www.ijemst.net

Investigating the Relationship between STEAM and NOS Education Bibliometrically

Konstantinos Karampelas
University of the Aegean, Greece

To cite this article:

Karampelas, K. (2025). Investigating the relationship between STEAM and NOS education bibliometrically. *International Journal of Education in Mathematics, Science, and Technology (IJEMST), 13*(2), 357-383. https://doi.org/10.46328/ijemst.4719

International Journal of Education in Mathematics, Science and Technology

2025, Vol. 13, No. 2, 357-383 https://doi.org/10.46328/ijemst.4719

Investigating the Relationship between STEAM and NOS Education Bibliometrically

Konstantinos Karampelas

Article Info

Article History

Received:
27 September 2024
Accepted:
13 February 2025

Keywords

STEAM education
Nature of Science
Bibliometrics
Sustainable Development Goals

Abstract

This paper provides a comprehensive bibliometric analysis of the relationship between Science, Technology, Engineering, Arts and Mathematics (STEAM) education and the Nature of Science. From the Web of Science platform, 8,546 articles were analyzed to address four key research topics: publication trends over time, primary academic fields contributing to research, geographical distribution of contributions and alignment of this research with the Sustainable Development Goals. The findings reveal a significant increase in the number of publications since 2020, indicating growing academic interest in interdisciplinary educational models. Technical fields such as Physics, Materials Science and Chemistry dominate STEAM research, with China and Japan leading global contributions. Additionally, this paper highlights the strong alignment between STEAM and the Nature of Science research and the Sustainable Development Goals, particularly in addressing health, clean energy and climate action. These results offer valuable insights for researchers and policymakers in developing innovative, interdisciplinary approaches to education, which address global challenges.

Introduction

In recent years, an increasing number of scholars and researchers have recognized the importance of understanding research trends in educational approaches, particularly those that employ interdisciplinary models such as Science, Technology, Engineering, Arts and Mathematics (STEAM) and foundational concepts such as the Nature of Science (NOS). Both STEAM and NOS aim to prepare students for an increasingly complex and rapidly changing world, in which skills in critical thinking, creativity and scientific literacy are paramount (Donthu et al., 2021). The integration of STEAM into traditional STEM fields adds a dimension of creativity and innovation, essential for students' holistic development and aligned with global efforts to foster problem-solving skills for future challenges (Maryanti et al., 2022; Ullah et al., 2022).

Bibliometrics is a key tool for identifying and understanding research trends, to comprehensively map publications, research areas and geographical contributions (Donthu et al., 2021). Through such analysis, one can trace how fields such as STEAM and NOS have evolved, identifying key contributions, influential authors and

areas requiring further exploration. Research trends can provide critical insights into the shifting focus of educational approaches and highlight global efforts in addressing educational challenges, particularly concerning the Sustainable Development Goals (SDGs), such as SDG 4, which emphasizes quality education for all (Maryanti et al., 2022). As education systems worldwide strive to satisfy the demands of 21st-century learning, understanding how STEAM and NOS research align with these global goals is essential.

A growing number of countries have adopted STEAM education in recent years, with notable contributions from the United States, South Korea and China (Supriyadi et al., 2023). The interdisciplinary approach fosters collaboration across disciplines, encouraging students to develop critical skills relevant across both the sciences and the arts (Ullah et al., 2022). Meanwhile, NOS provides students with a framework for understanding the construction of scientific knowledge and emphasizing the empirical, tentative and creative aspects of science (Lederman & Lederman, 2019). NOS instruction is vital in promoting scientific literacy, helping students critically engage with scientific claims and fostering informed decision-making in a society increasingly influenced by science and technology.

Meanwhile. the United Nations established the SDGs in 2015 as part of the 2030 Agenda for Sustainable Development, aiming to address global challenges and promote prosperity while protecting the planet. The 17 goals are interconnected and include the following: (1) No Poverty, (2) Zero Hunger, (3) Good Health and Well-Being, (4) Quality Education, (5) Gender Equality, (6) Clean Water and Sanitation, (7) Affordable and Clean Energy, (8) Decent Work and Economic Growth, (9) Industry, Innovation and Infrastructure, (10) Reduced Inequalities, (11) Sustainable Cities and Communities, (12) Responsible Consumption and Production, (13) Climate Action, (14) Life Below Water, (15) Life on Land, (16) Peace, Justice and Strong Institutions and (17) Partnerships for the Goals. These goals serve as a universal call to action for countries, organizations and individuals to work together toward a more sustainable and equitable future. STEAM education and NOS play an increasingly important role in achieving many of these goals, particularly in areas such as Goal 4 (Quality Education), Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action), by fostering innovation, critical thinking and problem-solving skills needed to address global challenges (Maryanti et al., 2022).

Even though there have been bibliometric studies around the trends on STEAM and NOS respectively, there has been no such study that examines both STEAM and NOS research. A study like this would not only outline how these educational models have developed but also identify how trends in research developed over time, as well as key research areas and geographical contributions. Such an analysis would help map the global impact of STEAM and NOS education and reveal how these approaches contribute to the SDGs, particularly in promoting inclusive and equitable education. By analyzing publication trends, research areas and country affiliations, a comprehensive understanding of STEAM and NOS can guide future educational policies and practices, ensuring that both approaches are leveraged to foster innovation, creativity and scientific literacy in learners worldwide.

Literature Review

The existing literature on STEAM education and NOS underscores the increasing recognition of interdisciplinary

approaches in education. Both areas emphasize the integration of creativity and scientific inquiry to enhance critical thinking, problem-solving and scientific literacy among students. These educational frameworks are being explored globally as tools for addressing 21st-century challenges (Lederman & Lederman, 2019; Supriyadi et al., 2023).

STEAM Education

STEAM education, as an innovative integrating field of Science, Technology, Engineering, Art and Mathematics, has emerged as a significant interdisciplinary approach in modern education systems, aimed at fostering critical thinking, creativity and problem-solving skills among students. As education systems around the world seek to prepare students for a rapidly changing and technologically advanced society, STEAM offers a more holistic approach than traditional STEM—Science, Technology, Engineering and Mathematics—does by integrating the arts. This interdisciplinary model not only addresses technical skills but also emphasizes creative, artistic and social dimensions crucial for the development of well-rounded individuals in the 21st century (Ismiati, 2024; Niu & Cheng, 2022).

The transition from STEM to STEAM reflects an evolving understanding of the role of education in equipping students with the necessary tools for the future. While STEM emphasizes technical and scientific knowledge, STEAM integrates the arts to promote a broader range of skills, including creativity, critical thinking and innovation (Qizi, 2024). According to Niu and Cheng (2022), adding the arts into STEM transforms learning into a more inquiry-based and encouraging creativity, which is an increasingly critical skill in modern economies. STEAM education seeks to bridge the gap between scientific and artistic disciplines, recognizing that creativity is not confined to the arts alone. Both scientific and artistic fields benefit from imaginative thinking, experimentation and innovation. As Steve Jobs famously said, "Technology alone is not enough." In his view, the fusion of technology with the humanities produces innovative outcomes that appeal to human emotions and aspirations, an essential element for success in today's market. Incorporating arts into science and technology fosters a deeper understanding of how these fields interact with societal and cultural contexts. This approach is especially relevant in addressing contemporary challenges, such as environmental sustainability, in which both technical solutions and ethical considerations must be balanced (Nyaaba et al., 2024; Qizi, 2024).

STEAM education has been shown in the literature to have significant benefits. First, STEAM education can promote a comprehensive skill set. STEAM encourages the development of not only technical skills but also creativity, collaboration and communication. These competencies are critical for success in a world increasingly dominated by automation and artificial intelligence. Many traditional STEM fields, such as programming and engineering, are vulnerable to automation, but skills in creative thinking and human-centered design are more resistant to this trend (Ismiati, 2024; Qizi, 2024; Salcedo et al., 2024).

Second, STEAM education emphasizes hands-on learning and project-based approaches, which help students connect theoretical knowledge to practical applications. This method makes learning more relevant to real-world scenarios. According to Ismiati (2024), project-based learning in STEAM promotes critical analysis of real-world

phenomena, fostering students' abilities to approach problems from multiple perspectives. Such experiences are essential in preparing students for the complexities of modern challenges, in which interdisciplinary solutions are often required.

Third, by integrating arts and creativity into the curriculum, STEAM education fosters greater student engagement. Studies have shown that students are more motivated when they can explore their interests and connect learning to their own experiences. The flexibility of STEAM allows students to engage with subjects meaningfully, leading to higher levels of participation and enthusiasm (Ismiati, 2024; Qizi, 2024).

Finally, a key goal of STEAM education is cultivating an innovative mindset. Creativity, often nurtured through the arts, is fundamental to innovation. By encouraging students to think beyond traditional disciplinary boundaries, STEAM prepares them to devise novel solutions to problems. This innovative capacity is crucial in fields such as engineering, technology and even business, in which creative problem-solving is often the key to success (Niu & Cheng, 2022; Nyaaba et al., 2024; Qizi, 2024).

The STEAM approach is gaining traction globally, with education systems across various countries integrating it into their curricula. For example, in the United States, STEAM is seen as a response to the growing need for more creative professionals in fields such as technology and engineering. In Finland, STEAM education aligns with the country's innovative educational practices, which emphasize interdisciplinary learning and critical thinking (Niu & Cheng, 2022; Nyaaba et al., 2024; Perales & Arostegui, 2024). Countries such as China and Taiwan have also adopted STEAM approaches to foster innovation and creativity among students. Research conducted in these regions highlights the effectiveness of STEAM in promoting critical thinking and creativity, skills essential for adapting to the fast-changing global economy (Niu & Cheng, 2022; Qizi, 2024). In Indonesia, STEAM has been incorporated into the "Merdeka Curriculum," which emphasizes independent learning and 21st-century skill development. This approach not only enhances student engagement but also prepares them for future careers by emphasizing real-world applications of knowledge (Perales & Arostegui, 2024; Qizi, 2024).

The successful implementation of STEAM education depends heavily on the competencies of teachers. Studies have shown that teachers with creative competencies are more likely to engage students in innovative learning activities. Teachers must be equipped to foster both the technical and the creative aspects of STEAM, which involves not only teaching subject-specific content but also guiding students in interdisciplinary thinking and problem-solving. Furthermore, the classroom environment plays a crucial role in facilitating STEAM education. A creative and flexible learning environment encourages students to collaborate and explore ideas freely. Teachers are tasked with setting up inquiry-based learning experiences for students to experiment and take ownership of their learning (Niu & Cheng, 2022; Perales & Arostegui, 2024).

Despite its many benefits, STEAM education faces several challenges. One of the primary barriers is the need for teacher training and professional development. Many educators are not yet equipped to implement STEAM curricula effectively, often lacking resources and infrastructure to support this type of education. Moreover, integrating arts into traditionally STEM-focused subjects can encounter resistance, particularly in educational

systems that prioritize standardized testing and rigid curricula. Overcoming these barriers requires a shift in educational priorities, emphasizing creativity, innovation and interdisciplinary learning as key outcomes of the educational process (Ismiati, 2024; Qizi, 2024).

STEAM education represents a forward-thinking approach to learning that aligns with the demands of the 21st century. By integrating the arts with science, technology, engineering and mathematics, STEAM fosters a more holistic set of skills that include creativity, collaboration and critical thinking. These competencies are essential for preparing students for a future in which technological advances will continually reshape the job market and societal expectations. As countries around the world increasingly adopt STEAM approaches, this interdisciplinary model clearly offers valuable tools for both educators and students. STEAM not only enhances academic performance but also prepares students to navigate the complexities of modern life, in which innovative and creative problem-solving will be more critical than ever before (Ismiati, 2024; Niu & Cheng, 2022; Nyaaba et al., 2024; Qizi, 2024). By embracing STEAM, educational systems can cultivate a generation of learners who are not only technically proficient but also capable of thinking creatively and critically in ways that will define the future of innovation (Perales & Arostegui, 2024).

NOS and Education

Bell and Lederman (2003) emphasize the importance of teaching NOS to foster scientific literacy, which goes beyond the simple memorization of facts and theories. NOS refers to the values, assumptions and principles inherent in scientific knowledge, including its tentativeness, creativity and empirical nature. Teaching NOS is crucial for developing individuals' abilities to evaluate scientific claims critically and apply scientific understanding to real-world decisions, particularly in areas involving complex science and technology issues. The authors argue that NOS instruction helps students understand not only the outcomes of scientific inquiry but also the processes of constructing scientific knowledge. This, in turn, equips students with tools to distinguish between sound scientific practices and pseudoscientific claims, making them better-informed citizens capable of making reasoned decisions in a society increasingly impacted by science and technology. However, the article reveals a gap between the intended outcomes of NOS education and its practical application in decision-making. The study showed that participants, regardless of their understanding of NOS, often based decisions on personal values and social concerns rather than on scientific reasoning alone. Thus, the authors suggest that NOS instruction, while essential, should be complemented by value-based education and attention to intellectual and moral development to improve decision-making on science-related issues.

Irzik and Nola (2011) advocate the Family Resemblance Approach (FRA) in science education as an alternative to the "consensus view" of NOS. The consensus view, widely adopted in science education, focuses on a set of agreed-upon characteristics of science, such as its empirical, tentative, theory-laden and socially and culturally embedded nature. However, the authors argue that this view is too narrow and monolithic, as it overlooks the diversity within scientific disciplines and fails to capture the full richness of science. The FRA, inspired by Wittgenstein's notion of family resemblance, suggests that science should be viewed as a system with overlapping characteristics across different disciplines, rather than a single set of defining features. It encompasses four major

categories: scientific activities, aims and values, methodologies and methodological rules and scientific products. This approach emphasizes that while different scientific disciplines may share some of these features, not all features are present in every discipline. For example, some sciences rely more on observation than on experimentation and not all sciences focus on predictions. The FRA is presented as a more flexible and comprehensive framework accounting for both the unity and the diversity of scientific practices. The article also highlights the pedagogical advantages of FRA in the classroom, as it encourages critical thinking and allows students to appreciate the complexity and dynamic NOS without being constrained by rigid definitions.

Wu and Erduran (2024) highlight the importance of teaching NOS as a key component of science education, particularly to foster scientific literacy. NOS encompasses the values, assumptions and methodologies that define scientific knowledge and practice, including its tentative, empirical and creative aspects. Understanding NOS allows students to evaluate scientific claims critically, grasp the processes behind scientific discoveries and engage more thoughtfully with science-related issues in society. The authors argue that NOS instruction extends beyond factual knowledge. It helps students comprehend the methods and reasoning that scientists use to develop theories and conclusions. This understanding empowers individuals to make informed decisions about science and technology, especially in an era in which such issues dominate public discourse. By learning NOS, students become more adept at distinguishing between legitimate scientific practices and pseudoscience, fostering their role as informed citizens. The article also discusses the challenges of effectively teaching NOS. Despite the educational value of NOS, many individuals make decisions based on personal values or societal concerns rather than purely scientific reasoning. This observation suggests that NOS instruction, while critical, needs to be paired with education in ethics, values and critical thinking to improve science-related decision-making. The authors advocate for a more integrated approach to science education, in which NOS is not just a stand-alone topic but also woven into broader educational goals, helping students to develop a more nuanced and reflective understanding of both science and society.

Simultaneously, Bugingo et al. (2024) discuss the importance of improving teachers' and students' understanding of NOS through active instructional approaches. NOS refers to the epistemology and sociology of science, including its processes, values and assumptions. Understanding NOS is essential for fostering scientific literacy, enabling both students and teachers to grasp how scientific knowledge is developed, validated and applied. It also empowers them to engage with socio-scientific issues critically. The literature review reveals that both teachers and students often have misconceptions about NOS. For instance, the relationship between scientific theories and laws is misunderstood, with many viewing theories as proven facts that become laws over time. Additionally, misconceptions exist regarding the empirical NOS, observations and inferences and the creative aspects of scientific inquiry. Active instructional approaches, particularly explicit and reflective methods, are emphasized as effective tools for improving the understanding of NOS. These approaches involve directly addressing NOS concepts within the science curriculum, encouraging students to reflect on the nature and processes of science as part of their learning. Studies show that these methods enhance comprehension of key NOS concepts, though some regions still show a significant gap, especially in developing countries such as Sub-Saharan Africa. The article underscores that while instructional interventions have been successful, more needs to be done to ensure these approaches are consistently applied, particularly in contexts in which educational resources and teacher

training are limited. The integration of NOS into science education, combined with effective instructional strategies, is vital for developing a scientifically literate population capable of informed decisions about science and technology.

Dagher and Erduran (2016) explore the importance of expanding how NOS is conceptualized and taught in science education. The authors propose an enhanced version of the FRA, initially developed by Irzik and Nola (2011), which integrates both cognitive-epistemic and social-institutional aspects of science. This expanded framework aims to offer a more holistic view of science, which is essential for curriculum development and instruction. The FRA framework identifies shared and distinct features across scientific disciplines, emphasizing that science is not defined by a single set of characteristics but by a broad range of practices, methodologies and social norms. This approach is valuable because it allows for flexibility in teaching NOS, providing educators with a more inclusive tool to explain the complex and multifaceted NOS. The authors argue that the traditional "consensus view" of NOS, focusing on seven key tenets, is too limited and oversimplifies the nature of scientific inquiry. The expanded FRA encourages a broader understanding by including elements such as scientific ethos, professional activities and social values. The article emphasizes the need for an instructional shift from rigid NOS tenets, instead fostering critical thinking and inquiry-based learning. This reconceptualized approach to NOS not only enhances scientific literacy but also prepares students to engage critically with real-world scientific and technological issues. The FRA framework supports a more nuanced and reflective understanding of science, which can be integrated into curricula, textbooks and teacher training programs.

Bibliometric Studies on STEAM Education

STEAM education has attracted the interest of bibliometricians over the last few decades. Supriyadi et al. (2023) provides a comprehensive bibliometric analysis of research trends in STEAM education, based on the Scopus database. The study focuses on three key research questions: the progress of STEAM education research, influential contributors in the field and the global affiliations and countries contributing to this research. The study utilized bibliometric tools, specifically the Bibliometrix R-tool and BiblioShiny software, to analyze data from Scopus, identifying patterns and trends in STEAM education publications. The findings reveal that the annual growth rate of STEAM-related publications is 24.19%, reflecting a significant spurt in research in this field. Over 529 documents, including journal articles, conference papers and books, were analyzed, showing the increasing popularity of STEAM in educational discourse. The study also highlights South Korea as the leading contributor to STEAM research, with Jeju National University and the Korea National University of Education producing the highest number of STEAM-related publications. This bibliometric study underscores the global interest in STEAM education and its growing impact on educational research and practice. By identifying key contributors and trends, this study provides insights for researchers and policymakers to enhance global cooperation and further advance the field of STEAM education.

Jamali et al. (2023) presented a bibliometric analysis of the connection between STEM education and the improvement of educational quality, particularly in the context of Sustainable Development Goal 4 (SDG 4)—Quality Education. This study emphasizes the growing role of STEM (Science, Technology, Engineering and

Mathematics) in shaping educational outcomes, addressing both cognitive and socio-economic challenges and preparing students for real-world problems. The authors comprehensively analyze 150 publications from the Scopus database between 1993 and 2020. Through tools such as VoSviewer and Bibliometrix, the study highlights key trends, the most influential authors and journals, research hotspots in STEM education and its role in enhancing educational quality. The United States emerged as the leading research contributor, with "Science Education" ranked as the most frequently cited journal. Topics such as early childhood education, computing education and environmental education are among the most active research areas within STEM as per the study. The analysis suggests that integrated STEM approaches, particularly those linked to project-based learning and problem-solving, can significantly enhance the quality of education by fostering interdisciplinary skills, creativity and real-world application. This study provides a foundation for future research, advocating for further exploration of STEM's role in educational systems, especially in the context of global sustainability initiatives.

Phuong et al. (2032) analyzed 750 publications from the Scopus database from 2006 to 2022 to assess through case studies the global progress in implementing STEM education. This study aims to provide an in-depth understanding of key trends, influential authors and the research directions within the field. The analysis reveals a significant increase in STEM case study publications, particularly over the last five years, with a 30.47% annual growth rate. The most productive country is the United States, accounting for 57.7% of the total publications and 72% of total citations. Other notable contributors include the UK, Türkiye, Australia and China. The study also highlights the most impactful authors, with the majority from the United States and key publications that have shaped the discourse on STEM education. Three main research directions are identified: STEM education in higher education, the expansion of STEM to STEAM (integrating the arts) and STEM activities in K-12 education. The study underscores the growing significance of interdisciplinary approaches and the increasing integration of STEAM in education. Overall, this bibliometric study offers valuable insights for educators and policymakers, providing a roadmap for future research on the global implementation of STEM education. It also emphasizes the necessity for continuous monitoring and analysis of the rapidly evolving research landscape to enhance STEM education outcomes worldwide.

Wijayanti et al. (2024) investigated the integration of STEAM and ideology-based education, focusing on developing students' critical and creative thinking skills. This bibliometric analysis uses VOSviewer and Scopus databases to analyze 704 documents, concentrating on the intersection between national ideology and STEAM approaches in science education. The authors explore how the STEAM approach, which traditionally emphasizes interdisciplinary learning by integrating science and the arts, can be aligned with nation-centric pedagogies. Specifically, the study highlights the potential of using national ideologies, such as Indonesia's Pancasila, to shape education and promote the development of essential cognitive skills in students. This approach supports the growth of students' national identity and character alongside their academic and scientific knowledge. The findings from the bibliometric analysis reveal that integrating national ideology with STEAM in science education is a relatively underexplored area, presenting opportunities for future research. The study identifies key themes, research trends and influential authors in the field, shedding light on how this intersection can be further explored to benefit educators, policymakers and researchers. Ultimately, the article concludes that combining ideology-based education with the STEAM approach promises to advance education by nurturing critical and creative

thinking, fostering national identity and improving the quality of science education programs.

Several trends are common across various bibliometric analyses, illustrating the global rise and importance of STEAM education research. One of the shared findings is the significant annual growth in STEAM-related publications, reflecting increasing global recognition of the value of integrating arts into traditional STEM fields. This trend is supported by Supriyadi et al. (2023), Jamali et al. (2023) and Phuong et al. (2023), who consistently emphasize that STEAM's interdisciplinary approach fosters critical thinking, creativity and innovation, which are vital for preparing students for complex, real-world challenges. Countries such as the United States and South Korea and institutions such as Jeju National University emerge as leading contributors, highlighting the global commitment to advancing STEAM education. Another recurring theme across the studies is the growing emphasis on real-world applications through project-based learning and problem-solving approaches. This shift from theoretical knowledge to practical, hands-on learning is a defining characteristic of STEAM education, facilitating students' ability to engage with interdisciplinary challenges and promoting a more holistic skill set. Bibliometric analyses highlight that this approach is becoming increasingly central to educational systems worldwide, particularly in K-12 and higher education settings (Ismiati, 2024; Niu & Cheng, 2022). Moreover, all studies acknowledge the necessity of equipping teachers with the skills to implement STEAM curricula effectively. A common challenge identified in these analyses is the need for more comprehensive teacher training and resources, which are crucial for fostering creative competencies and guiding interdisciplinary learning in classrooms (Perales & Arostegui, 2024). The studies also point to an emerging, yet underexplored, area: the integration of national ideologies with STEAM education. Wijayanti et al. (2024) highlight the potential for this integration to foster not only cognitive development but also national identity and character, providing new opportunities for research and pedagogical innovation. Collectively, these bibliometric studies underline the evolving nature of STEAM education as a globally relevant, interdisciplinary framework that enhances both technical skills and cultural awareness, positioning it as a key driver in the future of education (Nyaaba et al., 2024; Qizi, 2024).

Bibliometric Studies on NOS

NOS has also been a field that bibliometricians have investigated. Bilen and Kurtuluş (2021) conducted a comprehensive bibliometric analysis of research trends in NOS within science education from 1986 to 2019. By analyzing 799 studies from the Web of Science Core Collection database, the study identifies key trends, prolific authors and geographic contributions to NOS research over 33 years. The analysis shows that the first publication on NOS was by Lederman in 1986, with research interest accelerating after 2005. The highest publication rate occurred between 2016 and 2019, accounting for 33% of total publications, reflecting increasing global engagement with NOS topics. Key leading journals in NOS publications include the Journal of Science Education, Science & Education and Science Education. The United States, Türkiye and the United Kingdom are identified as the top contributors to NOS research, with the USA producing the most publications. The study also highlights the importance of international collaborations, with countries such as South Korea and Canada having a higher rate of multiple-country publications, suggesting stronger collaborative research networks compared to countries such as the USA and Türkiye, which have lower multiple-country publication scores. Common keywords across the studies include "views," "students," and "knowledge," indicating consistent research focuses on students'

understanding of NOS. The study concludes that NOS remains a crucial topic in science education, with growing attention over time and suggests further exploration of NOS through expanded bibliometric analyses using other databases such as Scopus and ERIC.

Xue et al. (2018) provided a comprehensive bibliometric analysis of resilience research across various domains, such as social-ecological systems, engineering, disaster management and organizational behavior. Resilience, originating from the Latin word "resilio," meaning "to jump back," has evolved significantly as a scientific concept since the 1970s. This analysis uses data from the Web of Science from 1985 to 2014, examining 6,502 articles to trace the evolution of resilience research. The article identifies three primary research domains: social-ecological resilience, engineering and disaster resilience and economic and organizational behavior resilience. Each domain has distinct definitions and focuses, but all emphasize the ability of systems—natural, human, or engineered—to recover from disturbances and maintain their functions. The authors use bibliometric tools to map the geographic distribution of resilience research, highlighting that the United States, the United Kingdom and Australia are leading contributors. Moreover, collaborations between institutions and the growing body of international co-authored publications underscore the global importance of resilience research. The article also tracks the evolution of research topics, with resilience in social-ecological systems being the most developed and influential area, while resilience in engineering and disaster domains has demonstrated increasing prominence due to growing concerns about climate change and urban infrastructure. Bibliometric analysis identifies key authors, journals and institutions, providing a roadmap for future research to address emerging challenges in resilience science. The study concludes by emphasizing the need for continued interdisciplinary collaboration and the refinement of resilience measurement methods to support sustainable development and disaster preparedness.

Yanuarti and Suprapto (2021) presented a comprehensive bibliometric analysis of research trends over the last decade in the history of science, particularly focused on physics. Using data from the Scopus database, the study identifies 1,978 relevant publications from 2011 to 2020. The findings indicate that research in this field has been stable, with prominent sources including journals focusing on Science Education, Nature, Environment and Social Studies. The United States leads in the volume of research publications, followed by the United Kingdom and Germany. Major institutions contributing to this body of work include the Centre national de la recherche scientifique (CNRS) from France, the Russian Academy of Sciences and the University of Cambridge. The study identifies four main research clusters: (1) historical figures and their contributions, (2) the relationship between the history and philosophy of science, (3) the development of science in various countries over time and (4) the role of universities and relevant projects in advancing the history of science. Several multi-cited articles emphasize the intersection of natural history and science education. The analysis underscores the growing interest in integrating the history and philosophy of science into science education, providing a roadmap for future research. Overall, this bibliometric study offers valuable insights into the key trends and contributors shaping the field of the history of science in the past decade.

Literature Review Around STEAM and NOS

The review of existing literature on STEAM education and NOS highlights the growing emphasis on

interdisciplinary education to foster creativity, scientific literacy and problem-solving abilities in students. Studies such as Supriyadi et al. (2023), Jamali et al. (2023) and Ullah et al. (2022) have demonstrated the value of integrating these frameworks to address both educational and societal challenges, particularly in the context of developing 21st-century skills. Lederman and Lederman (2019) also emphasize the importance of NOS in promoting critical thinking and scientific reasoning, reinforcing the idea that understanding the nature of scientific inquiry is crucial for preparing students to engage with real-world issues.

Furthermore, Maryanti et al. (2022) highlight the growing alignment between STEAM education and global sustainability initiatives, such as the SDGs, particularly in the areas of health, clean energy and climate action. Despite these advancements, much of the existing research focuses on theoretical applications or regional studies, leaving gaps in understanding the broader, global trends of STEAM and NOS integration across educational systems. Xue et al. (2018) and Yanuarti and Suprapto (2021) have pointed out the necessity for more comprehensive global analyses to fully understand how these frameworks are being implemented and what their impact on educational outcomes is.

Method

This study employed bibliometrics to examine the research trends regarding the integration of STEAM education and NOS. By utilizing the WoS platform, a comprehensive dataset of 8,546 articles was analyzed, focusing on publication trends, academic fields, geographical contributions and alignment with the SDGs. The methodology clearly maps global research trends in these interdisciplinary fields.

Rationale of the Study

A bibliometric study focused on research trends in the relationship between STEAM and NOS is crucial to understanding how these interdisciplinary fields have developed and continue to shape educational practices worldwide. Such a study would help map the landscape of STEAM and NOS research, providing insights into publication trends, research areas, countries, affiliations and their alignment with the SDGs, particularly SDG 4 on Quality Education (Jamali et al., 2023). STEAM's interdisciplinary approach, integrating STEAM, has become increasingly recognized for fostering creativity, critical thinking and problem-solving skills essential for 21st-century learners (Supriyadi et al., 2023). Similarly, NOS emphasizes the values, assumptions and methodologies behind scientific inquiry, which are critical for developing scientific literacy and informed decision-making in complex, science-based societal issues (Bell & Lederman, 2003; Bilen & Kurtuluş, 2021).

Tracking the number of publications per year is important for identifying how research interest in these areas has grown. Bibliometric studies have shown an annual increase in publications related to STEAM education, with Supriyadi et al. (2023) reporting a 24.19% rise, reflecting growing global engagement. A bibliometric study examining both STEAM and NOS would reveal similar or distinct trends, helping to benchmark the development of these fields against each other and providing a timeline of key milestones. Analyzing the research areas, or fields of study, allows the identification of dominant themes in STEAM and NOS. STEAM, for instance, has been

strongly linked to creativity and innovation through project-based learning (Ismiati, 2024), while NOS research has focused on the empirical and tentative nature of scientific knowledge (Wu & Erduran, 2024). Identifying which fields of study have embraced these approaches will help educators and policymakers recognize areas of strength and those needing further exploration. Geographic contributions also play a significant role in understanding global research trends. Countries such as the United States, South Korea and the UK are major contributors to both STEAM and NOS research (Bilen & Kurtuluş, 2021; Supriyadi et al., 2023). This trend underscores the importance of cross-national collaboration in advancing these fields. A bibliometric analysis of STEAM and NOS research would map such collaborations and reveal potential gaps in global contributions. Finally, connecting these research trends to the SDGs, especially SDG 4, would provide valuable insights into how STEAM and NOS contribute to global educational priorities. Studies like those by Jamali et al. (2023) emphasize the role of STEM and STEAM in enhancing educational quality and addressing socio-economic challenges, demonstrating how such research aligns with broader global goals. In short, a bibliometric study examining research trends on the relationship between STEAM and NOS would comprehensively overview their development, highlighting key themes, contributors and their impact on sustainable education. This type of analysis can inform future research, guiding educators and policymakers toward more effective and innovative educational practices that align with global sustainability goals.

Data Collection and Analysis

The purpose of this research is to explore the trends in the relationship between STEAM and NOS through comprehensive bibliometrics. To achieve this, the WoS platform was utilized, as it is widely recognized for bibliometric studies due to its vast database and robust analytical tools (Donthu et al., 2021). The study focused on a detailed query, searching for all articles that contained STEAM education (including 'STEAM Education', 'STEM Education' and other variations) and NOS terms. Specifically, the query was structured as follows:

> (ALL=(STEAM Education OR 'Science, Technology, Engineering, Arts, Mathematics Education' OR 'STEM Education' OR 'Science, Technology, Engineering and Mathematics Education' OR STEAM OR STEM)) AND ALL=('Nature of Science' OR NOS Education).

This search yielded 8,546 articles. Utilizing the advanced functions of the WoS platform, the extracted data was organized and analyzed to address four key research questions:

1. What are the publication rates of articles that examine STEAM and NOS over time?
2. What are the main academic fields of the authors contributing to these publications?
3. Which countries, regions and affiliations lead in the number of publications on this topic?
4. How do these publications align with the United Nations' SDGs?

By answering these questions, the study aims at a comprehensive review of the trends in research focused on the intersection of STEAM education and NOS. This analysis offers insights into the growth of the field, the geographical and disciplinary spread of research and the ways in which this research aligns with global educational and sustainability priorities (Donthu et al., 2021; Korkmaz & Toraman, 2024; Muhammad et al., 2024).

Results

The findings reveal several key trends in the relationship between STEAM education and NOS. A significant rise in publications has been observed since 2020, primarily driven by contributions from East Asia. Technical fields, such as Physics and Materials Science, dominate the research, while STEAM and NOS research aligns strongly with global sustainability goals, especially in health and clean energy.

Publication Rates

The first key research question examined the publication rates of articles focusing on the relationship between STEAM education and NOS. The analysis of data, as seen in Figure 1, reveals a significant upward trend in publications over recent years, especially from 2020 onwards, with a notable peak in 2022. Before 2010, research on the intersection of STEAM and NOS was relatively limited, comprising less than 3% of the total output, indicating the still nascent interest in this field. The steady growth after 2015 signals a growing academic awareness of the value of integrating into these interdisciplinary fields. This surge in publications underscores the increasing recognition of the need for educational models that combine scientific literacy with creative thinking to prepare students for the challenges of a rapidly evolving world. As STEAM education introduces the arts into traditional STEM disciplines, it promotes not only technical proficiency but also innovation, design thinking and problem-solving, making it a key focus for researchers. Simultaneously, the emphasis on NOS provides a crucial framework for understanding the scientific process, encouraging students to appreciate the empirical, creative and tentative nature of scientific knowledge.

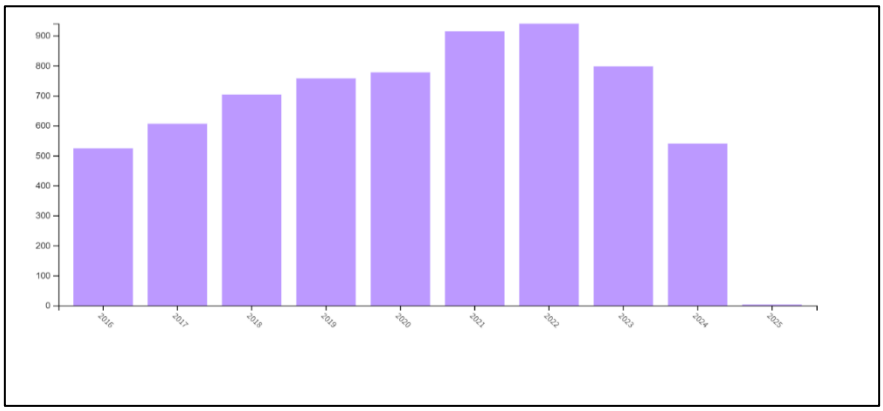

Figure 1. Publication Rates

This growth in publication rates aligns with findings from previous bibliometrics (Supriyadi et al., 2023; Jamali et al., 2023; Phuong et al.,2023). Research on NOS has also followed a comparable path, as evidenced by earlier studies too (Xue et al., 2018; Yanuarti & Suprapto, 2021). The convergence of these two fields demonstrates their growing importance in modern educational practices, with both STEAM and NOS increasingly viewed as essential components for fostering well-rounded, scientifically literate individuals. The parallel rise in publications suggests that interdisciplinary approaches to education, which emphasize creativity alongside scientific understanding, are gaining momentum, reflecting a broader shift toward preparing students for the

complexities of the 21st century (Supriyadi et al., 2023; Xue et al., 2018).

Academic Fields

The second key research question focused on identifying the research areas contributing to publications on the relationship between STEAM education and NOS. The data, as shown in Figure 2, reveal that the majority of publications fall within scientific and technical disciplines, with Physics (18.179%) and Materials Science (17.418%) making up the largest proportion of the total research output. Chemistry (15.744%) and Science and Technology (14.070%) are also prominent, while Engineering (11.951%) further highlights the emphasis on fields that integrate technical expertise and innovation. Education and Educational Research, while directly related to the context of STEAM and NOS, represent a smaller fraction (2.013%) of the total, suggesting that research in these areas is still emerging in comparison to more traditional scientific fields. Other significant areas include Mathematics (7.971%), Cell Biology (7.246%) and Biochemistry and Molecular Biology (5.022%).

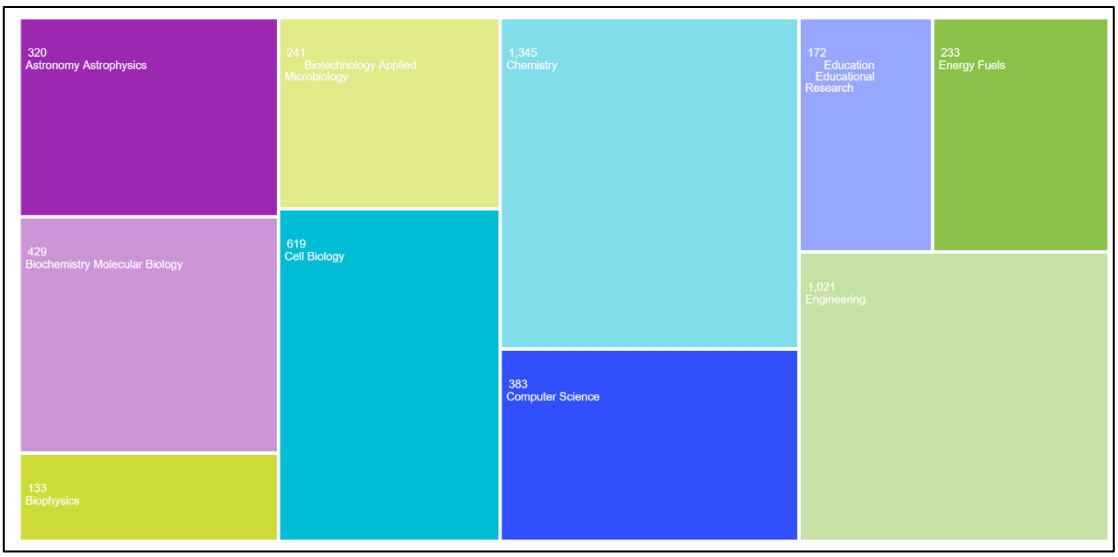

Figure 2. Academic Fields

These findings indicate that the relationship between STEAM and NOS is primarily explored within technical and scientific fields, reflecting the strong focus on integrating STEM disciplines with NOS to enhance students' understanding of scientific processes and innovation. In STEAM education, the emphasis on bridging scientific rigor with creativity, particularly in fields such as Engineering, Materials Science and Physics, underscores the growing recognition of interdisciplinary approaches that combine scientific inquiry with problem-solving and design thinking (Jamali et al., 2023; Supriyadi et al., 2023). In contrast, NOS-focused research has traditionally found stronger ties in educational fields, particularly as it relates to improving students' understanding of how scientific knowledge is constructed (Xue et al., 2018). The smaller representation of Education and Educational Research in this study suggests that integrating NOS with technical STEAM disciplines may still be an emerging trend, gaining momentum as researchers increasingly recognize the value of including NOS within broader educational frameworks (Yanuarti & Suprapto, 2021). The combination of technical fields with educational research points to a growing interdisciplinary dialogue that seeks to merge rigorous scientific training with

reflective, inquiry-based learning, aligning with the goals of both STEAM and NOS to develop well-rounded, scientifically literate students (Phuong et al., 2023).

Countries and Affiliations

The third key research question examined both the countries and the affiliations contributing to research on the relationship between STEAM education and NOS. In terms of countries, as seen in Figure 3, China leads by a wide margin, contributing 67.318% of the total research output, followed by the United States with 20.204% and Japan with 24.137%. Other notable contributors include Germany (6.075%), England (5.771%) and South Korea (4.881%). When examining institutional affiliations, as seen in Figure 4, the Chinese Academy of Sciences stands out as the most prolific contributor, with 11.050% of the total publications, reinforcing China's leadership in this area. Japanese universities such as Kyoto University (3.570%), the University of Tokyo (5.818%) and Shanghai Jiao Tong University (3.629%) also feature prominently, indicating that East Asia is heavily invested in research exploring the integration of STEAM and NOS. Other key affiliations include the Centre National de la Recherche Scientifique (CNRS) in France (3.313%) and the University of California System (3.348%) in the United States, highlighting the global engagement in this field.

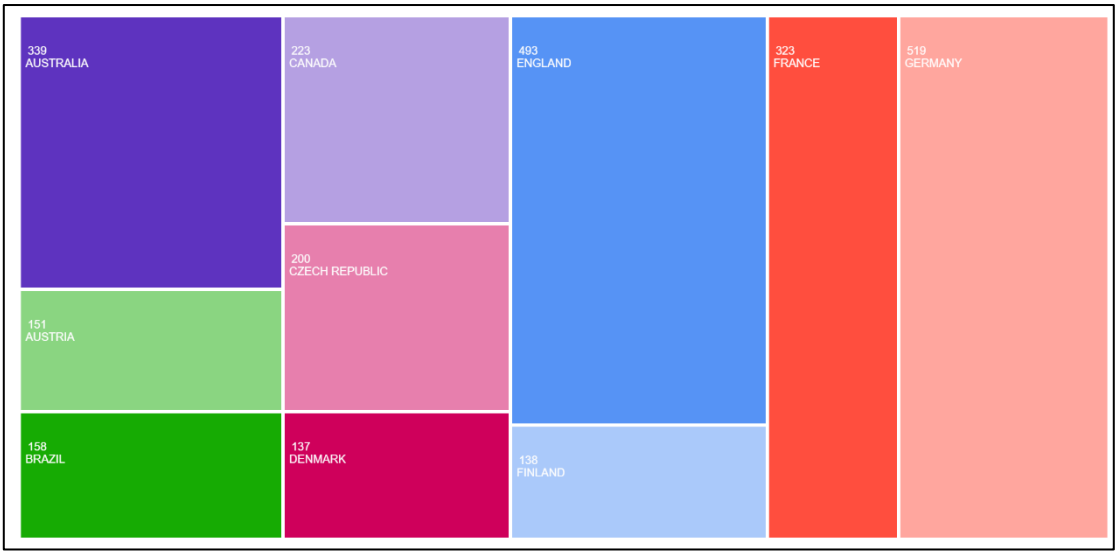

Figure 3. Countries and Regions

This geographical and institutional distribution reflects a broader trend of research concentration in regions with strong scientific and technological infrastructures, particularly East Asia and the United States. China's dominance, as seen through its leading affiliations and overall research output, is consistent with findings from other studies that note China's growing investment in educational reform and interdisciplinary research (Supriyadi et al., 2023; Phuong et al., 2023). The high presence of Japanese institutions further aligns with the country's long-standing focus on science and technology education. In comparison, NOS-focused research has traditionally had a more diverse geographical spread, with significant contributions from Europe and North America (Xue et al., 2018; Yanuarti & Suprapto, 2021). However, the integration of STEAM and NOS appears to be more concentrated in regions with strong STEM infrastructures, as evidenced by the leading roles of Chinese and Japanese

institutions, which are increasingly embracing interdisciplinary approaches in education. This trend emphasizes the growing global importance of STEAM and NOS, especially in countries and institutions aiming to push the boundaries of educational innovation and scientific literacy.

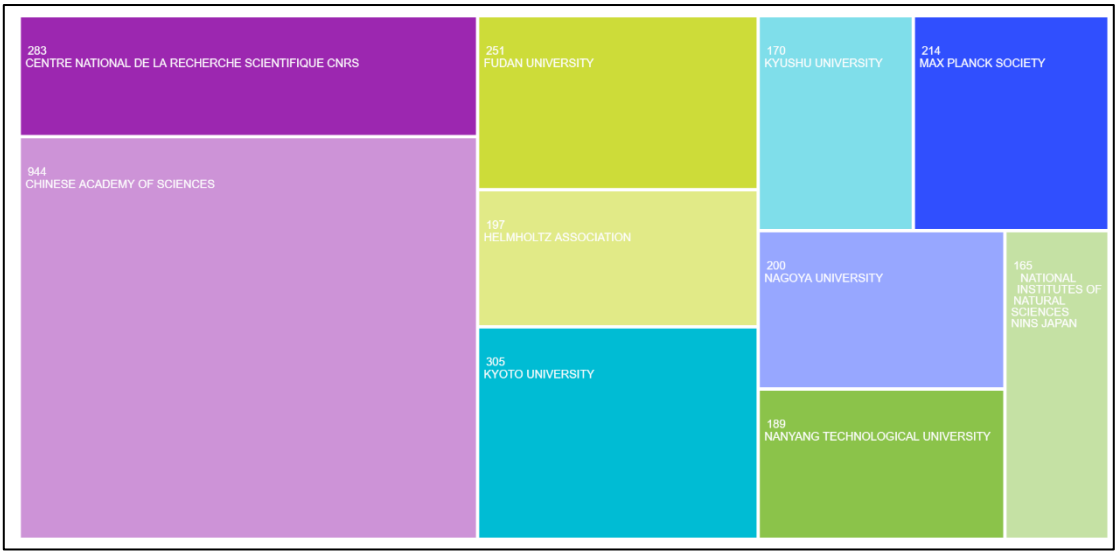

Figure 4. Affiliations

Sustainable Development Goals

The fourth key research question addressed which SDGs are represented in the research on the relationship between STEAM education and NOS. The analysis, as shown in Figure 5, indicates that Goal 3 (Good Health and Well-Being) is the most frequently addressed, with 43.029% of the total publications contributing to this SDG.

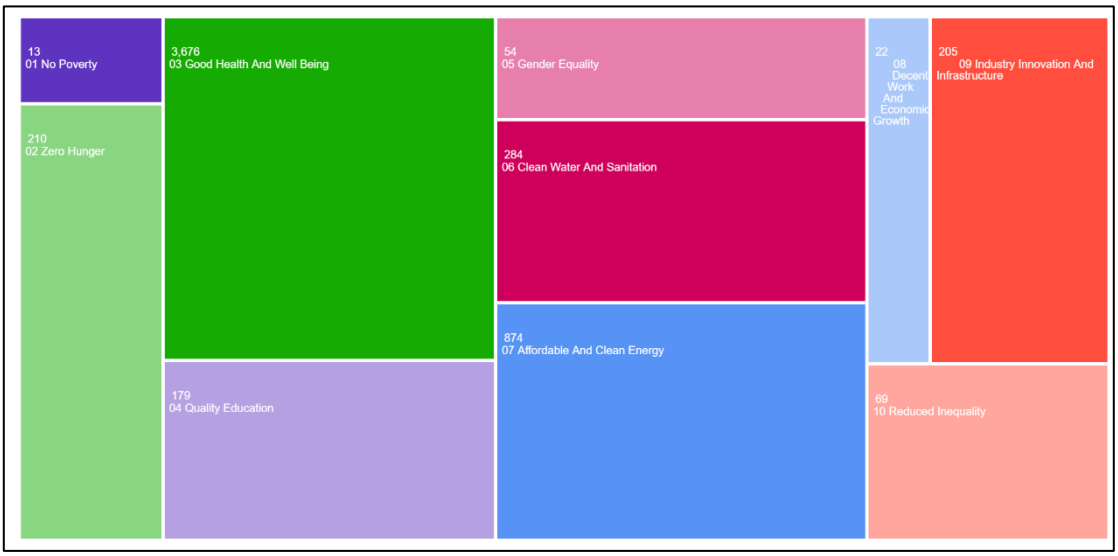

Figure 5. Sustainable Development Goals

Other prominent goals include Goal 7 (Affordable and Clean Energy, 10.231%) and Goal 13 (Climate Action, 7.117%), highlighting the focus on health, energy and environmental sustainability in STEAM and NOS research.

Additionally, Goal 4 (Quality Education)—which directly aligns with the educational objectives of both STEAM and NOS—accounts for 2.095% of the research, reflecting growing attention to improving educational practices through interdisciplinary approaches.

This distribution indicates that research on STEAM and NOS is not only centered around advancing scientific and technological literacy but also addresses broader societal challenges, such as health and environmental sustainability. The integration of STEAM and NOS in educational research appears to resonate strongly with SDGs focused on developing sustainable solutions to global issues, particularly those related to health and the environment. The focus on Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action) mirrors global concerns about sustainable development, in which interdisciplinary research, such as that promoted by STEAM education, can play a crucial role in developing innovative solutions to these challenges (Phuong et al., 2023; Supriyadi et al., 2023). Maryanti et al. (2022) highlight the importance of aligning educational research with the SDGs, particularly in the context of Goal 4 (Quality Education). Their work underscores how STEAM education, by integrating the arts and creativity into science and technology, fosters critical thinking and problem-solving skills that are essential for achieving sustainable development. Similarly, NOS-focused research plays a critical role in fostering scientific literacy and reflective inquiry, aligning with the objectives of Goal 4 to ensure inclusive and equitable education for all (Xue et al., 2018; Yanuarti & Suprapto, 2021). Overall, the research trends demonstrate that STEAM and NOS are not only advancing educational practices but also contributing significantly to global sustainability efforts. This intersection of education and sustainable development highlights the potential of interdisciplinary approaches in addressing the SDGs and preparing future generations to tackle complex global challenges.

Summary of Findings

The findings from the four key research questions provide a comprehensive view of the bibliometric trends regarding the relationship between STEAM education and NOS.

First, the publication rates reveal significant growth in research on STEAM and NOS, particularly from 2020 onwards, peaking in 2022. This surge reflects the growing recognition of interdisciplinary approaches in education, which combine scientific inquiry with creativity, a trend consistent with findings in other bibliometric studies on STEAM and NOS (Supriyadi et al., 2023; Xue et al., 2018).

Second, the research areas contributing to publications are primarily rooted in technical and scientific fields, with Physics (18.179%), Materials Science (17.418%) and Chemistry (15.744%) being the most prominent. This emphasizes the technical nature of STEAM and the focus on integrating STEM fields with NOS to foster innovation and scientific literacy. Although Education and Educational Research represent a smaller portion (2.013%), their presence highlights the emerging interest in applying STEAM and NOS concepts in educational contexts (Phuong et al., 2023; Yanuarti & Suprapto, 2021).

Third, the geographical and institutional distribution shows that China leads both in research output (67.318%)

and key affiliations, such as the Chinese Academy of Sciences (11.050%). Other significant contributors include the United States and Japan, with leading institutions like the University of Tokyo and Kyoto University playing crucial roles. This regional concentration reflects the strong investment in science and technology education in East Asia, consistent with trends observed in previous studies (Phuong et al., 2023; Supriyadi et al., 2023).

Finally, the research aligns with various SDGs, particularly Goal 3 (Good Health and Well-Being, 43.029%) and Goal 7 (Affordable and Clean Energy, 10.231%). The intersection with Goal 4 (Quality Education, 2.095%) highlights the educational focus of STEAM and NOS, supporting global efforts to improve educational practices and sustainability (Maryanti et al., 2022). Together, these findings set the stage for a deeper analysis of how these trends reflect broader educational and societal goals.

Discussion

The findings from the analysis of publication trends and academic fields provide valuable insights into the global landscape of research on STEAM and NOS. These insights not only highlight current trends but also help map the ongoing developments in these interdisciplinary areas, offering a comprehensive overview of how research in STEAM and NOS is evolving across different fields.

Publication Rates

The analysis of publication rates reveals a clear upward trajectory in research focusing on the relationship between STEAM and NOS, particularly from 2020 onwards. The peak in 2022, with a significant rise in publications, suggests a growing academic and societal recognition of the importance of interdisciplinary education models. This aligns with findings Supriyadi et al. (2023) and reflects the increasing global engagement with educational practices that integrate creativity and scientific literacy.The rise in research output can be linked to a broader understanding of the importance of combining arts, technology and scientific inquiry to address complex global challenges. STEAM education, emphasizing the role of creativity in problem-solving, has become a key focus area for researchers and policymakers alike (Jamali et al., 2023). In parallel, NOS, with its emphasis on understanding the processes, values and methodologies behind scientific inquiry, has witnessed increased attention due to its role in promoting scientific literacy and critical thinking (Xue et al., 2018; Yanuarti & Suprapto, 2021).

The sharp increase in publication rates reflects the increasing importance of interdisciplinary education frameworks in addressing modern educational needs. Researchers and policymakers can use these trends to further explore the integration of STEAM and NOS and develop new methodologies for teaching that enhance both creativity and scientific literacy. This trend also suggests that future research should focus on understanding the specific factors driving the growth of publications, such as the rise of technology in education, the emphasis on creative problem-solving and the global demand for interdisciplinary skills. Moreover, tracking these trends provides valuable insights for the development of curricula that align with emerging educational and societal needs, such as sustainability, innovation and global competence (Jamali et al., 2023; Supriyadi et al., 2023). By

expanding the analysis of publication rates, researchers can also investigate the influence of global initiatives, such as the SDGs, on the rise of interdisciplinary research in STEAM and NOS education. The growing body of research offers a rich dataset that can be mined for insights into how educational models are evolving and what new pedagogical practices are being developed in response to these trends (Maryanti et al., 2022).

Academic Fields

The analysis of academic fields reveals that research on the relationship between STEAM and NOS is predominantly concentrated on scientific and technical disciplines. Physics (18.179%), Materials Science (17.418%) and Chemistry (15.744%) emerge as the most significant contributors, emphasizing the foundational role of STEM disciplines in driving interdisciplinary education. These findings are consistent with previous studies that have highlighted the importance of integrating scientific and technological fields with creative and reflective approaches (Jamali et al., 2023; Supriyadi et al., 2023).

This dominance of technical fields reflects the growing importance of interdisciplinary approaches in addressing real-world problems. STEAM education, by incorporating the arts into STEM, allows for a broader set of skills, including design thinking, creativity and innovation, which are critical for solving complex challenges in fields like engineering, physics and materials science as noted by previous studies (Phuong et al., 2023; Jamali et al., 2023).On the other hand, Education and Educational Research represent a smaller portion of the total research output, accounting for only 2.013%. This suggests that while the technical aspects of STEAM are well-researched, the integration of NOS into educational contexts is still emerging, as has been identified (Xue et al., 2018; Yanuarti & Suprapto, 2021).

However, as the findings show, recognition is increasing of the value of integrating NOS within technical fields, which can enhance students' critical thinking and scientific literacy. The concentration of research in technical fields suggests that future studies should focus on expanding the integration of NOS into STEAM-related education. The dominance of Physics, Chemistry and Materials Science demonstrates that these fields are well-positioned to benefit from further research exploring how NOS principles can enhance the understanding of scientific inquiry and promote reflective learning. Researchers could investigate how interdisciplinary approaches that merge technical rigor with the reflective and critical aspects of NOS influence student outcomes, particularly in areas such as problem-solving, innovation and scientific literacy (Phuong et al., 2023). Additionally, the smaller representation of educational research points to a need for more studies that examine how NOS and STEAM principles can be embedded into broader educational models to foster holistic learning. This approach could include exploring the role of teacher training in facilitating the integration of these interdisciplinary frameworks, as well as the development of curricula that balance both technical skills and reflective inquiry (Jamali et al., 2023; Xue et al., 2018).

Countries and Affiliations

The findings from the analysis of countries and affiliations contributing to research on the relationship between

STEAM and NOS provide a clear picture of the global distribution of academic engagement in these fields. This analysis reveals not only the geographic concentration of research but also the institutional landscapes driving the development of STEAM and NOS education. The analysis shows that China leads in research output, contributing 67.318% of the total publications. The United States follows with 20.204% and Japan makes up 24.137%, reflecting strong engagement from East Asia and North America. Other significant contributors include Germany (6.075%), England (5.771%) and South Korea (4.881%). This geographical distribution highlights the significant role of East Asian countries, particularly China and Japan, in advancing research on the integration of STEAM and NOS, a trend that aligns with these countries' broader educational reforms and investments in science and technology (Maryanti et al., 2022; Phuong et al., 2023; Supriyadi et al., 2023).

The dominance of China in this research space is particularly noteworthy and reflects the country's prioritization of education, science and technological innovation. China's Ministry of Education has been a driving force behind its efforts to develop interdisciplinary models such as STEAM, focusing on fostering innovation and competitiveness in the global economy (Phuong et al., 2023). The notable increase in publications from China aligns with the country's broader national strategies to enhance its educational and research outputs, particularly in STEM and interdisciplinary fields (Supriyadi et al., 2023). Similarly, Japan's focus on STEAM education is grounded in its long-standing commitment to educational excellence in science and technology, as seen through its leading institutions, such as Kyoto University and the University of Tokyo, which are major contributors to STEAM and NOS research (Jamali et al., 2023).

When looking at affiliations, the Chinese Academy of Sciences leads with 11.050% of the total publications, underscoring China's institutional strength in scientific research. Other major contributors include the University of Tokyo (5.818%) and Kyoto University (3.570%), as well as the University of California system (3.348%) in the United States and France's CNRS (3.313%). These leading institutions reflect the central role that large, research-intensive universities and national research agencies play in shaping the academic discourse around STEAM and NOS (Xue et al., 2018). The strong showing from East Asian institutions further highlights the importance of regional collaboration and government support in advancing interdisciplinary research in these fields (Supriyadi et al., 2023; Yanuarti & Suprapto, 2021).

In comparison, the contributions from countries such as Germany, England and South Korea, while smaller, reflect a broader, global commitment to advancing interdisciplinary education models combining scientific and creative fields. Germany, for instance, has led educational innovation, particularly through initiatives that align with global sustainability goals, such as climate action and clean energy, which are key areas in STEAM research (Maryanti et al., 2022). The United States, with institutions such as the University of California and its vast network of research universities, continues to play a significant role in both STEAM and NOS research, contributing to advancements in educational practices and the promotion of scientific literacy (Phuong et al., 2023; Xue et al., 2018).

The geographical and institutional landscape of STEAM and NOS research highlights several key outcomes. First, the strong contribution from East Asia, particularly China and Japan, points to the region's leadership in advancing

interdisciplinary education models. This regional dominance reflects the investments by these countries in education and research, positioning them as global leaders in STEAM and NOS (Jamali et al., 2023; Supriyadi et al., 2023). The notable presence of institutions such as the Chinese Academy of Sciences and Kyoto University suggests that they are central to advancing educational innovation through interdisciplinary frameworks. In contrast, contributions from countries such as Germany, England and South Korea, though smaller, emphasize the global nature of research in these fields and the widespread interest in improving educational practices through STEAM and NOS integration (Maryanti et al., 2022).

Sustainable Development Goals

Findings from the analysis of SDGs addressed in the research on STEAM education and NOS provide insights into how interdisciplinary education models are contributing to global sustainability efforts. The alignment of research with specific SDGs highlights the broader societal relevance of STEAM and NOS, linking educational practices with real-world challenges such as health, clean energy and climate action.

The analysis reveals that Goal 3 (Good Health and Well-Being) is the most frequently addressed SDG, with 43.029% of publications contributing to this goal. This significant focus on health-related topics underscores the importance of interdisciplinary approaches in addressing global health challenges. STEAM education, by integrating creativity and scientific inquiry, offers a comprehensive framework for developing innovative solutions to health problems, particularly in fields such as biotechnology, medical engineering and public health (Phuong et al., 2023; Supriyadi et al., 2023). Research related to Goal 3 often focuses on applying science and technology to healthcare, aiming to improve well-being through innovative medical solutions and the promotion of health literacy, which aligns with NOS principles of critical thinking and informed decision-making (Xue et al., 2018).

Goal 7 (Affordable and Clean Energy, 10.231%) and Goal 13 (Climate Action, 7.117%) also feature prominently, reflecting the growing intersection between education, sustainability and environmental challenges. STEAM education's emphasis on innovation and problem-solving is particularly relevant in these areas, in which interdisciplinary collaboration is crucial for developing sustainable energy solutions and addressing climate change. The integration of NOS principles further enhances this approach by encouraging students to assess scientific data critically, explore the environmental impacts of technology and engage with ethical considerations in the pursuit of sustainability (Maryanti et al., 2022; Yanuarti & Suprapto, 2021). These findings align with previous research that has shown how STEAM education, combined with NOS, can foster a deeper understanding of environmental issues and encourage sustainable practices (Jamali et al., 2023).

Interestingly, Goal 4 (Quality Education), which is directly related to the educational aims of STEAM and NOS, accounts for only 2.095% of the research output. While this may seem counterintuitive given the educational nature of the research, it suggests that much of the work in STEAM and NOS is being applied to other sectors, such as health and environmental sustainability, rather than being focused solely on education itself. However, this situation also points to the increasing integration of education into broader societal and global challenges,

such that educational frameworks are seen as tools for addressing issues beyond the classroom (Phuong et al., 2023). The relatively low percentage for Goal 4 could also indicate that researchers are increasingly focusing on applying STEAM and NOS concepts to tackle real-world problems, rather than concentrating on educational theory alone.

The alignment of STEAM and NOS research with specific SDGs highlights the interdisciplinary potential of these educational models to contribute to global sustainability efforts. The strong focus on Goal 3 (Good Health and Well-Being) underscores the role of interdisciplinary education in addressing global health challenges, offering pathways for developing innovative medical and healthcare solutions. The prominence of Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action) further emphasizes the relevance of STEAM and NOS in fostering sustainability through developing clean energy technologies and addressing climate change. Meanwhile, the smaller but significant focus on Goal 4 (Quality Education) reflects the broader application of educational frameworks in addressing societal challenges, positioning STEAM and NOS as key drivers of innovation and sustainability across multiple sectors (Maryanti et al., 2022; Supriyadi et al., 2023).

Summary of Discussion

The analysis of the four key research questions reveals several significant scientific outcomes regarding the relationship between STEAM education and NOS. First, the sharp rise in publication rates, particularly after 2020, reflects a growing global recognition of the importance of interdisciplinary education frameworks. This increase highlights the integration of creativity and scientific literacy as essential components of modern education systems, reinforcing STEAM and NOS as key educational models for fostering critical thinking and problem-solving skills (Supriyadi et al., 2023; Xue et al., 2018).

Second, the concentration of research in technical fields such as Physics, Materials Science and Chemistry underscores the central role that STEM disciplines play in driving interdisciplinary approaches. These fields, while traditionally focused on technical expertise, are increasingly incorporating NOS principles to enhance students' understanding of scientific inquiry and promote reflective learning. This trend reflects the growing acknowledgment of the value of combining technical skills with broader reflective insights to create more holistic educational practices (Jamali et al., 2023; Phuong et al., 2023).

Third, the geographical and institutional landscape of research points to East Asia's leadership, particularly China and Japan, in advancing STEAM and NOS education. Institutions such as the Chinese Academy of Sciences and Kyoto University are at the forefront of educational innovation, highlighting the global influence of these regions in shaping interdisciplinary educational models (Phuong et al., 2023; Yanuarti & Suprapto, 2021).

Finally, the alignment of STEAM and NOS research with the SDGs demonstrates the broader societal relevance of these educational frameworks. The focus on Goal 3 (Good Health and Well-Being), Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action) illustrates how STEAM and NOS contribute to addressing global challenges, emphasizing their role as tools for fostering sustainability and innovation across multiple sectors

(Maryanti et al., 2022; Supriyadi et al., 2023).

Conclusion

This study expands on previous findings by offering a detailed exploration of how STEAM and NOS research trends have developed globally, emphasizing the relationship between educational innovation and broader societal goals.

First, significant growth in publication rates reflects a global emphasis on interdisciplinary education. The sharp rise in STEAM and NOS publications, particularly post-2020, reflects a growing global recognition of the value of interdisciplinary educational frameworks. This trend suggests that educational systems and researchers are increasingly prioritizing the integration of creativity and scientific literacy to prepare students for complex, real-world challenges. The increase in research output is consistent with previous studies by Supriyadi et al. (2023) and Phuong et al. (2023). This surge in research reflects broader educational reforms and global initiatives aimed at fostering innovation and problem-solving skills through interdisciplinary approaches. The peak in publication rates during 2022 highlights how STEAM and NOS have become central to discussions about educational innovation. The growing body of research suggests that integrating creativity with scientific inquiry not only is gaining traction within academia but is also seen as critical for educational policymakers seeking to enhance learning outcomes. This reflects a shift toward educational models that prioritize holistic development, combining technical proficiency with creativity and critical thinking. Such models are essential for fostering a generation of learners equipped to navigate the demands of modern society.

Second, the dominance of technical and scientific fields highlights the importance of STEAM in interdisciplinary research. The majority of publications on STEAM and NOS come from technical and scientific disciplines, with Physics (18.179%), Materials Science (17.418%) and Chemistry (15.744%) leading the research output. This dominance underscores the central role of STEM fields in driving interdisciplinary approaches to education. While traditionally focused on technical expertise, these fields are increasingly incorporating NOS principles to enhance students' understanding of the processes behind scientific inquiry. This convergence of technical fields with NOS reflects a growing emphasis on the need for critical thinking and reflective learning within scientific education (Jamali et al., 2023; Xue et al., 2018). These findings align with prior bibliometric studies that emphasize the importance of integrating creative thinking into scientific and technical fields to foster innovation (Phuong et al., 2023; Jamali et al., 2023). However, the smaller representation of education-related research (2.013%) still suggests room for growth in integrating NOS more comprehensively into educational contexts. This highlights a potential gap in which STEAM and NOS can be further explored to enhance learning outcomes through a more balanced interdisciplinary approach.

Third, East Asia leads global research contributions in STEAM and NOS. The geographical distribution of research shows that China leads the global effort in STEAM and NOS research, contributing 67.318% of the total publications. This significant contribution is followed by the United States (20.204%) and Japan (24.137%). The dominance of East Asian countries, particularly China and Japan, underscores the region's strong commitment to

advancing interdisciplinary education models, a trend reflected in the national education strategies and investments in these countries (Phuong et al., 2023; Supriyadi et al., 2023). China's leading role, with institutions such as the Chinese Academy of Sciences driving much of the research, reflects the country's broader focus on fostering innovation and competitiveness through educational reform. Japan, with institutions such as Kyoto University and the University of Tokyo, also plays a significant role in shaping global research in STEAM and NOS. In contrast, while contributions from countries such as Germany, England and South Korea are smaller, they nonetheless highlight the global commitment to interdisciplinary education models that integrate scientific and creative fields (Jamali et al., 2023; Xue et al., 2018). These findings provide a clear picture of how different regions are leading the way in research, with East Asia emerging as a dominant player in advancing STEAM and NOS education. The global spread of research highlights how interdisciplinary education models are being adopted across various regions, reflecting their increasing relevance in addressing both educational and societal challenges.

Fourth, the alignment with SDGs demonstrates a broader societal impact. The alignment of STEAM and NOS research with specific SDGs highlights the broader societal relevance of these educational models. The focus on Goal 3 (Good Health and Well-Being, 43.029%) underscores the role of interdisciplinary education in addressing global health challenges. By integrating creativity and scientific inquiry, STEAM education is shown to contribute to innovative solutions in healthcare, biotechnology and medical engineering (Maryanti et al., 2022; Supriyadi et al., 2023). Additionally, the significant focus on Goal 7 (Affordable and Clean Energy, 10.231%) and Goal 13 (Climate Action, 7.117%) reflects how STEAM and NOS contribute to global sustainability efforts. These educational models are positioned as key tools for fostering innovation in areas such as clean energy technology and environmental sustainability. The integration of NOS principles into these sectors encourages critical thinking, ethical considerations and the exploration of scientific data to address urgent global issues (Yanuarti & Suprapto, 2021). Although Goal 4 (Quality Education, 2.095%) represents a smaller portion of the research, this reflects the broader application of STEAM and NOS beyond the classroom, demonstrating their impact across multiple sectors, from health to energy and the environment. The alignment with SDGs positions STEAM and NOS as critical educational frameworks that contribute to both individual learning outcomes and broader societal challenges (Maryanti et al., 2022).

In short, the four key conclusions can be summarized provide valuable insights into global trends regarding the relationship between STEAM education and the Nature of Science (NOS) through a bibliometric analysis. First, the analysis reveals a sharp acceleration in publications rates, especially from 2020 onwards, with 2022 marking a peak. This trend can be explained with a growing global recognition of interdisciplinary education models that combine scientific literacy and creativity to address 21st-century challenges (Supriyadi et al., 2023; Jamali et al., 2022). Second, research contributions are mostly from technical disciplines, such as Physics (18.179%), Materials Science (17.418%), and Chemistry (15.744%). This dominance shoes the central role of STEM fields in STEAM-NOS research, where NOS principles are increasingly integrated to enhance understanding of scientific inquiry and promote reflective learning (Phuong et al., 2023; Xue et al., 2018). Third, China leads in research contributions (67.318%), followed by the United States and Japan. Institutions such as the Chinese Academy of Sciences, Kyoto University, and the University of Tokyo are at the forefront, reflecting East Asia’s leadership in advancing

educational innovation. This global distribution highlights the strong investment in STEAM and NOS research in regions prioritizing science and technology education (Phuong et al., 2023; Yanuarti & Suprapto, 2021). Finally, there is a strong alignment of STEAM and NOS research with Goal 3: Good Health and Well-Being (43.029%), followed by Goal 7: Affordable and Clean Energy (10.231%) and Goal 13: Climate Action (7.117%). This demonstrates the broader societal relevance of STEAM and NOS frameworks in addressing global challenges such as health, energy sustainability, and climate change (Maryanti et al., 2022; Jamali et al., 2022). The study provides a comprehensive understanding of global research trends on STEAM education and the Nature of Science (NOS). It highlights their role in fostering interdisciplinary learning, scientific literacy and creativity. It can offer valuable insights for researchers and policymakers to align educational practices with global challenges and sustainability goals.

Recommendations

While this research provides comprehensive insights into the trends and global contributions of STEAM and NOS, several limitations should be acknowledged. First, the analysis was limited to data from the WoS platform, which, while robust, may exclude relevant studies indexed in other databases such as Scopus or ERIC. Future research could expand the dataset to include these additional databases for a more comprehensive view of global research trends (Donthu et al., 2021; Korkmaz & Toraman, 2024; Muhammad et al., 2024).

Additionally, while the analysis identified key regions and institutions contributing to STEAM and NOS research, it did not delve into the specific educational outcomes from the integration of these interdisciplinary approaches. Future studies could focus on empirical investigations into how these models impact student learning, creativity and problem-solving skills. Further exploration into the underrepresented areas, such as education research in STEAM and NOS, could also provide valuable insights into how these frameworks can be better integrated into curricula to foster holistic student development.

Acknowledgments

This research would not have been possible without the support of the University of the Aegean.

References

Bell, R. L., & Lederman, N. G. (2003). Understandings of the nature of science and decision making on science and technology-based issues. *Science Education*, *87*(3), 352–377. https://doi.org/10.1002/sce.10063

Bilen, K., & Kurtuluş, M. A. (2021). Bilimin Doğası Üzerine Bibliyometrik Bir Analiz: 1986–2019 yılları arası örneği. *Scientific Educational Studies*., *5(1)*, 47-65 https://doi.org/10.31798/ses.941238

Bugingo, J. B., Yadav, L. L., Mugisha, I. S., & Mashood, K. K. (2024). Improving teachers' and students' views on nature of science through active instructional approaches: A review of the literature. *Science & Education*, *33*(1), 29–71. https://doi.org/10.1007/s11191-022-00382-8

Dagher, Z. R., & Erduran, S. (2016). Reconceptualizing the nature of science for science education: Why does it

matter? *Science & Education*, *25*(1–2), 147–164. https://doi.org/10.1007/s11191-015-9800-8

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education*, *20*(7–8), 591–607. https://doi.org/10.1007/s11191-010-9293-4

Ismiati, N. (2024). Implementing STEAM education in the independent curriculum: Enhancing 21st century skills. *Tadibia Islamika*, *4*(1), 21–27. https://doi.org/10.28918/tadibia.v4i1.7238

Jamali, S. M., Ale Ebrahim, N., & Jamali, F. (2023). The role of STEM education in improving the quality of education: A bibliometric study. *International Journal of Technology and Design Education*, *33*(3), 819–840. https://doi.org/10.1007/s10798-022-09762-1

Korkmaz, G., & Toraman, C. (2024). Reflective thinking: A bibliometric analysis of four decades of research and insights for future studies. *International Journal of Education in Mathematics Science and Technology*, *12*(4), 1053–1070. https://doi.org/10.46328/ijemst.4231

Lederman, N. G., & Lederman, J. S. (2019). Teaching and learning of nature of scientific knowledge and scientific inquiry: Building capacity through systematic research-based professional development. *Journal of Science Teacher Education*, *30*(7), 737–762. https://doi.org/10.1080/1046560x.2019.1625572

Maryanti, R. I. N. A., Rahayu, N. I., Muktiarni, M., Husaeni, D. F., Hufad, A. C. H. M. A. D., Sunardi, S., & Nandiyanto, A. B. D. (2022). Sustainable development goals (SDGs) in science education: Definition, literature review and bibliometric analysis. *Journal of Engineering Science and Technology*, *17*, 161–181.

Muhammad, I., Rusyid, H. K., Maharani, S., & Angraini, L. M. (2024). Computational thinking research in mathematics learning in the last decade: A bibliometric review. *International Journal of Education in Mathematics Science and Technology*, *12*(1), 178–202. https://doi.org/10.46328/ijemst.3086

Niu, W., & Cheng, L. (2022). Editorial: Creativity and innovation in STEAM education. *Frontiers in Education*, *7*. https://doi.org/10.3389/feduc.2022.1045407

Nyaaba, M., Akanzire, B. N., & Mohammed, S. H. (2024). Prioritizing STEAM education from the start: The path to inclusive and sustainable STEAM education. *International Journal of STEM Education for Sustainability*, *4*(1), 54–69. https://doi.org/10.53889/ijses.v4i1.322

Perales, F. J., & Aróstegui, J. L. (2024). The STEAM approach: Implementation and educational, social and economic consequences. *Arts Education Policy Review*, *125*(2), 59–67. https://doi.org/10.1080/10632913.2021.1974997

Phuong, N. L., Hien, L. T. T., Linh, N. Q., Thao, T. T. P., Pham, H.-H. T., Giang, N. T., & Thuy, V. T. (2023). Implementation of STEM education: A bibliometrics analysis from case study research in Scopus database. *Eurasia Journal of Mathematics Science and Technology Education*, *19*(6), Article em2278. https://doi.org/10.29333/ejmste/13216

Qizi, Q. S. B. (2024). *Problematic education, which is one of the foundations of the STEAM approach in education*. Zenodo. https://doi.org/10.5281/ZENODO.10449276

Salcedo, O. H., Carrejo, D. J., & Luna, S. (2024). Engineering Praxis ethos: Designing experiences to support curricular and instructional improvement in STEM education. *International Journal of Education in*

Mathematics Science and Technology, *12*(1), 20–39. https://doi.org/10.46328/ijemst.3218

Supriyadi, E., Turmudi, T., Dahlan, J. A., & Juandi, D. (2023). Publication trends from STEAM in education from Scopus database: Bibliometric analysis. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 104–111. https://doi.org/10.29303/jppipa.v9i6.3576

Ullah, R., Asghar, I., & Griffiths, M. G. (2022). An integrated methodology for bibliometric analysis: A case study of Internet of Things in healthcare applications. *Sensors (Basel, Switzerland)*, *23*(1), 67. https://doi.org/10.3390/s23010067

Wijayanti, A., Wiyanto, W., Ridlo, S., & Parmin, P. (2024). Analysis of nation ideology-based education and STEAM approach in science education program: A bibliometric analysis using VOSviewer. In W.Striełkowski, , J. M Black., S. A., Butterfield, C.-C Chang., J. Cheng, F. P. Dumanig, R. Al-Mabuk, R. Al-Mabuk, M. Urban, S. Webb (Eds.) *Advances in social science, education and humanities research* (pp. 317–332). Atlantis Press SARL.

Wu, J.-Y., & Erduran, S. (2024). Investigating scientists' views of the family resemblance Approach to nature of science in science education. *Science & Education*, *33*(1), 73–102. https://doi.org/10.1007/s11191-021-00313-z

Xue, X., Wang, L., & Yang, R. J. (2018). Exploring the science of resilience: Critical review and bibliometric analysis. *Natural Hazards (Dordrecht, Netherlands)*, *90*(1), 477–510. https://doi.org/10.1007/s11069-017-3040-y

Yanuarti, E. A., & Suprapto, N. (2021). Ten years of research on history of science (physics): A bibliometric analysis. *Studies in Philosophy of Science and Education*, *2*(1), 7–16. https://doi.org/10.46627/sipose.v2i1.66

Author Information

Konstantinos Karampelas

https://orcid.org/0000-0001-6631-1408

University of the Aegean

1 Dimokratias Street, Rhodes, 85132

Greece

Contact e-mail: *kkarampelas@aegean.gr*