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The potential of STEM-based curriculum in realizing 21st-century learning: Bibliometric analysis

Wahyudin[1], Muhammad Rafi Valliansyah[2], Cindy Sri Meidina Adeliani[3], Muhammad Bahrul Ulum[4]
[1,2,3,4]Universitas Pendidikan Indonesia, Bandung, Indonesia
wahyudin_sanusi@upi.edu[1], rafivalli261@upi.edu[2], cindysrimeidina@upi.edu[3], 2003691muhammad.bahrul.ulum@upi.edu[4]

ABSTRACT

Education, in general, cannot be separated from various existing problems. One of these problems is a gap between graduate education and industry needs. This causes multidisciplinary learning, such as STEM, to be carried out. Extracting information related to research in the STEM curriculum field as an effort to realize 21st-century learning is important. This research aims to analyze the scope of STEM-based curriculum research in realizing 21st-century learning using a bibliometric review. Data collection was carried out through the Scopus database with the keywords ("STEM competency" AND "21st learning skills") OR (stem AND "21st learning skills") OR (stem AND curriculum AND student) from 2020 to 2025. This research discusses general information analysis, annual research production, most relevant sources, local impact sources, local impact authors, most relevant affiliations, country of correspondence author, country of production of scientific articles, most cited countries, most cited documents, tree map and related thematic map with previously defined keywords. This research found that the project-based learning model (PjBL) is suitable for implementation in STEM-based curricula to realize 21st-century learning. Some potential research keywords are students, curriculum, engineering education, engineering, motivation, and curriculum development.

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ABSTRAK

Pendidikan secara umum tidak lepas dari berbagai permasalahan yang ada. Salah satu masalah tersebut adalah terdapat kesenjangan antara lulusan pendidikan dan kebutuhan industri. Hal ini menyebabkan pembelajaran multidisiplin ilmu seperti STEM perlu dilakukan. Penggalian informasi terkait penelitian dalam bidang kurikulum STEM sebagai upaya mewujudkan pembelajaran abad ke-21 menjadi penting. Penelitian ini bertujuan untuk menganalisis ruang lingkup penelitian kurikulum berbasis STEM dalam mewujudkan pembelajaran abad ke-21 dengan menggunakan tinjauan bibliometrik. Pengumpulan data dilakukan melalui database scopus dengan kata kunci ("STEM competency" AND "21st learning skills") OR (stem AND "21st learning skills") OR (stem AND curriculum AND student) dari tahun 2020 sampai 2025. Penelitian ini membahas analisis informasi umum, produksi riset tahunan, sumber paling relevan, local impact sumber, local impact penulis, afiliasi paling relevan, negara korespondensi penulis, negara produksi artikel ilmiah, negara yang paling banyak disitasi, dokumen yang paling banyak disitasi, tree map dan thematic map terkait dengan kata kunci yang telah ditetapkan sebelumnya. Penelitian ini menemukan bahwa model pembelajaran berbasis proyek (PjBL) cocok diimplementasikan dalam kurikulum berbasis STEM dalam mewujudkan pembelajaran abad ke-21. Beberapa kata kunci penelitian yang potensial berupa students, curricula, engineering education, engineering, motivation, dan curriculum development.

Kata Kunci: *analisis bibliometrik; kurikulum berbasis STEM; pembelajaran abad ke-21; pemrograman R; pendidikan*

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INTRODUCTION

The development and maintenance of quality education are essential (Sahinoglu, 2022). Alongside using advanced technology, which has become necessary (Leng *et al*., 2022), modern education requires digitalization processes to support learning (Arisoy, 2022). The adaptation of modern education is marked by integrating technology in education to enhance students' access to information (Alenezi, 2023). Furthermore, digital transformation in education consistently involves new technologies, methodological and theoretical approaches, and pedagogical practices (Thompson, 2021). One evolving pedagogical approach is open education (Ibarra-Vazquez *et al*., 2023), unplugged activity (Agbo *et al*., 2024; Huang & Looi, 2020), innovative learning (Huda *et a*l., 2023; Rosmansyah *et al*., 2022), mastery learning (Johnston *et al*., 2024; Winget & Persky, 2022), outcome based education (Saha *et al*., 2023; Syeed *et al*., 2022), Science, Technology, Engineering, and Mathematic (STEM) (Chen *et al*., 2023; Xu & Ouyang, 2022).

STEM education has a positive influence on 21st-century learning. A study indicates that STEM education can enhance students' critical thinking skills (Hacioğlu & Gülhan, 2021). Critical thinking itself is one of the key 21st-century skills, alongside communication, creativity, digital literacy, and collaboration (Shadiev & Wang, 2022). It has been confirmed that STEM education contributes to developing 21st-century skills for prospective science teachers (Hacioğlu, 2021). This undoubtedly strengthens the potential of STEM in positively influencing students' 21st-century competencies.

Research on STEM and 21st-century skills has been previously conducted. Studies on STEM education about other disciplines have been examined by Martynenko et al (Martynenko *et al*., 2023). Research discusses a bibliometric analysis on STEM implementation (Phuong et al., 2023). Another bibliometric study has explored the role of STEM education in improving educational quality (Jamali *et al*., 2022). A meta-analysis has been conducted on the effectiveness of STEM-based learning in teaching 21st-century skills to Generation Z in science education. Based on the brief studies presented, a bibliometric analysis on the potential of STEM-based curricula in realizing 21st-century learning has not yet been conducted (Ichsan *et al*., 2023).

Education, in general, is not free from various existing challenges. One prominent issue concerns 'education' and 'the future.' This is supported by research indicating a gap between graduates of educational institutions and industry demands, as seen in architecture (Lasheen *et al*., 2022), engineering education (pendidikan teknik) (Broo *et al*., 2022), software engineering (rekayasa perangkat lunak/RPL) (Cico et al., 2021), STEM, and other fields. This issue subsequently impacts adolescents' 21st-century skill competencies. Therefore, exploring information based on historical research data related to STEM curricula is necessary to achieve 21st-century learning. Research on STEM-based curricula in realizing 21st-century learning needs to be conducted. Accordingly, this study aims to analyze the scope of research on STEM-based curricula in achieving 21st-century learning through a bibliometric review. This research is expected to contribute to the body of knowledge in STEM education toward realizing 21st-century learning.

LITERATURE REVIEW

21st-Century Learning

The 21st-century curriculum encourages learners to develop skills and knowledge relevant to the modern world, where they must quickly adapt to the increasingly complex and globally interconnected societal changes. The 21st-century education framework emphasizes several critical aspects, including critical thinking, communication, teamwork, planning, information and communication technology (ICT), contextual, and media literacy (Muhali, 2019). Leveraging information technology, particularly ICT, in

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education can enhance learners' motivation and creativity. Educators must utilize technology while maintaining its integrity, ensuring its alignment with educational objectives, and providing students with knowledge about digital signatures, personal data encryption, and internet security. 21st-century learning is designed to equip individuals with the skills required for Industry 4.0 and facilitate lifelong learning for all (González-Pérez & Ramírez-Montoya, 2022).

Science, Technology, Engineering, and Mathematics (STEM)

In this era of continuous digital and globalization development, the role of STEM in education has become increasingly crucial. STEM leverages technological advancements as tools to enhance interactive learning, preparing students to become proficient in utilizing digital tools and platforms. Furthermore, STEM is vital in equipping students to face future challenges, particularly the complex and ever-changing demands of the digital age. Students are expected to develop their potential and skills in critical thinking, creativity, and the ability to collaborate with diverse individuals. STEM education teaches students to acquire competencies in analysis, evaluation, and solving complex problems (Hulwani *et al*., 2021).

Shifting attitudes toward STEM education across various educational levels, including universities, secondary schools, and elementary schools, have become increasingly evident. The benefits of focusing on STEM fields for students' future careers and the importance of accommodating diverse learning styles are particularly noteworthy. Research in STEM education indicates that students' attitudes toward STEM learning have evolved significantly in recent years, with an emphasis on analytical thinking and problem-solving skills. It is crucial to support students in achieving success in STEM subjects while considering how different types of learners respond to varied teaching approaches (Martynenko *et al*., 2023). As such, STEM education fosters academic skills and cultivates individuals prepared to face future challenges in an era of digitalization and globalization. Furthermore, STEM is expected to continue yielding positive outcomes from educational experiences and programs, influencing student attitudes toward STEM across all educational levels and contributing to developing a highly skilled workforce in the years to come.

Bibliometrics

Bibliometrics is a field of study that applies quantitative and statistical analysis to literature to provide historical perspectives, evaluate research trends, and measure the impact of publications and authors. This discipline emerged in the early 20th century and has grown rapidly with the advancements of digital databases and computational tools. Bibliometric analysis was first applied to scientific publications by Alfred Lotka and Samuel Bradford and has since expanded to medicine and healthcare (Thompson & Walker, 2015). Bibliometric research methods identify major topics, authors, sources, most-cited articles, and other elements within scientific literature (Rojas-Sánchez *et al*., 2022). Scientific journals are the primary subject of bibliometric analysis because they represent repositories of human knowledge about various global phenomena, organized by topic and their influence across different academic disciplines (Palla *et al*., 2015).

The advancement of bibliometrics has brought significant convenience to researchers. Bibliometrics constitutes a set of quantitative methods employed to measure, track, and analyze print-based scientific literature. The analysis conducted through bibliometrics involves utilizing data on publication quantities and authorship, including citation metrics, to evaluate researchers, institutions, and countries.

Following bibliometric analysis, users are expected to identify core journals within various academic disciplines, predict knowledge trends across different fields of study, and examine scientific literature's obsolescence and dissemination patterns (Habibi, 2022).

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R Programming

The R programming language is used within software environments specifically designed for statistical computing and graphics. R analyzes complex data, performs statistical modeling, and makes graphical representations. This program also incorporates numerous popular open-source packages, becoming the standard language for conducting sophisticated statistical analysis and computational tasks. R utilizes the term "package" to describe the location where data and functions are stored. R packages consist of two types: standard packages that are essential components of every R software installation, and specialized packages developed by numerous experts to extend statistical computing capabilities. (Amir & Tiro, 2022).

METHODS

The method employed in this study is bibliometric analysis. As previously explained, the bibliometric analysis in this research provides historical perspectives on prior studies and evaluates trends within the scope of STEM and 21st-century learning. Following the analysis results, the research discussion will examine the potential of STEM-based curricula in realizing 21st-century learning. This study consists of several stages, as illustrated in **Figure 1**. After identifying the research problem and conducting literature reviews, the study proceeds to the data collection phase..

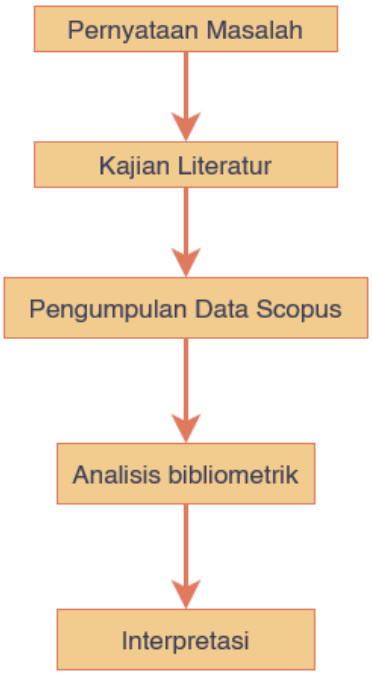

Figure 1. Research Design for Bibliometric Analysis
Source: Author Documentation 2024

Data collection must be conducted as a preliminary step for performing bibliometric analysis (Chen *et al*., 2023; Donthu *et al*., 2021). The required data consists of research articles, review articles, book chapters, and other scholarly works in the domains of STEM-based curriculum and STEM and 21st-century learning. These data were obtained from the Scopus database (Kusuma et al., 2024). The specific search parameters used for data collection in the Scopus database are as follows.

Table 1. *Query the database* Scopus

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Rentang Waktu	Pencarian	Hasil	Unduh
2020 - 2025	TITLE-ABS-KEY (("STEM competency" AND "21st learning skills") OR (stem AND "21st learning skills") OR (stem AND curriculum AND student))	4855	26 Mei 2024

Source: Author Documentation 2024

The sequence of keywords used in the search can be seen in Table 1. The search period was set from 2020 to 2025, with the language restriction limited to English. The search results yielded 4,855 articles without any article type restrictions, including journal articles, conference papers, books, etc. These data were downloaded on May 26, 2024. The discussion will not cover the entire population; instead, a sample comprising half of the population will be selected to facilitate the presentation of results and discussion. The following section will present the bibliometric analysis of the retrieved data, including analyses of: general information, annual research output, most relevant sources, local impact of sources, local impact of authors, most relevant affiliations, corresponding authors' countries, scientific article production by country, most cited countries, most cited documents, tree maps, and thematic maps.

RESULTS AND DISCUSSION

Scopus Data Information

Table 2 presents the primary information from the analyzed Scopus file, including: document types, content, authors, and author collaborations.

Table 2. Core Paper Data Information

Description	Results
Timespan	2020:2024
Sources (Journal, Books, etc.)	782
Documents	2204
Annual Growth Rate %	-70.44
Document Average Age	2.2
Average citations per doc	3.364
References	0
DOCUMENT TYPES	
Article	1056
Article, book chapter	1
Article, conference paper	3
Review	41
Editorial	2

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Description	Results
Conference paper	844
Review article	2
DOCUMENT CONTENTS	
Keywords Plus (ID)	5981
Author's Keywords (DE)	4531
AUTHORS	
Authors	7013
Authors of single-authored docs	252
AUTHORS COLLABORATION	
Single-authored docs	278
Co-Authors per Doc	3.73
International co-authorships %	11.75

Source: Author's Data Processing Results using R Studio 2024

This study utilizes a paper database spanning research from 2020 to 2024, comprising 2,204 documents with an average of 3.364 citations per document. The bibliometric results also indicate the presence of 1,056 articles and 844 conference papers among the 2,204 detected documents. Additionally, 5,981 keywords and 4,531 author keywords are used in related research. The analysis further reveals that at least 5,981 authors have contributed to the relevant research topic, followed by 4,531 single authors.

Annual Scientific Production

Figure 2 illustrates the annual production growth (2020-2025) of research on STEM-based curriculum implementation. The study demonstrates a substantial year-over-year increase in research output.

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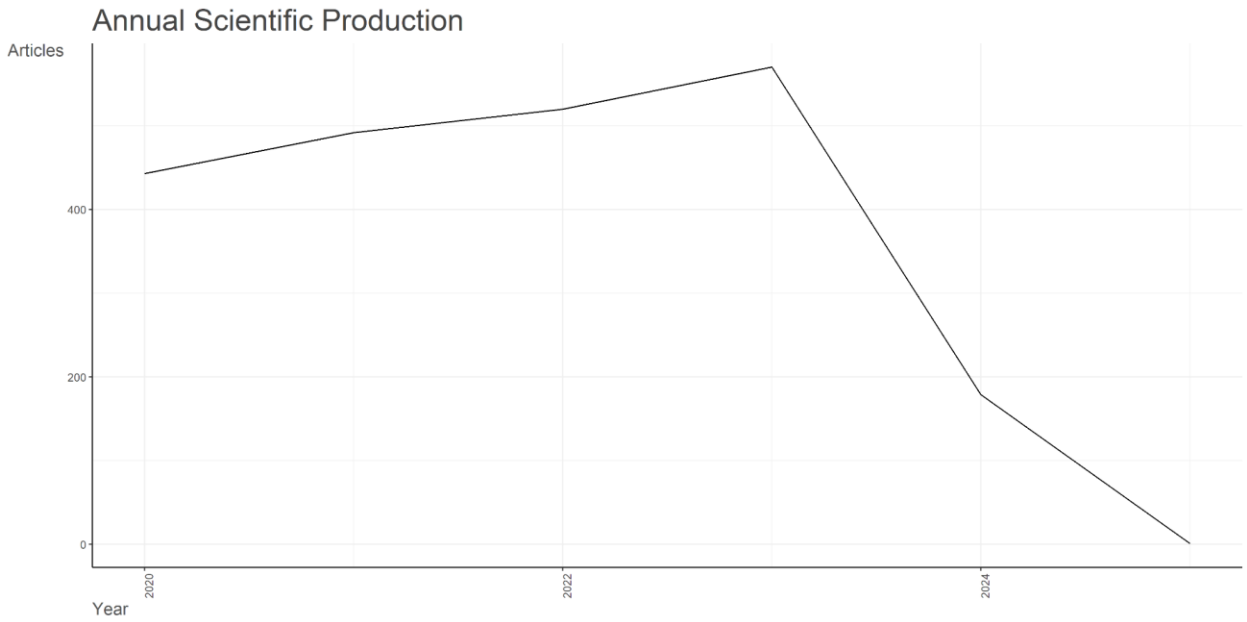

Figure 2. Annual Scientific Production (2020 - 2025)
Source: Author's Data Processing Results using R Studio 2024

The records indicate 443 studies in 2020, with an increase of 127 studies by 2023 (totaling 570). Research on STEM-based curricula remains active in 2024, with 179 studies already collected, while 1 study has been recorded for 2025.

Most Relevant Sources

Table 3 displays the top ten most relevant sources (2020-2025) in research on STEM-based curriculum implementation.

Table 3. Top 10 Most Relevant Sources 2020-2025

Rank	Sources	Articles
1	ASEE ANNUAL CONFERENCE AND EXPOSITION, CONFERENCE PROCEEDINGS	301
2	JOURNAL OF CHEMICAL EDUCATION	70
3	PROCEEDINGS - FRONTIERS IN EDUCATION CONFERENCE, FIE	56
4	EDUCATION SCIENCES	54
5	JOURNAL OF PHYSICS: CONFERENCE SERIES	49
6	FRONTIERS IN EDUCATION	41
7	ACM INTERNATIONAL CONFERENCE PROCEEDING SERIES	38
8	INTERNATIONAL JOURNAL OF STEM EDUCATION	30
9	LECTURE NOTES IN COMPUTER SCIENCE (INCLUDING SUBSERIES LECTURE NOTES IN ARTIFICIAL INTELLIGENCE AND LECTURE NOTES IN BIOINFORMATICS)	24
10	SUSTAINABILITY (SWITZERLAND)	24

Source: Author's Data Processing Results using R Studio 2024

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Ranked first, ASEE ANNUAL CONFERENCE AND EXPOSITION, CONFERENCE PROCEEDINGS published 301 articles, followed by JOURNAL OF CHEMICAL EDUCATION in second place with 70 articles.PROCEEDINGS - FRONTIERS IN EDUCATION CONFERENCE, FIE ranked third with 56 articles, while EDUCATION SCIENCES placed fourth with 54 published articles. JOURNAL OF PHYSICS: CONFERENCE SERIES secured fifth position with 49 articles, and FRONTIERS IN EDUCATION ranked sixth with 41 articles. In seventh place was ACM INTERNATIONAL CONFERENCE PROCEEDING SERIES with 38 articles, followed by INTERNATIONAL JOURNAL OF STEM EDUCATION in eighth position with 30 articles. Ninth place went to LECTURE NOTES IN COMPUTER SCIENCE (INCLUDING SUBSERIES LECTURE NOTES IN ARTIFICIAL INTELLIGENCE AND LECTURE NOTES IN BIOINFORMATICS) with 24 articles, and SUSTAINABILITY (SWITZERLAND) also had 24 articles, sharing the tenth position.

Sources' Local Impact **(H-Index)**

Table 4 presents the top ten studies with the highest H-Index values in research related to STEM implementation.

Table 4. Top 10 Sources' Local Impact based on H-Index, TC (Total Citations), NP (Number of Publications), and PY (Publication Year Start)

Rank	Sources	H-Index	TC	NP	PY Start
1	INTERNATIONAL JOURNAL OF STEM EDUCATION	12	529	30	2020
2	JOURNAL OF CHEMICAL EDUCATION	9	312	70	2020
3	EDUCATION SCIENCES	7	304	54	2020
4	INTERNATIONAL JOURNAL OF TECHNOLOGY AND DESIGN EDUCATION	7	197	22	2020
5	JOURNAL OF RESEARCH IN SCIENCE TEACHING	7	178	12	2020
6	SUSTAINABILITY (SWITZERLAND)	7	116	24	2020
7	FRONTIERS IN EDUCATION	6	97	41	2020
8	IEEE TRANSACTIONS ON EDUCATION	6	126	17	2020
9	ASEE ANNUAL CONFERENCE AND EXPOSITION, CONFERENCE PROCEEDINGS	5	262	301	2020
10	CBE LIFE SCIENCES EDUCATION	5	52	11	2020

Source: Author's Data Processing Results using R Studio 2024

The table reveals that the INTERNATIONAL JOURNAL OF STEM EDUCATION attained the highest H-Index of 12, accumulating 569 total citations (TC) from 30 publications (NP). Following closely, the JOURNAL OF CHEMICAL EDUCATION (H-Index 12, 312 citations, 70 documents), EDUCATION SCIENCES (H-Index 7, 304 citations, 54 documents), INTERNATIONAL JOURNAL OF TECHNOLOGY AND DESIGN EDUCATION (H-Index 7, 197 citations, 22 documents), JOURNAL OF RESEARCH IN SCIENCE TEACHING (H-Index 7, 178 citations, 12 documents), SUSTAINABILITY (SWITZERLAND) (H-Index 7, 116 citations, 24 documents), FRONTIERS IN EDUCATION (H-Index 6, 97 citations, 41 documents), IEEE TRANSACTIONS ON EDUCATION (H-Index 6, 126 citations, 17 documents), ASEE

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ANNUAL CONFERENCE AND EXPOSITION, CONFERENCE PROCEEDINGS (H-Index 5, 262 citations, 301 documents), and CBE LIFE SCIENCES EDUCATION (H-Index 5, 52 citations, 11 documents).

Authors' Local Impact (H-Index)

Table 5 demonstrates the impact of authors on related research.

Table 5. Top 10 Authors' Local Impact based on H-Index, TC (Total Citations), NP (Number of Publications), and PY (Publication Year Start)

Rank	Authors'	H-Index	TC	NP	PY Start
1	BISWAS G	4	107	9	2020
2	CRAIG CA	4	21	4	2020
3	GILBERTZ S	4	21	5	2020
4	HORN M	4	67	5	2020
5	MOORE TJ	4	32	17	2020
6	PETRUN SAYERS EL	4	21	4	2020
7	VAN PETEGEM P	4	34	4	2020
8	WILENSKY U	4	68	6	2020
9	ZHANG H	4	135	5	2020
10	ANWAR S	3	24	7	2020

Source: Author's Data Processing Results using R Studio 2024

Among the top three contributors, BISWAS G ranks first in authors' local impact with an H-Index of 4 and 107 citations from 9 publications, demonstrating a significant correlation with STEM-based curriculum implementation. Following closely are CRAIG CA, H-Index 4, 21 citations, four publications, and GILBERTZ S, H-Index 4, 21 citations, and five publications.

Most Relevant Affiliations

Table 6 displays affiliated institutions classified by country, number of articles, and university ranking (using the Quacquarelli Symonds (QS) World Ranking 2024 as reference).

Table 6. Top 10 Most Relevant Affiliations

Rank	Affiliation	Country	Articles	QS 2024
1	PURDUE UNIVERSITY	USA	98	99
2	UNIVERSITY OF CALIFORNIA	USA	57	10
3	GEORGE MASON UNIVERSITY	USA	37	951-1000
4	NORTH CAROLINA STATE UNIVERSITY	USA	35	274
5	MICHIGAN STATE UNIVERSITY	USA	32	136

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Rank	Affiliation	Country	Articles	QS 2024
6	NATIONAL TAIWAN NORMAL UNIVERSITY	TAIWAN	28	431
7	VANDERBILT UNIVERSITY	USA	27	261
8	PACE UNIVERSITY	USA	26	-
9	FLORIDA INTERNATIONAL UNIVERSITY	USA	24	556
10	UNIVERSITY OF MICHIGAN	USA	24	33

Source: Author's Data Processing Results using R Studio 2024

Among the top ten affiliated institutions, nine originate from the United States (USA): PURDUE UNIVERSITY, UNIVERSITY OF CALIFORNIA, GEORGE MASON UNIVERSITY, NORTH CAROLINA STATE UNIVERSITY, MICHIGAN STATE UNIVERSITY, VANDERBILT UNIVERSITY, PACE UNIVERSITY, FLORIDA INTERNATIONAL UNIVERSITY, and the UNIVERSITY OF MICHIGAN. “This 'monopoly' of rankings can be considered expected, given that STEM itself is an acronym introduced in the United States by the U.S. National Science Foundation (NSF) (https://www.britannica.com/topic/STEM-education). Meanwhile, NATIONAL TAIWAN NORMAL UNIVERSITY is the sole non-U.S. institution that has secured a position among the top ten, with 28 articles.

Corresponding Author's Countries

Figure 3 and **Table 7** present the top 10 countries of corresponding authors based on document count, intra-country collaboration (SCP), and international collaboration (MCP). The corresponding author refers to the individual who submits the article to the journal publisher and is responsible for all correspondence with the journal prior to acceptance and publication (Mattsson *et al*., 2010).

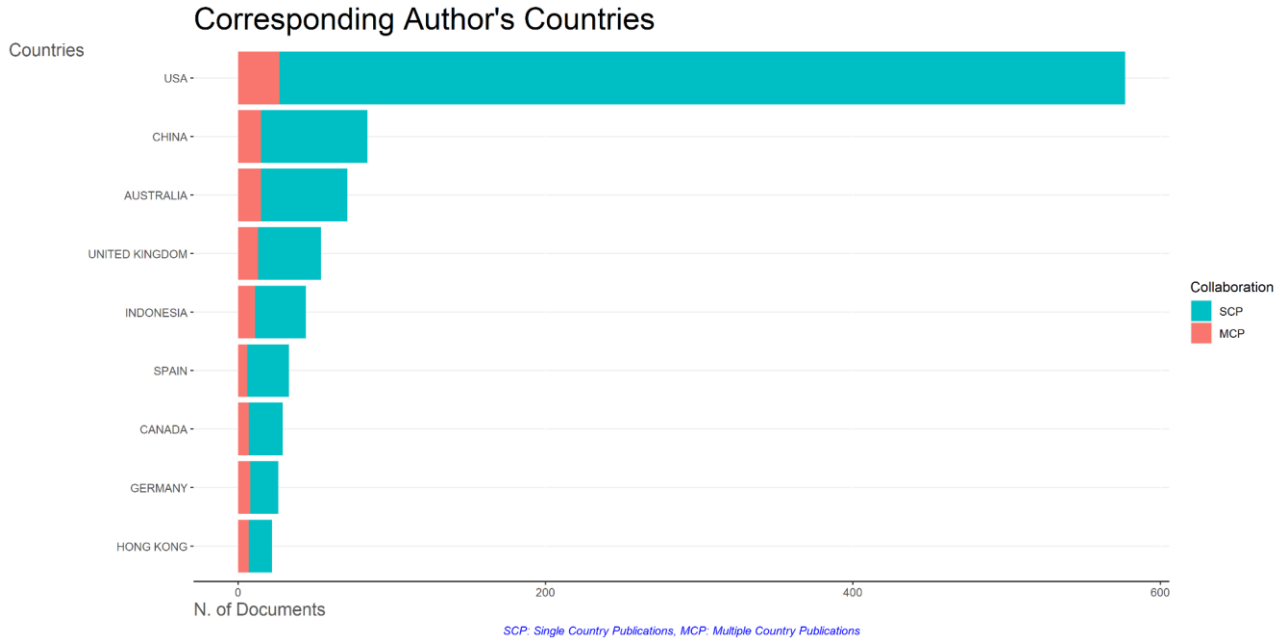

Figure 3. Top 10 Corresponding Authors' Countries
Source: Author's Data Processing Results using R Studio

Table 7. Top 10 Corresponding Authors' Countries by articles, SCP, and MCP

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Rank	Country	Articles	SCP	MCP	Freq
1	Tidak Terdefinisi	897	839	58	407
2	USA	577	550	27	262
3	CHINA	84	69	15	38
4	AUSTRALIA	71	56	15	32
5	UNITED KINGDOM	54	41	13	24
6	INDONESIA	44	33	11	20
7	SPAIN	33	27	6	15
8	CANADA	29	22	7	13
9	GERMANY	26	18	8	12
10	HONG KONG	22	15	7	10

Source: Author's Data Processing Results using R Studio 2024

The data presentation reveals discrepancies between **Figure 3** and **Table 7**. **Table 7** fails to identify the top-ranked country of corresponding authors, displaying only the article count, SCP, MCP, and frequency obtained through bibliometric analysis. In contrast, **Figure 3** distinctly positions the USA as the leading nation among nine countries. Disregarding potential measurement errors, the United States ranked second (**Table 7**), producing 577 relevant articles from 2020-2025, with SCP 550 and MCP 27 values. Subsequent rankings show: CHINA (84 articles, 69 SCP, 15 MCP), AUSTRALIA (71 articles, 56 SCP, 15 MCP), UNITED KINGDOM (54 articles, 41 SCP, 13 MCP), INDONESIA (44 articles, 33 SCP, 11 MCP), SPAIN (33 articles, 27 SCP, 6 MCP), CANADA (29 articles, 22 SCP, 7 MCP), GERMANY (26 articles, 18 SCP, 8 MCP), dan HONG KONG (22 articles, 15 SCP, 7 MCP).

Countries' Scientific Production

Figure 4 displays the distribution map of countries' scientific production for 2020-2025.

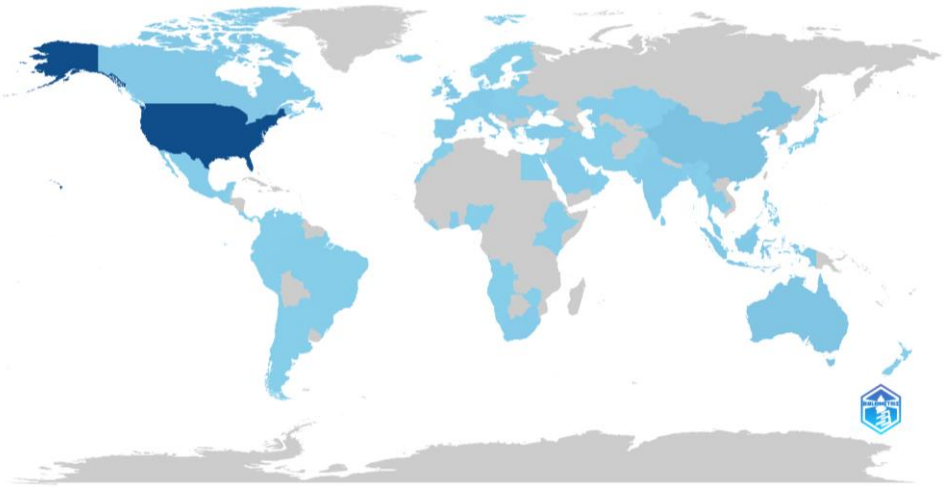

Figure 4. Distribution Map of Countries' Scientific Production
Source: Author's Data Processing Results using R Studio 2024

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The color intensity displayed on the map indicates the quantity of scientific article production. Darker shades represent higher scientific article output from the respective country. The map clearly shows the United States as having the darkest color among other nations. For frequency details, please refer to **Table 8** below.

Table 8. Top 10 Countries' Scientific Production

Rank	Region	Freq
1	USA	2583
2	CHINA	231
3	AUSTRALIA	174
4	UK	140
5	INDONESIA	114
6	CANADA	102
7	SPAIN	96
8	GERMANY	83
9	GREECE	54
10	MALAYSIA	53

Source: Author's Data Processing Results using R Studio 2024

According to the data presented in Table 8, with an article production frequency of 2,583, the United States (USA) ranks first in scientific article production related to STEM-based curriculum implementation. Following this, CHINA (231 freq) holds second place, AUSTRALIA (174 freq) ranks third, the UK (140 freq) places fourth, INDONESIA (114 freq) comes fifth, CANADA (102) ranks sixth, SPAIN (96) is seventh, GERMANY (83) occupies eighth position, GREECE (54) ranks ninth, and MALAYSIA (53) completes the top ten.

Most Cited Countries

Table 9 presents the countries with the highest citation counts in the related research topic.

Table 9. Top 10 Most Cited Countries by Total Citations (TC) and Average Article Citations (AAC)

Rank	Country	TC	AAC
1	USA	2885	5.00
2	CHINA	307	3.70
3	HONG KONG	246	11.20
4	AUSTRALIA	240	3.40
5	UNITED KINGDOM	237	4.40
6	SPAIN	210	6.40
7	TURKEY	205	12.10
8	BELGIUM	114	16.30
9	NETHERLANDS	111	11.10
10	GREECE	98	6.50

Source: Author's Data Processing Results using R Studio 2024

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The top three most cited countries are the USA with a total citation count (TC) of 2,885 and an average article citation (AAC) value of 5.00, followed by CHINA with a total citation count (TC) of 307 and average article citation (AAC) of 3.70, and HONG KONG with a total citation count (TC) of 246 and average article citation (AAC) of 11.20.

Most Global Cited Documents

Table 10 presents the most cited documents (TC) and average total citations per year (TCpY) in related research. Among the top three, MCGUNAGLE D's article "Employability skills for 21st-century STEM students: the employers' perspective" ranks first. The study examines identified skill gaps in Science, Technology, Engineering, and Mathematics (STEM) industries from employers' perspectives to assist STEM educational institutions in developing more relevant programs, including workforce competencies (McGunagle & Zizka, 2020).

Table 10. Top 10 Most Cited Documents by Total Citations (TC) and Total Citations per Year (TCpY)

Rank	Paper	TC	TCpY
1	MCGUNAGLE D, 2020, HIGH EDUC SKILLS WORK BASED LEARNING	114	22.80
2	LEE I, 2021, SIGCSE - PROC ACM TECH SYMP COMPUT SCI EDUC	101	25.25
3	JESIONKOWSKA J, 2020, EDUC SCI	88	17.60
4	KELLEY TR, 2020, INT J STEM EDUC	88	17.60
5	CONDE M, 2021, COMPUT APPL ENG EDUC	76	19.00
6	HUTCHINS, NM, 2020, J SCI EDUC TECHNOL	72	14.40
7	ROEHRIG GH, 2021, INT J STEM EDUC	62	15.50
8	PRINCE M, 2020, ADV ENG EDUC	62	12.40
9	JOVANOVIĆ J, 2021, COMPUT EDUC	56	14.00
10	SEAGE SJ, 2020, INT J RES EDU SCI	56	11.20

Source: Author's Data Processing Results using R Studio

In second position is LEE I with the article "Developing Middle School Students' AI Literacy," which discusses the creation of a summer AI workshop designed for 10-14-year-olds, where 87% of participants came from groups historically underrepresented in STEM and computing fields. Ranking third is JESIONKOWSKA J with the article "Active Learning Augmented Reality for STEAM Education—A Case Study," examining the implementation of active learning methods for STEAM subjects through a framework where students were tasked with developing AR applications as part of their coursework (Jesionkowska et al., 2020).

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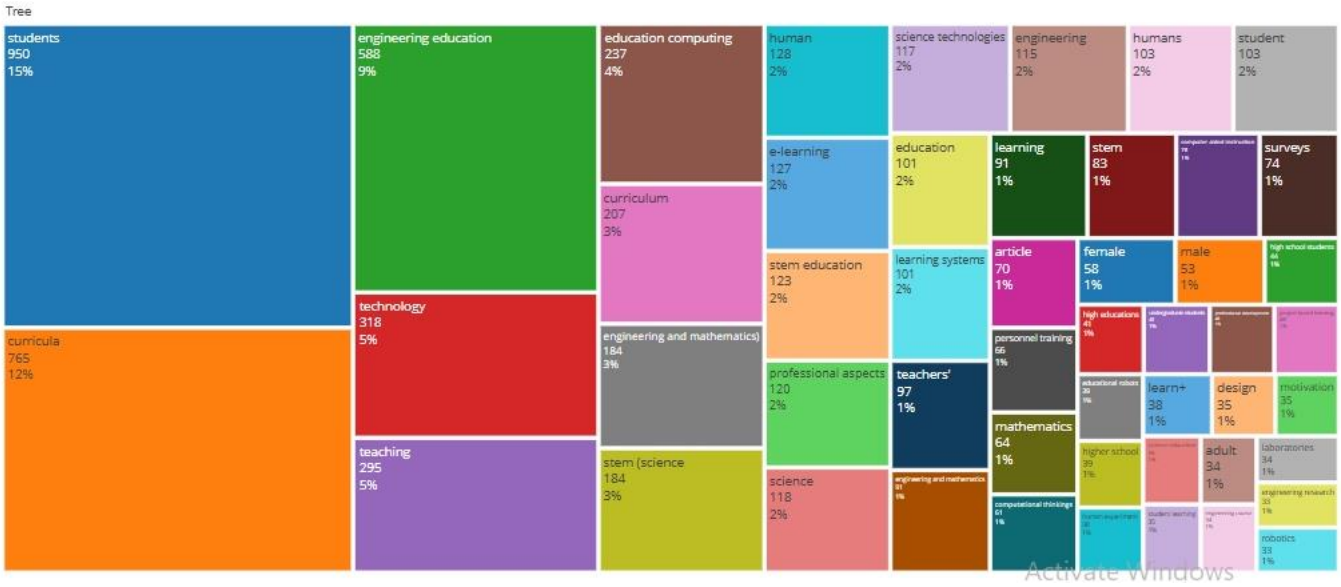
Keyword Plus TreeMap

Terminology related to the implementation of STEM-based curriculum topics can be observed in Figure 5 below. The keyword "student" ranks first with a frequency of 950 occurrences, followed by "curricula" (freq 765), "engineering education" (freq 588), "technology" (freq 318), and others as displayed in **Figure 5.**



Gambar 5. Keyword Plus TreeMap
Source: Author's Data Processing Results using R Studio

Thematic Map: Strategic Diagram

Figure 6 presents a strategic diagram of the thematic map for research related to STEM-based curriculum implementation over the past five years (2020-2025). The thematic map features four distinct quadrants categorized by two dimensions: centrality (y-axis) and density (x-axis). The first quadrant (motor themes) represents themes with high impact and substantial research volume. The second quadrant (niche themes) encompasses peripheral and marginal themes. The third quadrant (basic themes) includes generic and transversal themes. In contrast, the fourth quadrant (emerging declining themes) captures either developing themes (emerging) or those losing prominence (declining) (Peláez-Repiso et al., 2021).

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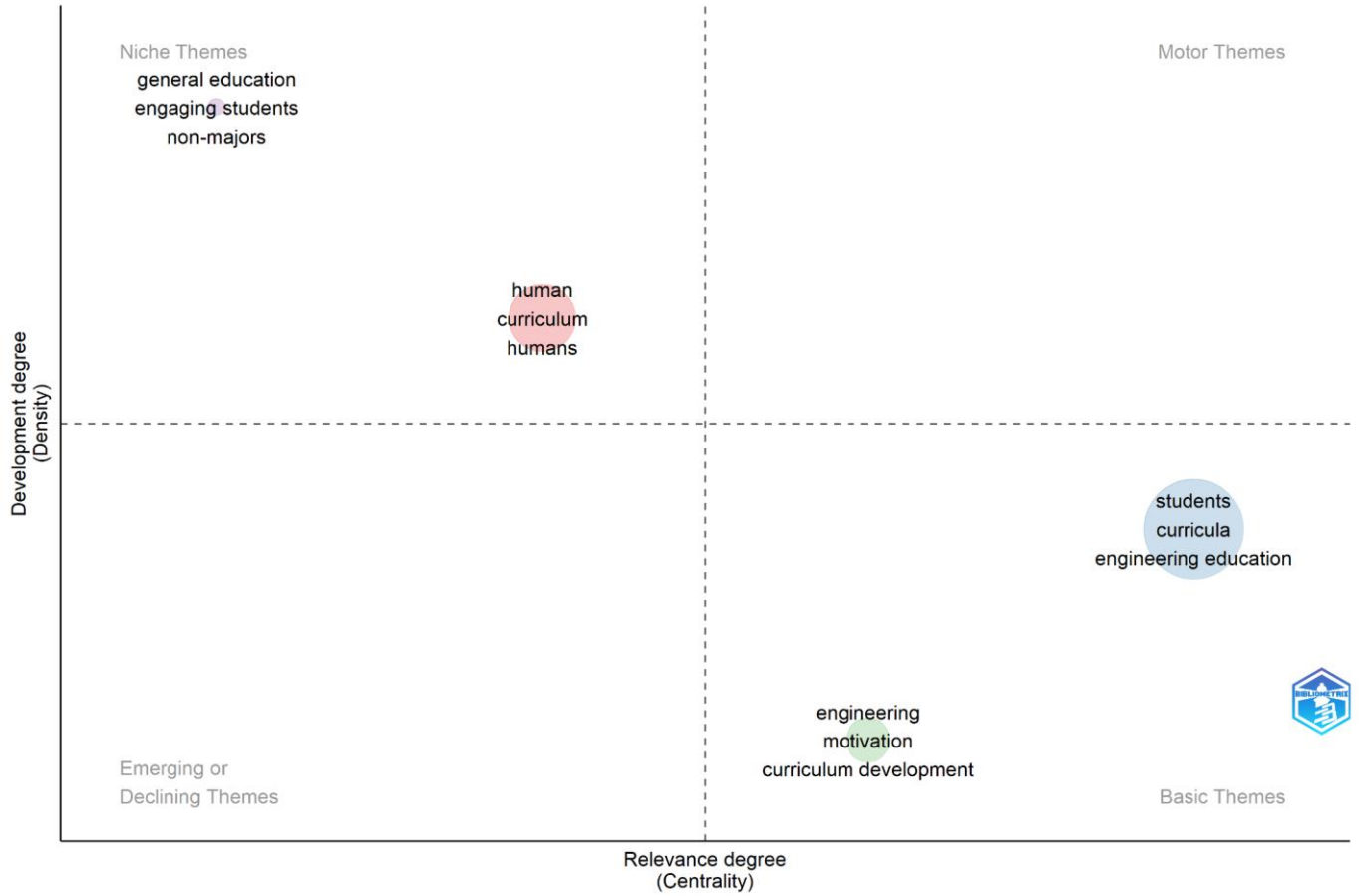

Figure 6. D. Strategic Diagram of Thematic Map
Source: Author's Data Processing Results using R Studio

The first quadrant does not indicate any emerging or critically important themes requiring examination. The second quadrant contains at least two distinct clusters with specific thematic focuses. The first cluster comprises themes related to human, curriculum, and humans, while the second cluster includes themes concerning general education, engaging students, and non-major. The third quadrant similarly features two thematic clusters. The first cluster consists of themes addressing students, curricula, and engineering education, whereas the second cluster encompasses themes such as engineering, motivation, and curriculum development. Notably, the fourth quadrant demonstrates no emerging or declining themes, indicating that STEM-related research remains highly prevalent and maintains significant potential for continued development and exploration.

Discussion

Research Potential in STEM-Based Curriculum

The bibliometric analysis conducted on the potential implementation of STEM-based curriculum in achieving 21st-century learning has yielded several significant findings that may prove valuable for future research. STEM remains an exceptionally popular topic among researchers worldwide, with a consistently growing research trend. From 2020 to 2023, the number of STEM-related studies and publications increased by 28.7%. In 2024 alone, 179 new studies were published on this topic, demonstrating sustained and growing interest in STEM-based education. Additionally, the bibliometric analysis revealed several other important findings from this research.

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The "INTERNATIONAL JOURNAL OF STEM EDUCATION" ranks as the most cited journal during the 2020-2025 period. Published by Springer, this journal maintained Q1 status from 2019 to 2023 (www.scimagojr.com), reflecting its quality and influence in STEM research. With 529 citations, it serves as a primary resource for researchers seeking reliable references in STEM studies.

Besides the journal, the analysis also examines impactful authors in the field. This study identifies BISWAS G as the foremost author with the most significant research impact in STEM. From 2020 to 2024, this researcher contributed nine articles with 107 citations. These accomplishments reflect BISWAS G's exceptional dedication and substantial contributions to advancing STEM research.

The United States plays a pivotal role in STEM research, with nine universities and affiliated institutions producing the highest number of scientific publications in this study. The records show 577 scientific articles and 2,885 citations from STEM-related research during 2020-2025. The U.S. dominance in publication output and citation counts demonstrates its position as the central hub for innovation and development in STEM education.

The Keyword "student" emerges as the most frequently used term, indicating that STEM research during the 2020-2025 period focused on examining the impact of STEM-based learning on students. Studies such as MCGUNAGLE D's article "Employability skills for 21st-century STEM students: the employers' perspective" and LEE I's work "Developing Middle School Students' AI Literacy" demonstrate concerted efforts to understand and enhance students' STEM competencies aligned with 21st-century requirements.

Themes derived from keywords in the basic themes quadrant (Kuipers *et al*., 2022) present significant opportunities for further research. Keywords such as students, curricula, engineering education, engineering, motivation, and curriculum development demonstrate high centrality, indicating their fundamental importance in STEM-based curriculum studies. While these themes exhibit strong centrality, they maintain relatively low density levels, suggesting substantial research potential remains unexplored due to the limited number of scientific articles currently utilizing these related keywords.

This study provides a comprehensive overview of STEM-based research trends and directions, serving as a valuable guide for researchers, educators, and policymakers in developing more effective educational strategies and policies that align with future needs.

STEM-Based Curriculum for Achieving 21st-Century Learning

The STEM-based curriculum holds significant potential for realizing 21st-century learning outcomes. The integration of all four STEM components into education will enrich students' learning experiences. However, several critical points require careful consideration to fully optimize this integration process and effectively achieve 21st-century learning (McGunagle, 2020).

First, the selection of an appropriate learning model is crucial. An unsuitable instructional approach may render the learning process ineffective and less meaningful for students. One highly recommended model for STEM integration is Project-Based Learning (PjBL), which has demonstrated proven effectiveness in incorporating STEM components (Budiarti *et al*., 2022; Fatimah *et al.,* 2023). This model engages students with authentic projects requiring the application of various STEM concepts. For instance, learners may undertake bridge construction projects (Ashley *et al*., 2017) or application development initiatives (Jesionkowska *et al*., 2020). Such projects teach technical concepts and cultivate practical skills with significant future applicability.

Second, it is essential to ensure that assigned projects maintain relevance to real-world challenges (Smith *et al*., 2022). In this context, educators may design projects aligned with professions implementing STEM applications in daily practice, such as architecture, programming, engineering, etc. This approach enables students to observe how STEM concepts are applied in everyday life and across various occupations.

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Furthermore, projects should be carefully designed to enhance students' development of critical skills, including critical thinking, collaboration, communication, creativity, and character. These competencies represent essential 21st-century learning outcomes (Shadiev & Wang, 2022). Challenging and relevant projects facilitate students' acquisition of these capabilities, ultimately equipping them to address future challenges.

CONCLUSION

Advancements in educational technology necessitate educators to incorporate technology into learning processes to support modern pedagogy. Contemporary education requires digitalization to enhance students' access to information. It must involve various methodological and theoretical approaches and pedagogical practices, such as open education, unplugged activities, innovative learning, and STEM. STEM education, in particular, positively influences the development of 21st-century skills, including critical thinking, communication, creativity, digital literacy, and collaboration. However, a gap persists between educational outcomes and industry demands, highlighting the need for further research on STEM-based curricula to meet 21st-century learning requirements. Bibliometric analysis was employed to evaluate research trends and publication impacts related to STEM. The findings demonstrate that STEM education remains highly prevalent and warrants continued development, particularly emphasizing the impact of STEM-based learning on students and the importance of preparing learners to address future challenges in an era of digitalization and globalization. Subsequent research should explore the potential of STEM-based curricula in equipping students to meet 21st-century demands.

AUTHOR'S NOTE

The authors declare no conflicts of interest regarding the publication of this article. This study has obtained publication approval from relevant parties. The authors affirm that all data and content in this article are plagiarism-free.

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