Volume 4 Number 2 (2026)
July-December 2026
Page: 1583-1595

EDUJAVARE: International Journal of Educational Research
ISSN: 3031-2884
https://edujavare.com/index.php/edujavare
DOI: 10.70610/edujavare.v4i02.1788

Arduino in STEM Education (2016-2025): Bibliometric Analysis of Research Trends and Collaboration Patterns

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Article history Submitted: 2026/07/27; Revised: 2026/07/27; Accepted: 2026/08/30

Abstract

Arduino is a low-cost open-source microcontroller that allows users to program and interactively control electronic components within an electronic circuit. As the demands of this digital era, Arduino has been applied to the learning process, such as in STEM education. This study aims to map the research landscape of Arduino in STEM education using a bibliometric analysis with data from Scopus database. The total data is 143 documents consist of journals and proceedings published between 2016 and 2025. Biblioshiny and VOSviewer were used for the data analysis including publication trends, leading contributors, international collaboration, and thematic structure. The results show the filed of arudino in STEM education is growing rapidly with 76.2% documents published from 2020-2025. Conference papers play a big role, reaching for 43% of the documents and the highest citation impact of the dataset. A limited international collaboration was identified from a low overall international co-authorship rate of 12.59%. The thematic analysis revealed Arduino and STEM education as the motor theme or the core of this field, with research moves from technical to pedagogical themes. These findings offer opportunities for further research such as assessment for this media and to support more international collaboration.

Keywords Arduino, Bibliometric analysis, STEM education, Research trends

INTRODUCTION

In the digital era, STEM (Science, Technology, Engineering, and Mathematics) education is critical due to its benefits. STEM Education fosters critical thinking, creativity, and problem-solving skills (Metpattarahiran, 2021), strengthen collaborative skills in this modern workplace (Li et al., 2025), and enhance students' adaptability towards 21st century era (Metpattarahiran, 2021). Technology in STEM Education plays an important role especially in this digital era as it navigates the demands of a technology-driven society and prepare students for future challenges. The contribution of technology in STEM activities is the design and implementation, such as coding through game design, app development, 3D modeling, digital storytelling. Based

on Çoban et al., (2023), the usage of Arduino in STEM education gains valuable skills for high school and undergraduate students.

Arduino is one of the hardware devices that can be connected to the Internet of Things (IoT) system (Barbon et al., 2016). Arduino is an open-source microcontroller that allows users to program and interactively control electronic components within an electronic circuit (Dolly, 2025). The use of Arduino in the classroom can foster 21st-century skills such as problem-solving and computational thinking (Sarı et al., 2022)(Paucar-curasma et al., 2023). Arduino has been applied in STEM activities such as in physics experiments (Çoban et al., 2023) and in biology education (Purnomo et al., 2025) research. Those researches proved that Arduino helps the enhancement of STEM skills (Karaahmetoğlu & Korkmaz, 2019). As Arduino starts growing fast through the application for education, literature of this study is similar. Researchers need data landscape of how the research trends and patterns of this topic interest particularly the updated one. A bibliometric analysis can be utilized to answer the issue since it is a tool to analyse academic literature systematically using quantitative and statistical methods (Kumar, 2025).

There are some previous studies talking about Arduino as part of bibliometric analysis. Firstly, (Prabowo & Irwanto, 2023) discussed about Arduino in science learning. They focus on the implementation of Arduino in science education in general, with more than a thousand documents published between 2008-2022. Besides that, (Sulimro et al., 2023) have conducted the analysis of digital learning for science and STEM classes which one of the digital devices is Arduino. However, those studies focused on Arduino applications in science education rather than specifically on STEM education. The closer explanation presenting about Arduino in STEM learning is from (Akış, 2024). His research focuses on Scopus-based articles from 2013-2022 with the main keywords of STEM Education and Arduino. The results show the most productive countries is Turkey with his projection in the next period would be similar. USA is a country that most cited and most of the papers have low-rate collaboration. However, the data collection was 79 only since it was only for articles from journals. Based on his limitations statement, he stated that it needs more type of documents to analyse in the future by including proceedings and also the settings of inclusion-exclusion criteria might need to be changed.

Building on the limitations stated, a researcher finds a gap to take the further study of this bibliometric analysis, as to answer the suggestion from earlier study. This paper focuses on finding the research trends as well as collaboration patterns in the topic of Arduino in STEM education, with a differ and newer year span (2016-2025) and the additional of proceedings as a data collection. This study aims to map the research landscape of Arduino in STEM Education. There are three objectives of this analysis which are the study examines publication trends and identifies the leading sources, countries, and authors. Then, the study analyses the international collaboration patterns in this field, and the last one is to investigates the thematic structure of how the research develop over time.

METHODS

In this study, a bibliometric analysis was used to map the research landscape of Arduino in STEM education. Bibliometric research is a quantitative method to measure the scientific outputs of different scientific items such as papers, authors, keywords, journals, institutions and countries for many research fields, (Öztürk et al., 2024) (Donthu et al., 2021). The analysis was focused on examines the publication trends and leading contributors over the period 2016-2025. Then, it further explores the patterns of international collaboration within the field and investigates the thematic structure and its developmental trajectory.

Data were retrieved from Scopus database due to the most comprehensive sources for literature and bibliometric research (Donthu et al., 2021). The data were collected on 10 July 2026 with some important keywords are "Arduino", "STEM Education", "STEAM Education, "STEM learning", "STEM teaching". The following search query is described on the graph like this:

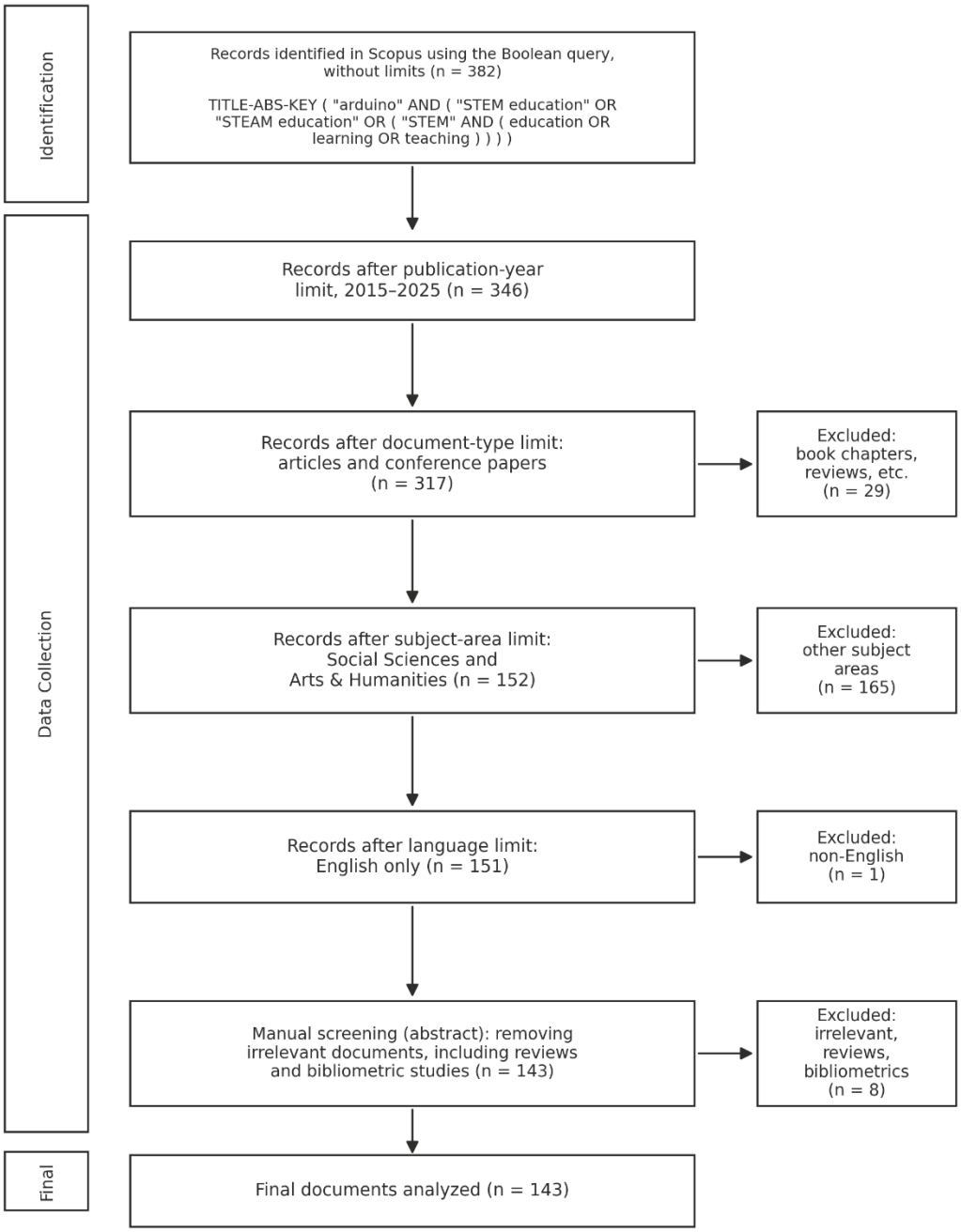

Figure 1. Data Collection Flow Diagram

Based on the figure 1, the records identified 382 articles in total for the keywords shown about Arduino in STEM education. However, there are some criteria to set as the inclusion and exclusion, such as the time span during 10 years only (2015-2025), language must be in English, subject-area limit, and document types which focus on two: articles and proceeding papers. One of considerations was determined from recommendation of Akış, (2024) who stated in his limitation to add proceedings and set the exclusion for subject-area. Besides that, the screening was continued to remove the documents manually due to irrelevant documents

like literature review article or any non-empirical studies. The summarization of the inclusion and exclusion criteria are listed down on Table 1.

TABLE 1. Inclusion-Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Empirical studies about Arduino in STEM Education	Not empirical studies
Articles and proceedings	Book Chapter, Reviews
Publications in English	Non-english
Subject area limit to Social Science, Arts and Humanities	Other subject areas

After the screening, the total of final documents are 143 articles of Arduino in STEM education. For the analysis, there are several tools used to analyze and discover the results from dataset. Firstly, Microsoft Excel was used for manual screenings and exported the Comma-Separated Values (CSV) format files. OpenRefine was used to clean the dataset, such as removing duplicates, standardizing the keywords, and correcting inconsistent of the data to enhance the accuracy of the analysis (Nowakowska, 2025) (Utami et al., 2025). RStudio and the Bibliometrix R package for getting into Biblioshiny were employed to identify the quantitative information from the dataset and visualize the results through graphics, tables by importing the dataset first (Aria et al., 2026). Also, Vosviewer to discover the relations in co-authorship and networks.

RESULTS AND DISCUSSION

A total of 143 documents on Arduino in STEM Education, with a ten-year span from 2016-2025, were analyzed as shown in Table 2.

TABLE 2. Descriptive Statistics

Description	Results
Timespan	2016:2025
Sources (Journals, Books, etc)	75
Documents	143
Annual Growth Rate %	18,19
Average citations per doc	11,12
Author's Keywords (DE)	384
Authors	440
Authors of single-authored docs	17

Single-authored docs	20
Co-Authors per Doc	3,75
International co-authorships %	12,59
DOCUMENT TYPES	
article	82
conference paper	61

The sources of the documents are from journals, books, and others with 75 sources in total and 440 authors. There are two types of documents which are 82 journal articles (57%) and the rest 43% are 61 conference papers. An annual growth rate of 18.19% and an average of 11.12 citations per document showed an active and steadily growing research area.

There are 17 single-authors that resulting 20 single-authored docs with mostly documents were written by 3,75 authors (co-authors per doc). Thus, the average number of authors in each paper have almost four authors. It shows the collaborative research shown in this field. However, the international co-authorship stood at 12,59% that indicates most of collaboration occurs within the same country or institutions.

Publication Trends

The data of annual scientific production described in the figure 2 starting 2016-2025. There is no data of 2015 since in that year no papers include in the criteria set for this study.

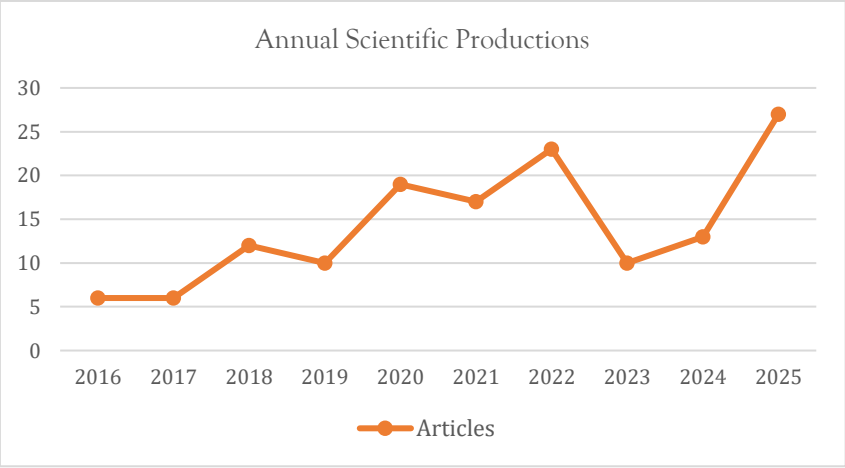

Figure 2. Annual Scientific Production

The result shows the output of documents always fluctuated over the ten years. To begin with, it remained low during 2016-2017 with the same documents in each year (6), but rising to 12 in the next year. The second highest number of documents was in 2022 with 23 papers in total but then fell again to 10 documents in 2023. The highest number of publications was 27 docs in 2025. Based on the number of documents, 109 of 143 or around 76% of the total published

from 2020 – 2025. It indicates an accelerating interest of scholars who conduct the research of Arduino in STEM Education.

Leading Sources and Countries

In terms of the most productive sources and countries, the result shows that Physics Education published 23 documents with the highest h-index 6, then followed by two conference venues which are the IEEE Global Engineering Education Conference (EDUCON, 10 docs) and the Frontiers in Education Conference (FIE, 13 documents). The proceedings from FIE also recorded the highest total citations of any source (209), showing that conference papers are impactful too with an average about 16 citations per document. Compared to Physics Education journal who received 102 citations from 23 documents, means that the average of citation is 4.4 per document. Thus, conference papers about Arduino in STEM education are common and supports the decision to include proceedings into this study as what it suggests from Akış, (2024) study earlier.

TABLE 3. Top 10 Source Impact

Source	h_index	TC	NP	PY_start
PHYSICS EDUCATION	6	102	23	2019
IEEE GLOBAL ENGINEERING EDUCATION CONFERENCE, EDUCON	5	108	10	2016
PROCEEDINGS - FRONTIERS IN EDUCATION CONFERENCE, FIE	5	209	13	2016
COMPUTER APPLICATIONS IN ENGINEERING EDUCATION	3	165	3	2019
ELEARNING AND SOFTWARE FOR EDUCATION CONFERENCE	3	13	3	2019
EURASIA JOURNAL OF MATHEMATICS, SCIENCE AND TECHNOLOGY EDUCATION	3	154	4	2018
PHYSICS TEACHER	3	57	3	2018
2021 SUSTAINABLE LEADERSHIP AND ACADEMIC EXCELLENCE INTERNATIONAL CONFERENCE, SLAE 2021	2	7	2	2021
COMPUTERS IN HUMAN BEHAVIOR	2	52	2	2017
EDUCATION AND INFORMATION TECHNOLOGIES	2	61	2	2022

Beside sources, the most productive based on countries are listed in figure 3 showing Top 10 countries producing outputs about Arduino in STEM education, either single-author or

become co-author. Spain contributed 79 documents as the most productive country, followed by the USA 71 documents, Brazil (62), Turkey (44), and China (34). Indonesia itself, contributed to 18 documents indicate a notable presence joining this field.

As a result of the most cited countries, the number of citations show a differ result, with the USA is the most cited documents (199), followed by Turkey (194) and China (184). Spain as the most productive country ranked seventh (44) citations. The cause resulting that may vary, but there is a probability the publication time still the newer years so that the number of citations remain low. This finding also similar with Akis (2024) that the most productive countries were not always be the most cited one.

TABLE 4. Leading Countries (based on production and citations)

Country	Total Productions	Total Citations
Spain	79	44
USA	71	199
Brazil	62	12
Turkey	44	192
China	34	184
Portugal	21	27
Greece	19	52
Indonesia	18	12
India	17	11
Italy	17	13

International Collaboration

Based on corresponding-author analysis, the percentage of multiple-country publications (MCP) remains low, and consistent with the overall international co-authorship rate of 12.59%. Most of outputs only collaborate within the county or single-country publication (SCP). Turkey as the most productive country by corresponding author (17 documents, 11.9%), recorded zero of MCP rate meaning the absence of international co-authorship. Also, Brazil, India, Mexico, and Romania with 4 documents show no international collaboration, confirming collaboration only occurs mostly within the country or even the institutions.

Indonesia contributed only 3 documents as corresponding author, but in contrast 2 of 3 were internationally co-authored. Besides that, Portugal showed 40% of MCP from 5 articles as corresponding author. These findings support Akis (2024) report about the limited international collaboration in this field. For more details, table 3 depicts the corresponding author country and its international co-authorship.

TABLE 5. Top 10 Corresponding Author Country

Country	Articles	Articles %	SCP	MCP	MCP %
TURKEY	17	11,9	17	0	0
CHINA	8	5,6	7	1	12,5
USA	7	4,9	6	1	14,3
PORTUGAL	5	3,5	3	2	40
BRAZIL	4	2,8	4	0	0
INDIA	4	2,8	4	0	0
MEXICO	4	2,8	4	0	0
ROMANIA	4	2,8	4	0	0
INDONESIA	3	2,1	1	2	66,7
ITALY	3	2,1	3	0	0

Thematic Structure and Development

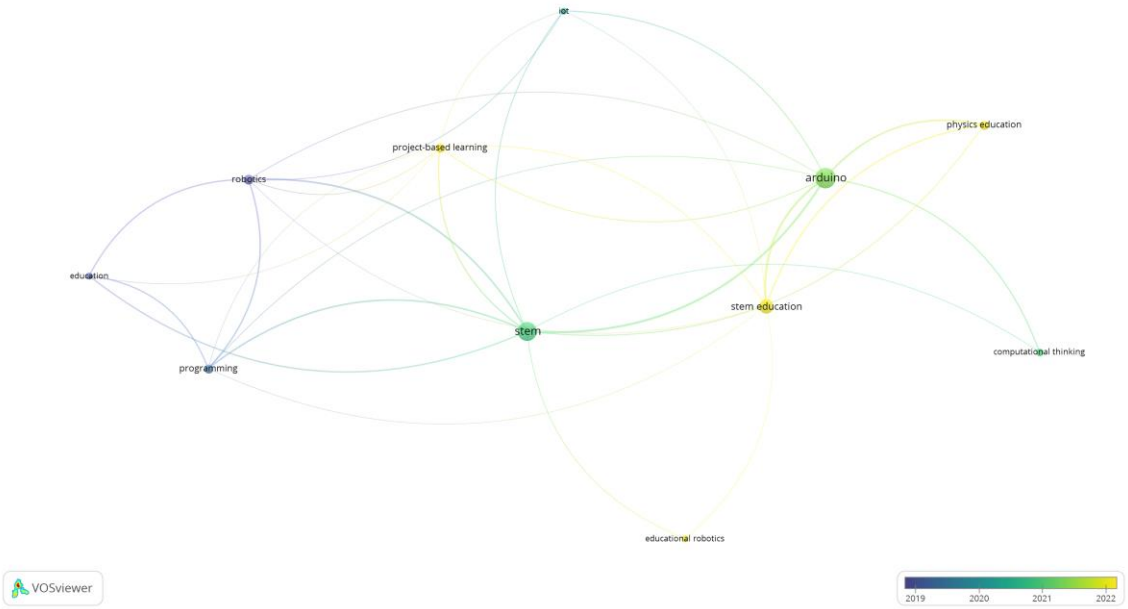

Figure 3. Thematic Structure and Development

This figure depicts the keyword co-occurrence overlay based on author keywords from VOSviewer. The color represents the average publication year and shows how the field's focus has changed over time. "Arduino" and "STEM" form the largest and most connected nodes, ensuring their position as the core of the field. The color gradient shows a shift from around 2019 to 2022, the earlier keywords are “robotics”, “programming”, and “education”. It reflects an initial focus on technical and device-oriented side of Arduino. In contrast, the newest

keywords (around 2022) are "stem education," "project-based learning," "physics education," and "educational robotics", indicate a shifting focus on pedagogical concerns. Based on the pattern, the research attention has gradually moved from building and programming Arduino-based devices toward integrating them into teaching and learning.

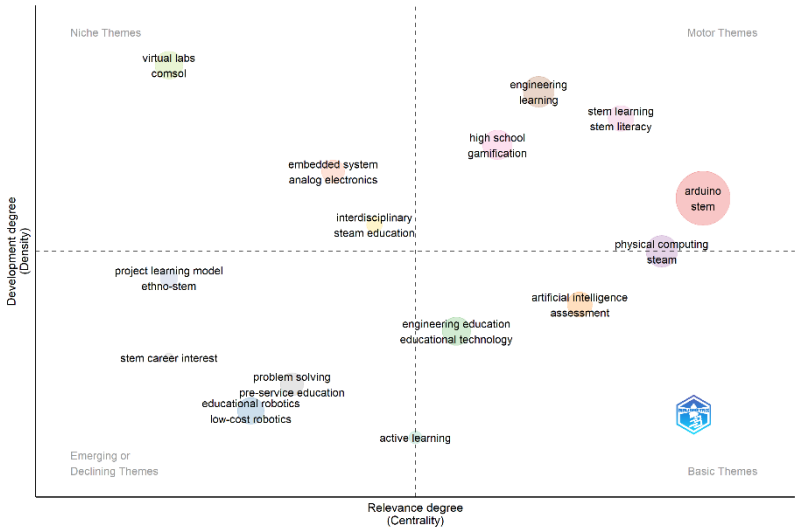

Figure 4. Thematic Map

This pattern is supported by the thematic map (Figure 4), from Bibliometrix R package mapped the keywords into four quadrants determined by relevance degree and development degree (Cobo et al., 2011). In motor themes quadrant positioned at top-right, the keywords "Arduino" and "STEM" appear meaning that they are both central and well developed. They form the core of the field along with "STEM learning, STEM literacy, "engineering learning". Otherwise, pedagogical themes such as "Project learning model", "problem solving", and "Active learning" appear as emerging themes, showing those keywords are not yet fully developed. Based on both analyses result similar conclusion about Arduino and STEM education. The keywords are already developed but the research shifts from technical to pedagogical themes.

DISCUSSION

Overall, the research on Arduino in STEM education is growing fast, shown by 76.2% of all documents were published from 2020 to 2025 with 18.19% annual growth rate. Similar to the result of dramatic increase in this field Akış (2024), (Soler-costa, 2020). Besides that, the majority of studies report the positive educational impacts on this field, such as improving problem-solving and entrepreneurship skills (Sarı et al., 2022), and increase STEM career interest (Prabowo & Paristiowati, 2024). In this study, the presence of conference papers plays important part since 43% of the dataset are coming from conferences. FIE conference was

recorded as the highest total citations of any source as well indicating an influential finding. Conference papers provide rapid dissemination of new findings, and any up-to-date result of researches, especially for fast-paced technology era (Franceschet, 2010).

Based on the result of international co-authorship rate shows a limited collaboration between countries, only 12.59%. Several productive countries such as Turkey, Brazil, India, Mexico, and Romania have a multiple-country publication (MCP) rate of 0% or zero link strength. This depicts research is mostly conducted by institutional groups only or separate national. This similar to (Akış, 2024) who found weak collaboration although this study conference papers are counted. A Systematic review was written by (Kurniati et al., 2022) also stated a minimal research collaboration among STEM researchers. The cause of this limited collaboration could be due to a relatively new disciplines and usually tied to local educational standards. Matthews et al., (2020) listed some possible barriers such as the lack of international funding, material restrictions, differences in academic standards.

For Indonesia, although it produced only three documents as corresponding author, two were written with international partners showing a high collaboration rate. It means that newer contributors (like Indonesian) may enter the field through partnership rather than through making a large number of publications. Overall, due to this potential growth of the research, a stronger collaboration might expect to expand more.

The keyword overlay presents that earlier research (2019-2020) focused on technical topics such as robotics and programming, while later research (2022-2023) focused on learning-related topics such as physics education and computational thinking. This finding shows that Arduino in STEM education has evolved from focusing on a practical tool to exploring its integration to pedagogical or learning strategies. For instance, a research from (Sarı et al., 2022) focus on problem-solving and entrepreneurship skills in STEM activities using Arduino. Even, there is a workshop for teachers to develop STEM skills with one of the phases is utilizing Arduino to build projects (Cano, 2022). Finding from (Akış, 2024) could not see this change because that data ended in 2022, so this is one of the new contributions of the present study. It also suggests that research field now looks for evidence of effective and innovative learning and strategies.

CONCLUSION

This study described the research landscape of Arduino in STEM education through a bibliometric analysis of 143 Scopus-indexed documents published between 2016 and 2025 with three main findings. First, the field is growing rapidly, especially the outputs appearing after 2020, but 43% of all documents are conference papers and even have the highest citation impact of any source. Although the conference papers may remain at applied stage but still could give an impact for this field. Second, international collaboration is very limited, showing that research is mostly conducted within internal or national groups. Third, Arduino and STEM are still the coure of the field, but the focus has shifted from technical topics to pedagogical topics to help students learn. The additional of conference proceedings with more

present time (until 2025) revealed aspects that differ from previous studies. The findings suggest that future research should move beyond developing Arduino based learning media toward evaluating their effectiveness for STEM learning, and create stronger cross-country collaboration.

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