

Publication volume and educational performance: Unraveling the global connection between STEM research and PISA scores with a focus on Türkiye

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Highlights

- A global bibliometric analysis reveals a statistically significant negative correlation between STEM publication volume and PISA performance across participating countries, challenging assumptions about research productivity and educational quality.
- High-performing PISA countries such as Finland achieve strong educational outcomes despite relatively lower STEM research output, while countries like United States and Canada demonstrate the opposite trend.
- Türkiye plays an active role in international STEM collaboration networks, offering a critical case for evaluating how national research activity aligns with educational performance indicators such as PISA.

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Keywords: STEM education, PISA, bibliometric analysis, research productivity, international collaboration

Abstract

This study addresses a critical gap in understanding the relationship between countries' STEM research output and their educational performance as measured by PISA scores. While prior studies have examined STEM education policies in connection with PISA, limited attention has been paid to whether higher STEM research output correlates with improved outcomes in reading, mathematics, and science. Using bibliometric analysis, we examined STEM-related publications from 1999 onward and analyzed correlations between publication volumes in the exam year and the preceding year, and PISA literacy scores. The dataset included 6,669 publications from Web of Science and Scopus, along with PISA scores for countries with no more than one missed participation since 2000. Findings indicate that the United States is the most collaborative country in STEM research, with Türkiye and several other nations frequently contributing. However, high publication output—such as that of the U.S. and Canada—does not correspond to high PISA scores, whereas countries with lower research volume, such as Finland, consistently perform well. A strong negative correlation was identified between STEM publication volume and PISA performance, suggesting a statistically inverse association, though no causal or directional inference is implied. This study offers a novel perspective by reversing the conventional focus: rather than examining how PISA impacts academic output, it investigates how academic STEM research activity relates to educational outcomes. Particular attention is given to Türkiye's position within this global landscape, providing context-specific insights with implications for aligning national research priorities with educational goals.

1. Introduction

In today's world, one of the most sought-after qualities is the ability of individuals to adapt to rapidly changing technologies and information. To cultivate individuals who can meet the needs of the 21st century, educational programs are being reshaped to instill these essential skills. Particularly, educational approaches that integrate science, technology, engineering, and mathematics (STEM) are emerging as key in preparing individuals for this new world.

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STEM education supports students in understanding scientific and mathematical concepts, while also encouraging them to integrate this knowledge with engineering design processes to develop solutions for a variety of problem areas (Ouyang & Xu, 2024). It encourages students to develop creativity and critical thinking skills, enabling them to tackle daily life challenges. Traditional educational methods, which position the teacher at the center and rely on direct knowledge transmission, may limit students' ability to take responsibility for their own learning and engage actively in the learning process (Erol & Canbeldek Erol, 2024). In situations where traditional learning methods may be insufficient, STEM education provides opportunities for students to solve real-world problems through interdisciplinary approaches (Nuangchalerm, 2023).

Over the last two decades, academic publishing has undergone rapid digitalisation, and the expansion of online institutional repositories has significantly accelerated the production and dissemination of scientific knowledge (Taner, 2020). In this process, digital archives, e-publishing systems, and online databases have increased the visibility and accessibility of STEM-related research, enabling faster dissemination of new educational approaches and findings. However, the transformation of high-volume STEM research outputs into open educational resources that can directly benefit K–12 teachers and students, as well as their integration into classroom practices, often does not progress at the same pace. This situation may widen the structural gap between rapidly expanding online knowledge production and traditional classroom implementation.

Countries need to track certain indicators in order to evaluate the results of their investments in STEM education, and the Programme for International Student Assessment (PISA) is one such indicator. The link between STEM education and performance on PISA is particularly important in this regard. STEM education and PISA emerged simultaneously; STEM has taken shape both as a product of globalization and as a responsible form of education supported by the Organisation for Economic Co-operation and Development (OECD) in line with its economic competitiveness goals (Pugliese & Santos, 2022). With the rapid development of technology and the impact of global challenges, STEM competencies play a fundamental role in increasing scientific literacy, supporting national power in international competition, and raising responsible citizens. In this context, it is argued that the data provided by PISA on student performance in STEM fields may influence the number of publications in this area. Additionally, PISA scores enable countries to compare their achievements in STEM fields on an international scale and identify areas for improvement (NSF, 2021). For example, the success of countries such as Finland, which perform well in PISA, has been associated with strong STEM education and investment in teachers' professional development (Boğar & Lavonen, 2022).

Thus, a link can be hypothesized between STEM education and PISA results. While STEM education equips students with essential 21st-century skills, PISA results provide insights into how effectively these skills are being taught. Consequently, STEM policies and PISA performance can influence the competitiveness of a country's educational system and, by extension, its economic and scientific standing.

2. Literature

2.1. *Studies on STEM Education*

Research from various countries highlights that STEM education equips students with essential competencies for global competitiveness (Kayan-Fadlelmula et al., 2022), and in Türkiye, studies aim to promote STEM education (İdin, 2019). STEM education integrates science, technology, engineering, and mathematics, often without a specific curriculum (Walden University, n.d.). It requires students to learn interdisciplinary knowledge in these fields and to solve open-ended, ill-structured real-world problems. This type of education fosters the ability to solve real-world problems by combining these disciplines. However, traditional teacher-centered approaches, which focus on transmitting and memorizing knowledge, may not sufficiently support students in achieving deep learning in STEM (Xu & Ouyang, 2022). For example, in conventional lecture-based instruction, students may struggle to grasp complex STEM concepts and may lack adequate opportunities to develop higher-order thinking skills such as

problem-solving, creativity, and cognitive reasoning (Umaschi Bers, 2021). Additionally, hands-on learning integrated STEM education encourages students to actively engage in higher-order thinking through inquiry-based and project-based activities and creates a student-centered learning environment (Fan et al., 2021). Strategies such as project-based learning foster creativity and learning through failure, while collaborative activities provide students with leadership roles and enhance their confidence through decision-making and reflection (Care et al., 2016). Furthermore, STEM education helps students use technology flexibly and creatively while developing critical thinking and problem-solving skills (Baharin et al., 2018). Activities such as robotics and design tasks allows students to tackle complex challenges, fostering essential 21st-century skills like communication and collaboration (Dare et al., 2018).

Beyond general education benefits, STEM prepares students for careers in fields like healthcare (Ludwig et al., 2017), where mastering technical skills such as medical technology and data analysis is essential. New technologies like artificial intelligence and virtual reality enable educators to explore real-world applications, enhancing students' design and problem-solving capabilities (Xu & Ouyang, 2022). Additionally, STEM education promotes environmental awareness, with projects focused on issues such as waste reduction and biodiversity conservation (Fastiggi, 2023). In industries like aviation, STEM fosters curiosity and creativity, where problem-solving and teamwork are crucial for technological advancement (English & King, 2015).

Research shows that STEM education influences educational reforms at various levels. Early exposure to STEM significantly impacts students' skill development (Aldemir & Kermani, 2017) and engagement, enhancing academic performance in elementary and middle school (Kazu & Kurtoglu Yalcin, 2021). Attending STEM schools has been linked to increased chances of taking advanced courses and pursuing STEM careers (Means et al., 2021). Early involvement also supports the development of 21st-century skills and strengthen students' identification with science and math fields, positively impacting their career aspirations (Rivera & Li, 2020). Career goals start to take shape in middle school, with experiences during this stage influencing STEM participation (Badri et al., 2016). Research continues to address the gender gap in STEM careers (Han, 2016). At the university level, STEM education builds strong mathematical and scientific foundations necessary for the modern workforce (Scientific American, 2019). Postgraduate programs aim to produce versatile professionals with advanced technological, research, and collaborative skills (National Academies of Sciences, Engineering, and Medicine, 2018), with active learning environments at undergraduate and graduate levels boosting confidence and motivation (Sellami et al., 2021).

2.2. STEM and PISA

Countries use international exams like PISA to compare educational policies and student achievement levels in STEM (Boğar & Lavonen, 2022). Finland's success in PISA has been attributed to its strong STEM education system and teacher training (Kayan-Fadlelmula et al., 2022). Countries with lower PISA scores attempt to attract students to STEM through ambitious projects, although resource limitations can hinder access to STEM education (Pugliese & Santos, 2022).

PISA results are used to develop STEM education policies (Pugliese & Santos, 2022). Countries shape their STEM curricula based on these results, improving students' engineering and problem-solving skills through targeted reforms (NSF, 2020). Moreover, PISA data helps identify students' career orientations and increases international interest in STEM professions (Kaufmann & Wittmann, 2018). For instance, Han (2017) found that PISA data revealed a decrease in expectations for careers in computer engineering, while interest in health services increased. Such insights are crucial for shaping national educational strategies.

PISA results also encourage teacher training in STEM fields. PISA-based tasks are valuable tools in teaching STEM concepts (Silver & Snider, 2014). By examining barriers and factors affecting student interest in STEM, strategies can be developed to increase participation (Kayan-Fadlelmula et al., 2022). Understanding the relationship between PISA results and STEM education can play a vital role in shaping a country's education policies (Domínguez et al., 2012). Furthermore, research highlights that there is often no direct correlation between countries' PISA scientific literacy scores and the number of scientific literacy

publications (Yıldırım Kırbaç, 2022). Despite the increasing use of PISA data in shaping educational strategies (Pugliese & Santos, 2022), studies directly examining the relationship between countries' PISA performance and their volume of STEM-related academic output remain scarce. Similarly, there is limited research exploring how PISA may influence the development of scientific literature.

STEM education and the PISA emerged around the same period and have developed as complementary frameworks aligned with goals of global competitiveness and scientific literacy (Pugliese & Santos, 2022). The OECD defines the core components of STEM—reading, mathematics, and scientific literacy—as essential skills for accessing information, solving problems, and engaging in scientific reasoning. These domains are assessed by PISA and serve as key indicators for evaluating countries' success in STEM education (NSF, 2021; Pugliese & Santos, 2022). Research has shown that countries implementing STEM education tend to perform better in PISA assessments (Ay & Seferoğlu, 2021). In this context, a meaningful relationship can be expected between PISA scores and STEM education.

Although Türkiye has increased its efforts toward STEM education, its PISA performance has shown fluctuations. Therefore, Türkiye presents a noteworthy case for both national and international comparisons, adding contextual relevance to the study.

The domains assessed by the PISA—reading, mathematics, and scientific literacy—evaluate students' ability to apply the knowledge and skills they acquire at school to real-life situations (OECD, 2021b). These three areas are directly related to the core components of STEM education and are critical indicators of students' acquisition of 21st-century skills (OECD, 2021a). Reading literacy serves as a fundamental tool for accessing and making sense of information across disciplines and is a prerequisite for academic success (OECD, 2019). Mathematical literacy supports individuals in developing reasoning and problem-solving abilities in everyday contexts (OECD, 2019), while scientific literacy involves making decisions based on scientific thinking and inquiry (OECD, 2021a). In today's rapidly evolving technological and social landscape, it is essential that individuals are equipped not only with rote knowledge but also with interdisciplinary thinking and problem-solving skills (Dare et al., 2021). In this context, STEM education aims to foster critical thinking, creativity, and collaboration by guiding students toward interdisciplinary and applied learning from an early age (Geotab, 2021; Ouyang & Xu, 2024).

Countries actively use PISA data in shaping their educational policies (Domínguez et al., 2012) and evaluate the impact of STEM practices on student achievement in PISA scores (Ay & Seferoğlu, 2021). STEM education is increasingly regarded as a strategic tool for enhancing a country's competitiveness and capacity for innovation (Assefa & Rorissa, 2013; Pugliese & Santos, 2022). Therefore, examining the relationship between scientific publications in the field of STEM and PISA literacy scores through bibliometric analysis offers meaningful insights into national educational approaches. It also helps identify gaps in the literature and provides a foundation for improving education systems (Chen et al., 2023; Chiu et al., 2025).

This study aims to map research on STEM using bibliometric analysis to identify leading countries and institutions in this field and explore the relationship between STEM publications and PISA scores in reading, mathematics, and scientific literacy, including those of Türkiye. Traditional literature reviews are limited and time-intensive, whereas bibliometric analysis efficiently synthesizes large datasets, highlighting influential countries, authors, and studies (Pellegrini et al., 2020). Bibliometric analysis also offers researchers a transparent and quantitative method to trace the development and trends of scientific knowledge in specific fields (Zupic & Čater, 2015). For instance, prior bibliometric studies on STEM education, such as those by Assefa and Rorissa (2013), examined curricula and policy trends using co-word analysis, while Silva Díaz et al. (2022) combined WoS and Scopus data to explore experimental research on instructional methods and technologies. By situating this study within such research, it contributes to a growing body of literature using bibliometric approaches to understand the scope and evolution of STEM-related scholarship, including connections to scientific literacy and international assessments like PISA. By characterizing key areas within STEM, this study offers insights for enhancing education and examines the connection between national STEM research output and PISA scores. To achieve this aim, the research addresses the following questions:

1. What is the distribution of STEM publications by country and institution?
2. How does the PISA literacy performance relate to STEM publication output?
 - a. What is the relationship between average PISA literacy scores and the number of publications per exam year by country?
 - b. How does the number of publications correlate with average PISA scores for the top five and bottom five countries, as well as Türkiye?

3. Methodology

3.1. Research Model/Design

This exploratory correlational study, incorporating a country- and institution-level bibliometric analysis, focuses on STEM-themed research and examines the relationship between the number of publications and PISA exam results in countries where the PISA is administered.

3.2. Data Collecting Tools

The keywords “stem,” “science,” “technology,” “engineering,” and “mathematics” were searched in WoS (abstract, title, author keywords, and keyword plus fields) and Scopus (title, abstract, and keywords fields) using the “or” operator between keyword combinations. In English, the word “stem” can also have other meanings such as “root” or “trunk.” To exclude unrelated items like “stem cell,” the “not” operator was applied to refine the dataset (Dare et al., 2018).

3.3. Sampling or Study Group

The primary data for this research comprise English-language STEM publications indexed in the Web of Science (WoS) and Scopus databases between 1999 and 2022, corresponding to the most recent PISA cycle. The inclusion and exclusion criteria are summarized in Fig. 1. In total, 7,323 publications were retrieved from WoS and 14,753 from Scopus, along with PISA scores from 93 countries. For analysis, 33 countries with consistent participation in the PISA reading, mathematics, and scientific literacy assessments, as well as reliable publication counts, were selected. This resulted in a final dataset of 6,999 English-language articles from WoS and Scopus. Data from Bulgaria, the Czech Republic, Hungary, Iceland, Lithuania, Luxembourg, Macao (China), Slovakia, and Uruguay were excluded due to the limitations of the Biblioshiny web interface of the Bibliometrix package in R, which restricts the visualization of publication counts by year to only the top 50 most productive countries. As these countries were not among the top 50, specific publication counts for them could not be obtained.

Particular attention was given to publications produced in the year of each PISA and the year immediately preceding it, in order to examine whether any observable changes in publication volume occurred during these periods. This focus also aims to explore the possible association between publication activity and student performance, and whether heightened academic attention to STEM coincides with measurable differences in PISA outcomes.

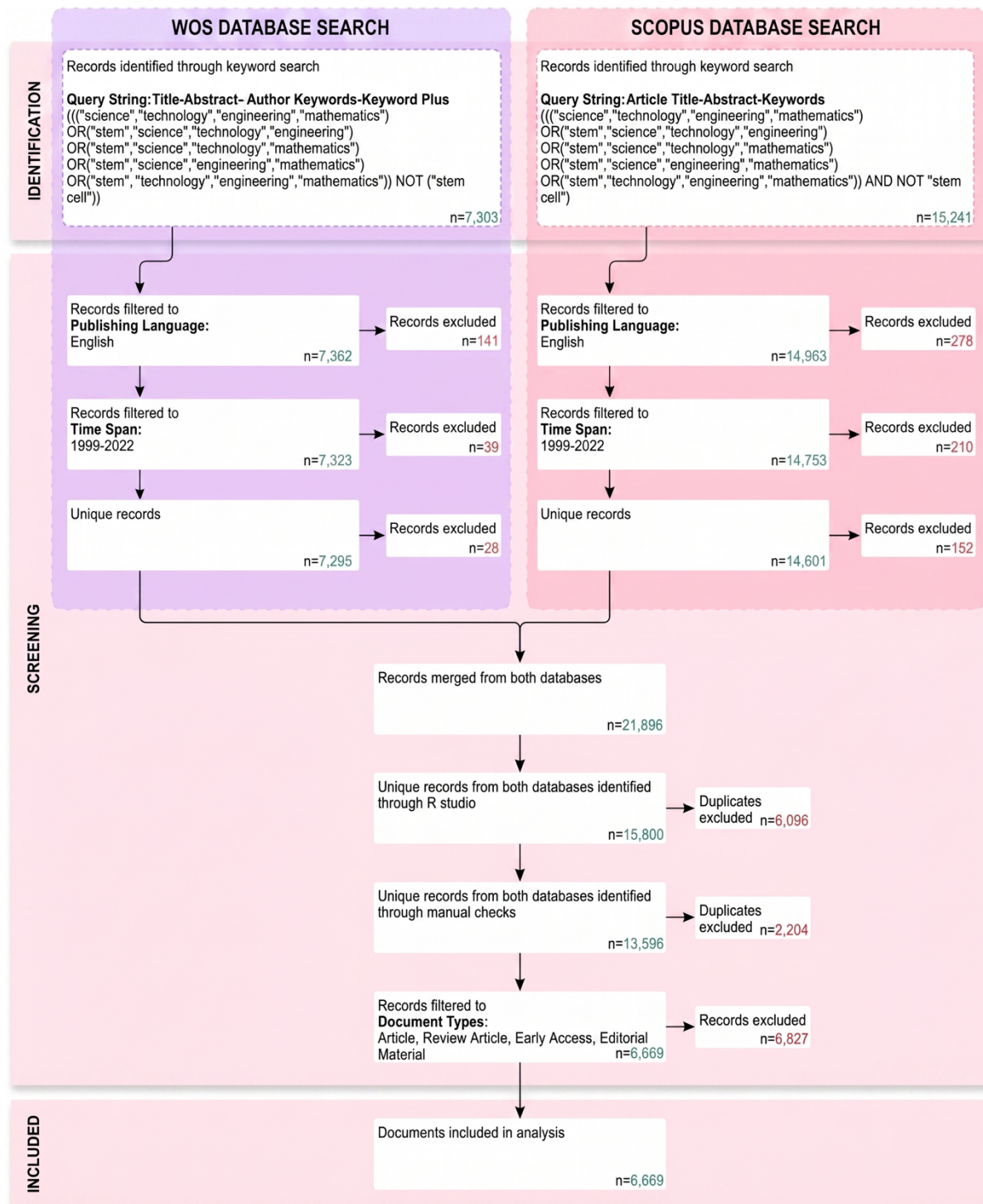


Fig. 1. Data collection steps.

3.4. Data Analysis

After filtering non-STEM studies, 6,669 publications were analyzed. To answer the first research question, bibliometric analyses were performed using the Bibliometrix R-package (version 4.0, It has been created and developed Massimo Aria and Corrado Cuccurullo), which enabled visualization of publication trends by country and institution. For the second research question, PISA reading, mathematics, and scientific literacy scores were sourced from OECD data, organized by year and country in Excel, and averaged for each assessment year. STEM-related publication counts were recorded for each exam year and the preceding year. To explore potential associations, correlation analyses were conducted between total STEM publication counts and PISA literacy scores, as well as between average PISA scores and total publication counts for both top- and bottom-performing countries, including Türkiye. Pearson's r correlations were

reported when the data met the assumption of normality; otherwise, Spearman's ρ was used. More specific details of the analyses are presented in the results section to avoid redundancy here.

4. Findings and Discussions

This section first presents bibliometric analyses of publications by country and institution. It then examines the relationship between PISA scores and publication counts for each PISA year. Lastly, it analyzes the correlations between publication counts and PISA scores in reading, mathematics, and science literacy for the top five and bottom five performing countries, as well as for Türkiye.

4.1. Bibliometric Analysis of STEM Studies

The collaboration network for STEM-themed publications from WoS and Scopus is shown by country in Fig. 2. Publications are grouped into five clusters, with countries of the same color indicating stronger collaborative relationships based on shared research topics. The thickness of the connecting lines reflects the intensity of collaboration between countries. However, larger node size does not necessarily indicate more international collaboration; rather, it reflects the number of total connections. Countries that frequently collaborate are grouped within the same color cluster. The United States demonstrates the most extensive and robust connections. In the pink cluster, Türkiye and Korea are prominent, while the United Kingdom and Canada stand out in the blue cluster. Australia, Germany, and Italy are key players in the purple cluster.

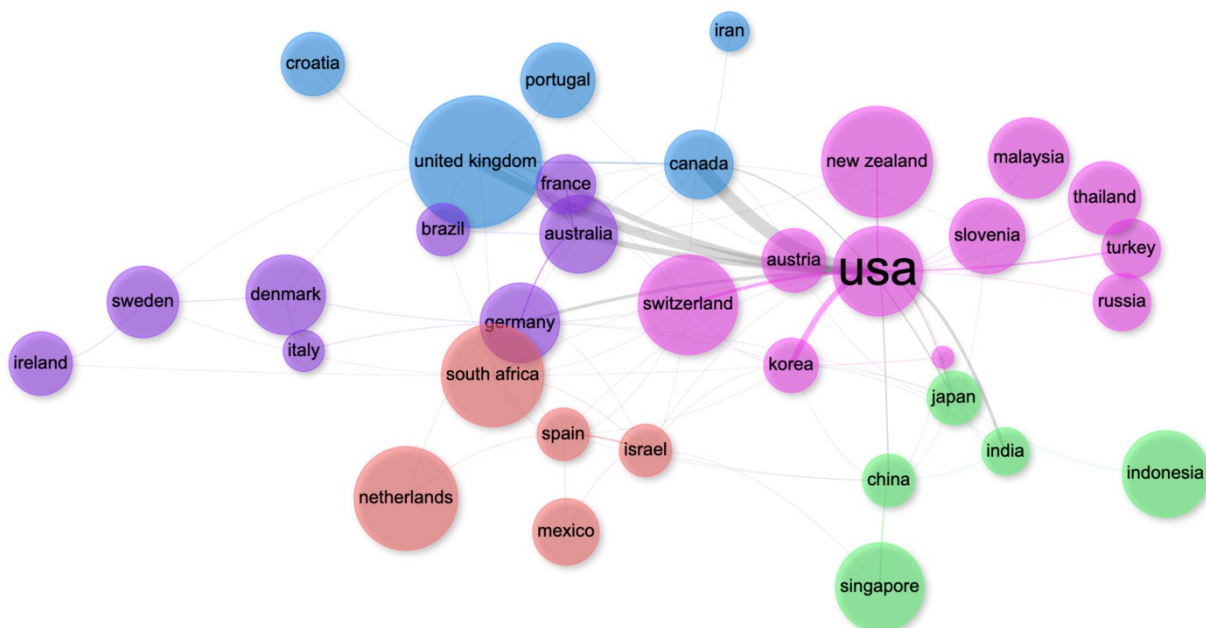


Fig. 2. Network of international cooperation.

Fig. 3 shows the institutional collaboration network for STEM publications, forming five color-coded clusters. In this visualization, larger nodes indicate institutions that are more active in the field and engage in higher levels of collaboration with other institutions. Thicker connecting lines represent a greater number of joint publications between institutions. Conversely, nodes that appear more isolated reflect institutions with fewer collaborative ties. In the pink cluster and across the entire network, the University of California stands out for its extensive STEM publications and high collaboration rates. In the blue cluster, Purdue University and Arizona State University are notable for frequent partnerships in STEM research. Notably, no university from Turkey appears to be significantly integrated into the collaboration network, suggesting limited international institutional partnerships in STEM-related research within the scope of the analyzed dataset.

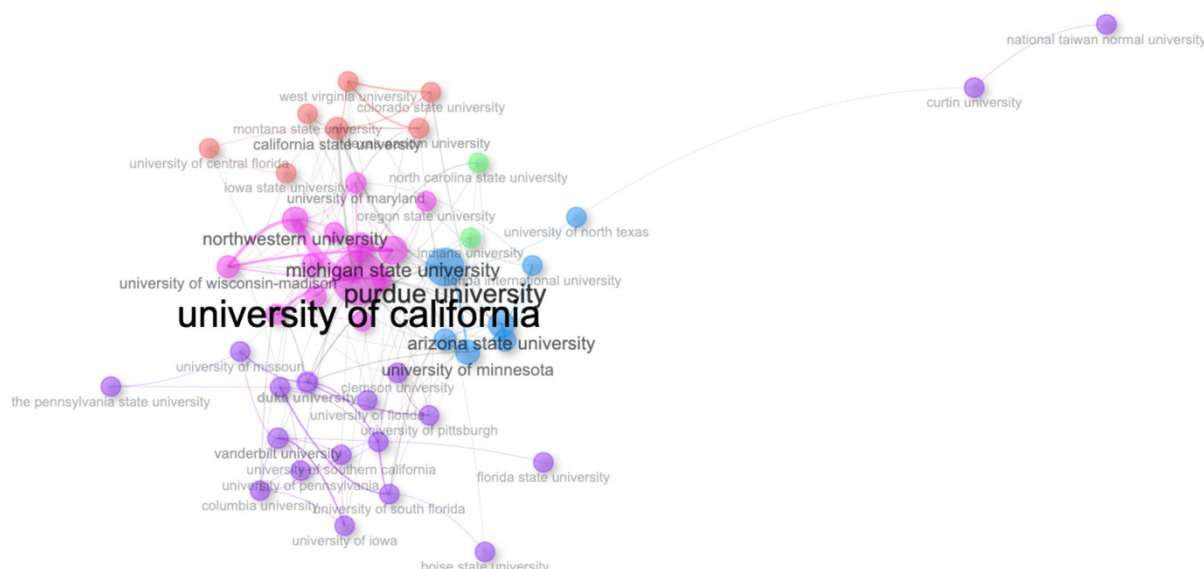


Fig. 3. Network of institutional cooperation.

4.2. Relationship Between PISA Scores and Publication Counts by Exam Year

Table 1 presents the average PISA literacy scores and STEM publication counts by exam year and the prior year for countries that participated in multiple PISA cycles. Publication counts are shown for the exam year (“same year”) and the preceding year (“previous year”), with each publication counted only once in the totals.

Table 1.

Average PISA literacy scores and total publication counts for all countries by exam year.

Variable	Exam Year							
	2000	2003	2006	2009	2012	2015	2018	2022
Average Literacy Score								
Reading	473	480	460	464	476	462	454	435
Mathematics	472	485	469	468	475	462	459	438
Scientific	474	488	473	472	481	466	459	447
Total Publication Count								
Same Year	4	5	26	71	226	448	687	1031
Previous Year	11	14	27	37	153	300	584	855

The Shapiro-Wilk test confirmed a normal distribution for literacy scores and same-year publication counts, though publication counts the previous year did not meet normality ($p < 0.05$).

A strong negative correlation was found between PISA scores (reading, mathematics, and scientific literacy) and the number of publications in the year before the exam year (Table 2). A similar negative high correlation emerged between same-year publications published and exam scores, based on Spearman’s ρ correlation.

Table 2.

Correlations between PISA literacy scores and total publication counts ($n=8$).

Average Literacy Score	Total Publication Count	Correlation
Reading	Same Year	-0.714* ^b
Reading	Previous Year	-0.851** ^a
Mathematics	Same Year	-0.810* ^b
Mathematics	Previous Year	-0.899** ^a
Scientific	Same Year	-0.810* ^b
Scientific	Previous Year	-0.890** ^a

^a Pearson r correlation; ^b Spearman ρ correlation; * The correlation is significant at $p < 0.01$; ** The correlation is significant at $p < 0.001$.

4.3. Relationship Between PISA Scores and High-, Low-Performing Countries, and Türkiye

The relationship between PISA scores and STEM publication volume was also analyzed for the top five and bottom five performing countries, as well as for Türkiye, across all exam years. Table 3 provides summary data for the groups included in the subsequent analyses (Tables 4–6); accordingly, it lists more than five countries to account for all relevant cases.

Table 3.

Average PISA scores and total publication counts for top- and bottom- performing countries, including Türkiye.

Countries	Literacy			Publication Count	
	Reading	Mathematics	Scientific	Same Year	Prev Year
Top Performers					
Finland	529	524	539	7	13
Netherlands	498	520	513	18	15
Hong Kong	528	539	546	10	17
Switzerland	495	524	507	8	12
Japan	514	534	541	17	11
Canada	524	520	525	60	69
Korea	530	539	531	3	3
New Zealand	515	509	519	8	55
Bottom Performers					
Brazil	406	372	397	12	14
Indonesia	384	374	391	17	17
Mexico	417	403	414	14	19
Chile	443	413	440	5	7
Russia	465	479	480	15	7
Thailand	414	418	426	11	15
Türkiye	454	438	449	46	58

In the following analyses, Türkiye ranked among the bottom five countries in reading literacy scores and was therefore not included separately (Table 4). For mathematics literacy, Finland and the Netherlands shared top rankings, so six countries are listed among high performers (Table 5). For scientific literacy, the top and bottom five countries plus Türkiye were included among the examined countries (Table 6). Literacy scores showed partial normality, publication counts did not; thus, Spearman's ρ was applied throughout. Countries with equal performance levels are alphabetically ordered in tables.

Reading Literacy

Table 4 presents correlations between reading literacy scores and the number of STEM publications in the exam year and the prior year for the top five and bottom five countries in reading literacy. Among the top-performing countries, Finland, Canada, Korea, and New Zealand show negative strong correlations between scores and same-year publications, with Canada and New Zealand also displaying negative correlations with prior-year publications. Among low-performing countries, only Indonesia exhibits a significant negative correlation between prior-year publications and exam scores. Russia, which did not participate in the 2000 exam and only published in 1999 and 2000, has an empty cell due to its limited data.

Table 4.

Correlations between PISA reading literacy scores and publication counts for top- and bottom-performing countries.

Average Reading Literacy Score	Publication Count	
	Previous Year	Same Year
	Spearman ρ	Spearman ρ
Top Performers		
Finland	-0.733	-0.866*
Hong Kong	-0.151	-0.464
Canada	-0.759*	-0.834**
Korea	-0.412	-0.733**
New Zealand	-0.768*	-0.878**
Bottom Performers		
Brazil	0.525	0.525
Indonesia	-0.713*	-0.494
Mexico	-0.252	-0.109
Russia	0.408	
Türkiye	-0.020	0.185

* The correlation is significant at $p < 0.01$; ** The correlation is significant at $p < 0.001$.*Mathematics Literacy*

Table 5 shows the correlation between mathematics literacy scores and STEM publications. Finland, the Netherlands, and Hong Kong display strong negative correlations between mathematics literacy scores and same-year publications, while no other significant relationship are found.

Table 5.

Correlations between PISA mathematics literacy scores and publication counts for top- and bottom-performing countries.

Average Mathematics Literacy Score	Publication Count	
	Previous Year	Same Year
	Spearman ρ	Spearman ρ
Top Performers		
Finland	-0.773*	-0.770*
Netherlands	-0.873*	-0.778*
Hong Kong	-0.481	-0.873*
Switzerland	-0.741*	-0.676
Japan	-0.041	0.118
Korea	-0.249	-0.486
Bottom Performers		
Brazil	0.234	0.234
Indonesia	-0.187	0.027
Mexico	0.000	0.082
Chile	-0.206	-0.206
Thailand	-0.633	-0.580
Türkiye	0.473	0.556

* The correlation is significant at $p < 0.01$; ** The correlation is significant at $p < 0.001$.*Scientific Literacy*

As seen in Table 6, among high-performing countries, only Finland and Canada exhibit a strong negative correlation between scientific literacy scores and prior-year publications. For Türkiye, the correlation is positive but insignificant.

Table 6

Correlations between PISA science literacy scores and publication counts for top- and bottom-performing countries.

Average Scientific Literacy Score	Publication Count	
	Previous Year	Same Year
	Spearman ρ	Spearman ρ
Top Performers		
Finland	-0.773*	-0.674
Hong Kong	-0.151	-0.027
Japan	-0.370	-0.449
Canada	-0.740*	-0.687
Korea	0.085	-0.351
Bottom Performers		
Brazil	0.237	0.237
Indonesia	-0.008	0.290
Mexico	0.064	0.207
Chile	-0.104	-0.104
Thailand	-0.629	-0.590
Türkiye	0.611	0.704

* The correlation is significant at $p < 0.01$; ** The correlation is significant at $p < 0.001$.

5. Conclusion and Suggestions

This study presents a bibliometric analysis of English-language STEM-related publications and examines the relationship between publication volume and PISA scores for countries participating in the PISA cycles with up to one missing cycle. According to the bibliometric findings, the United States leads in STEM-related publication collaborations—a trend previously highlighted by Özkaya (2019) for the United States, Australia, and Canada. Similarly, in the study by Irwanto and Hutahaean (2025), the United States and Purdue University stand out as the most productive country and institution, respectively. Türkiye, South Korea, Australia, and Canada also emerge as notable contributors. In terms of institutional collaboration, the University of California and Purdue University have established strong partnerships, particularly with institutions located within the United States. These findings indicate that the U.S. holds a central position in STEM research both through international collaborations and as the home of leading research institutions.

A closer look at the relationship between PISA literacy scores and total publication counts reveals a complex dynamic. Generally, there is an overall negative correlation between PISA scores and total publication volume in both same-year and prior-year publications. This suggests that high publication output does not necessarily align with improved educational outcomes. For example, while the U.S. is highly active in global STEM research, its PISA literacy scores remain relatively low. In contrast, Finland, a consistent high performer in PISA across literacy areas, produces fewer publications, challenging the assumption that increased scientific output links to better educational results. Domínguez et al. (2012) claim that PISA exams have a significant impact on academic publications in the field of education and social sciences. This contrasts with the approach in this study. Similar findings were reported by Yıldırım Kırbacı (2022), who observed a decline in PISA scientific literacy scores even as scientific literacy publications increased. These outcomes indicate the need for a deeper understanding of the complex interactions between research output and educational performance.

One possible explanation for this negative association is the difficulty of translating research outputs into educational practice (Furman Shaharabani & Yarden, 2019). Although STEM knowledge production has increased rapidly, its integration into curricula, teacher professional development, and classroom practice may not occur at the same pace (National Academies of Sciences, Engineering, and Medicine, 2019). In addition, the effects of research findings on student achievement may take time to emerge, creating a lag

between knowledge production and educational outcomes. These outcomes indicate the need for a deeper understanding of the complex interactions between research output and educational performance.

Analyzing country-specific relationships, a significant negative relationship is evident between reading literacy scores and publication volume for the highest-performing countries, including Finland, Canada, South Korea, and New Zealand. This implies an inverse trend, where higher exam scores correlate with fewer publications. A recent report by Statista (2024) notes that Finland has consistently outperformed the OECD average since 2000, although its scores have recently declined. Meanwhile, Hong Kong, despite its lower STEM research output, shows strong student reading performance due to classroom discipline and effective reading strategies (Lau & Ho, 2016). Among lower-performing countries, only Indonesia demonstrates a strong negative correlation between pre-exam publication volume and reading scores. For Brazil, while no significant relationship is found, PISA outcomes have sparked initiatives to strengthen STEM education (NSF, 2022). Table 3 highlights Canada and Türkiye as countries with relatively high publication counts, though this does not correspond to higher PISA scores.

When assessing math literacy scores, a significant negative correlation between pre-exam publication volume and scores emerges for Finland, the Netherlands, and Switzerland. In the exam year, this relationship remains significant for Finland, the Netherlands, and Hong Kong. Japan is the only high-scoring country where a positive, though insignificant, relationship exists between publication volume and scores. High PISA scores in some countries may correlate with a reduced emphasis on STEM publications, suggesting that success in PISA does not necessarily rely on extensive research output. In lower-scoring countries, such as Brazil, Indonesia, and Türkiye, positive but insignificant relationships exist between publication counts and exam scores. Table 3 shows that publication volume tends to increase during the exam year compared to the previous year.

Regarding scientific literacy scores, significant correlations are observed between pre-exam publication volume and exam scores for Finland and Canada. For Brazil, Indonesia, Mexico, and Türkiye, positive but insignificant correlations are found both in the exam year and the year prior.

This study contributes to the literature by exploring the relationship between STEM research and PISA scores, addressing a significant gap. Previous studies, such as Yıldırım Kırbaç's (2022), have noted a decline in PISA scores despite an increase in scientific literacy publications. However, this study goes further by examining specific country-level patterns, identifying a negative relationship between publication output and educational outcomes, particularly in successful countries like Finland and Canada.

Given the central role of the United States, Australia, and Canada in global STEM collaboration, other countries should be encouraged to join these networks to enhance knowledge sharing and build capacity. Collaborations with leading institutions such as the University of California and Purdue University—given their strength in this context—offer significant opportunities for growth in the STEM field, allowing other institutions to increase their contributions and impact.

In light of the findings of this study, it becomes clear that the number of STEM-related publications alone cannot be considered a reliable indicator of educational success. The lack of a direct correspondence between high publication volume and higher PISA scores suggests that the quality, content, relevance to target audiences, and especially the influence of these publications on policymakers may be more critical than their sheer quantity. Indeed, countries such as Finland and Canada, which perform highly in PISA assessments, may base their education policies more on pedagogical quality, teacher competencies, and systematic reforms rather than on extensive academic output. Conversely, in developing countries, the increase in publication numbers without a corresponding improvement in student performance may point to structural problems—such as the failure to integrate research into educational practice, insufficient translation into teacher training, or a lack of alignment with the actual needs in the field. Moreover, not only the direction but also the statistical significance of the correlation is important; in some countries, although positive relationships are observed, they are not statistically significant, indicating that these correlations may be weak or coincidental.

This finding also underscores the potential role of Educational Technology in bridging the gap between STEM research and educational practice. Online learning platforms, professional development networks, and open educational resources can facilitate the transfer of STEM research into classroom settings by providing teachers with accessible and up-to-date educational materials (Halawa et al., 2024; Kleinschmit et al., 2023). Strengthening such digital mechanisms may help ensure that growing research outputs contribute more directly to improvements in teaching and learning.

Against this backdrop, the study underscores the need to reassess the impact of STEM publications on education systems. Given the unexpected negative correlations observed between publication output and PISA scores, future research should explore whether a high volume of publications truly reflects an improvement in educational quality, or whether other factors—such as scientific culture, policy orientation, and resource allocation—play more decisive roles in educational achievement. Additionally, a deeper examination of the specific challenges faced by countries like Brazil, Indonesia, and Türkiye may offer valuable insights into how STEM education initiatives can be better optimized to enhance educational outcomes.

In this context, gender-focused analyses could also make significant contributions by examining PISA results and STEM career aspirations from a gender perspective. Such analyses would offer a more holistic understanding of how STEM education can be made more inclusive and effective across different contexts and demographics.

This study focuses on countries with participation in PISA and does not differentiate between publications based on age demographics of the target audience. Since PISA assesses the readiness of 15-year-olds in literacy, future studies could explore how STEM publications focused on the high school level relate to PISA outcomes.

This study is subject to certain methodological limitations. First, only academic publications written in English and indexed in the Web of Science (WoS) and Scopus databases were included in the analysis. This decision was made to ensure linguistic consistency and enhance comparability within the dataset. However, excluding publications in other languages may limit the comprehensive representation of global research trends, particularly in countries where significant scholarly output exists in local languages.

Second, the study included 33 countries that have consistently participated in the PISA assessments and have reliable publication data. Nevertheless, countries such as Bulgaria, the Czech Republic, Hungary, Iceland, Lithuania, Luxembourg, Macao (China), the Slovak Republic, and Uruguay were excluded due to insufficient publication volume. This exclusion may affect the generalizability of the findings and could overlook certain regional patterns or national research dynamics.

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