10.1016/j.joi.2024.101565

Wannapiroon, N., & Pimdee, P. (2022). Thai undergraduate science, technology, engineering, arts, and math (STEAM) creative thinking and innovation skill development: A conceptual model using a digital virtual classroom learning environment. *Education and Information Technologies, 27*(4), 5689–5716. https://doi.org/10.1007/s10639-021-10849-w

Ying, Y., & Tiemann, R. (2024). Development of an assessment tool for collaborative problem-solving skills in chemistry. *Disciplinary and Interdisciplinary Science Education Research, 6*(1), 25. https://doi.org/10.1186/s43031-024-00116-6

Zhang, S., Zhou, C., & Zhao, J. (2023). Chinese pre-service chemistry teachers' perception of augmented reality-assisted secondary chemistry learning. *Disciplinary and Interdisciplinary Science Education Research, 5*(1), 20. https://doi.org/10.1186/s43031-023-00090-5