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ORIGINAL ARTICLE

Using Arduino in Science, Technology, Engineering, and Mathematics (STEM) Education: Bibliometric Analysis

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ABSTRACT

The dramatic increase in science, technology, engineering, and mathematics (STEM) education studies has resulted in more authors promoting the use of Arduino in STEM education. Although there are educational research studies utilizing bibliometric procedures for the exploration of Arduino and STEM separately, there is a further need for research on their relationship. The current study utilizes several software tools (Vosviewer, Biblioshiny) and bibliometric procedures for this research domain. The documents were retrieved from the Scopus database from 2013 to 2022. Performance analysis was used to reveal publications and citation trends with the top contributors. Moreover, bibliographic mapping was used to comprehend the conceptual (co-occurrences), intellectual (bibliographic coupling), and social (collaboration network) structures of the retrieved data. The results revealed that the most prolific authors and institutes were addressed in Turkey. Besides, the most cited authors and institutes were from the USA. However, it seems this situation will change soon to the advantage of Turkey because of its highest annual growth rate and smallest document average age. This research also shows that there is a sign of the risk of monopolization in this area soon. Moreover, little cooperation was found within the dataset implying the importance and necessity of encouraging the mobility of researchers as well as increasing the collaboration between universities at both national and international levels. Overall, the study reveals that Arduino has great potential in using STEM activities in the future.

KEY WORDS: Arduino; bibliometric analysis; science, technology, engineering, and mathematics education

INTRODUCTION

Research in science, technology, engineering, and mathematics (STEM) education has grown to such an extent that new journals mainly focusing on this area have emerged, such as the International Journal of STEM Education, Journal for STEM Education Research, and Journal of STEM Teacher Education. A major reason behind the growing research on STEM education is that students need to be able to engage in complex problem-solving and critical-thinking skills in increasingly digital societies and knowledge economies (Erduran and Pabuçcu-Akış, 2023). The ubiquitous effort to promote STEM education has been argued to be driven by the environmental and social impacts of the 21st century (Kelley and Knowles, 2016). Although there are various STEM education definitions in the literature (Uysal and Cebesoy, 2020), STEM education could be defined as providing opportunities for students to use scientific and mathematical knowledge to explore technology while participating in engineering designing and thinking to manage daily life problems (Akgündüz and Ertepınar, 2018). The role technology plays in STEM education is therefore significant because it addresses digital skill gaps in students, including coding, data analysis, and digital literacy. A thorough understanding of these essential digital skills and tools prepares students for success in STEM-related fields. To help more students engage in hands-on activities and project-based learning in STEM-related curricula, Arduino technology has emerged as a low-cost example of such educational tools (Alò et al., 2020; Banzi and Shiloh, 2014).

Arduino is a microcontroller board that constitutes easy-to-use hardware and software (Kang et al., 2019). Since it is an open-source electronic board, even inexperienced students could use Arduino as a device to design their projects to overcome challenges. Moreover, Arduino can be incorporated with various sensors (sound, light, gas, etc.), so it is very convenient and versatile piece of equipment that can be utilized in teaching science subjects (e.g., Cakir and Guven, 2019; Sarı, 2019). For instance, Kang et al. (2019) used the Arduino microcontroller in the laboratory to create an Arduino–carbon dioxide fountain. In this experiment, when the measured pressure value was less than a setting value on the code, the microcontroller conveyed a signal to open the solenoid valve. By this means, researchers claimed that they created a convenient environment for their students to utilize their knowledge of chemistry; therefore, they strengthened their theoretical knowledge while coding a computer-operated carbon dioxide fountain. Similarly, many studies have stated that programming activities with Arduino tools improve understanding of the concepts (Ntourou et al., 2021) and overall performance (Omar, 2018). Furthermore, findings have reported that this new approach improves students' problem-solving (Wang et al., 2016), creativity (Cano, 2022; Kobsiripat, 2015), computational thinking (Juškevičienė et al., 2021; Ntourou et al. 2021); algorithmic thinking (Sari et al., 2022), collaborative work (Alimisis and Kynigos, 2009), establishing a cause-effect relationship (Görgülü Arı and Meço, 2021), entrepreneurship (Sarı and Yazıcı, 2020), and coding skills (Alimisis and Kynigos, 2009). In addition, block-based coding has recently started to be used in the programming of Arduino hardware, instead of text-based coding. Block-based coding does not involve writing lines of code. Instead, it includes dragging and dropping pre-made blocks to carry out the task at hand. Thus, anyone whose knowledge is limited or non-existent about what a microcontroller is can still conduct their designs easily (Sarı et al., 2022). For instance, Ntourou et al. (2021) studied the concept of electricity with fifth-grade students using Scratch visual coding and Arduino hardware. They observed that the simultaneous integration of Scratch visual coding and Arduino hardware has improved students' conceptual understanding and computational thinking. Moreover, Hsien-Sheng et al. (2022) integrated the 6E model (engage, explore, explain, engineer, enrich, and evaluate) into a robot-based activity to enhance sixth-grade students' learning motivation, learning performance, and computational thinking ability. Students had to investigate crab-related information, such as its ecology, structure, and movements, and decide on what information to use to make a "crab robot." For the activity, students learned about how to use Arduino electronic components, microcontrollers, and Scratch programming language. These two studies with the simultaneous integration of Arduino and Scratch are good examples of studies using Arduino in primary education. García-Tudela and Marín-Marín (2023) carried out a systematic review to analyze the uses of Arduino at the primary education level. Their study revealed that the most relevant methodology for incorporating the Arduino board into teaching is problem-based learning in the curricula of STEM subjects. Aside from problem-based learning, other pedagogical methods such as collaborative learning (Jawaid et al., 2020), project-based learning (Rengifo and Bravo, 2020), the 5E learning cycle model (Pabuçcu-Akış and Demirer, 2022), or task-centered hands-on STEM learning (Chang and Chen, 2020) have been preferred for the use of Arduino in classrooms throughout all levels by researchers.

In line with this trend, many esteemed researchers have stated that the use of Arduino offers an ideal learning environment for STEM education (Eguchi, 2016; Hoffer, 2012). For instance, some researchers suggest that not only does the use of Arduino in STEM applications increase conceptual understanding (Demirer and Pabuçcu-Akış, 2023) and motivation among learners (Dönmez, 2017; Sarı and Yazıcı, 2020) but also enhances their perceptions of STEM careers (Kuo et al., 2019). For instance, Görgülü-Arı and Meço (2021) developed Arduino-supported STEM activities for 6th-grade students about human body systems lessons to improve their aptitude in cause-effect relationships. This STEM activity combining three fields (Biology, Physics, and Robotics) offers a convenient resource to be used by science teachers and can be accepted as a way to help increase students' cause-and-effect relationship skills. To summarize, it can be stated that the use of Arduino technology in learning and teaching environments has great potential for development in the educational field (Cakir and Guven, 2019; Lopez-Belmonte et al., 2020; Sarı, 2019). Overall, the application of Arduino technology in STEM Education has great significance and broad prospects.

A large number of studies have run bibliometric analysis for the terms "Arduino" (García-Tudela and Marín-Marín, 2023; Lopez-Belmonte et al., 2020; Ocak, 2018) while the following studies have conducted bibliometric analysis on STEM (Akhmedova et al., 2023; Ali and Tse, 2023; Delen and Yuksel, 2022; Ha et al., 2020; Jamali et al., 2021; Jumini et al., 2022; Karampelas, 2023; Le Thi Thu et al., 2021; Marín-Marín et al., 2021; Tas and Bolat, 2022), which are carried out as separate studies. To clarify, the scientific method known as bibliometric analysis deals with a large-scale literature database to evaluate the contributions to a field of research, by countries, institutions, authors, and journals. At present, its popularity has steadily risen in many fields (Gurkan and Kahraman, 2021; Kaya and Keşan, 2022; Kaya-Capocci, 2023; Pala, 2023; Poçan, 2023; Tunç et al., 2023). For example, López-Belmonte et al. (2020) conducted a bibliometric analysis based on scientific mapping and analysis of co-words. They searched the term "Arduino" in the Web of Science and examined 346 documents. The results revealed that the use of Arduino in the field of education started in 2010 while the most commonly used aspects in this field of study are physical experiments, computational thinking, and computer-based learning. In the related literature, there are a few bibliometric analyses focused on Arduino-related applications in science education. Sulimro et al. (2023), for instance, conducted a bibliometric analysis on the application of Arduino-based systems in the digital learning environment for science and STEM education. For this analysis, they investigated 842 articles from 2012 to 2022. Their study revealed that the highest number of publications was seen in 2021. While the most prolific country was the United States throughout the whole period, among the authors, Yasmin B. Kafai had the highest frequency of citations. Based on author keywords, it was found that the term "Arduino" was strongly linked to several keywords, including "e-learning", "distance learning", "android", "low-cost", "Bluetooth", "IoT", and "STEM". Similar to this study, Prabowo and Irwanto (2023) conducted another bibliometric analysis to evaluate the publication and citation trends on Arduino-related science applications from 2008 until 2022. Out of the 1115 articles included in their study, an overwhelming majority of them (67.1%) were found to strongly relate to STEM Education. The rest of the articles focusing on Physics, Biology, and Chemistry are 12.1%, 6.3%, and 7.9% in respective order. The results also demonstrated a significant increase in the number of articles on Arduino boards in Biology, Physics, Chemistry, Science, and STEM categories of their study. As is seen, these two studies focused on Arduino-related applications in science education in general. To the best of our knowledge, there are no bibliometric studies that solely examine the use of Arduino microcontroller boards in the context of STEM Education. In the present study, unlike the other bibliometric studies in this field, two prime bibliometric procedures (Performance analysis and Science/Bibliometric mapping) were used to discover the research trends of using Arduino technology in STEM education. Thus, by analyzing the use of both keywords together, Arduino and STEM in the educational context, we aim to make a significant contribution to the literature.

METHODOLOGY

Database Selection and Search Query

We selected Scopus to extract the data because it is widely accepted as the most comprehensive database of the peer-reviewed scientific literature on a wide range of research areas. Many researchers have been using Scopus as a bibliometric data source (e.g. Gao et al., 2022; García-Tudela and Marín-Marín, 2023). Furthermore, Scopus is one of the databases that was used by the prime bibliometric analysis tools, such as Vosviewer and Biblioshiny. In this study, the data were analyzed through PRISMA (2020) guidelines. There are three phases according to PRISMA (Moher et al., 2009); identification, screening, and inclusion (Figure 1). In the following, each phase is introduced.

Identification

This phase consists of a data mining process and the control of duplicate publications. In this study, no duplicate results were identified. The data was obtained with the following retrieval strategy: TITLE-ABS-KEY (Arduino) AND TITLE-ABS-KEY (STEM OR STEAM) and yielded a total of 281 publications (Figure 1). Since the first publication appeared in 2013 and the dataset of this study was obtained on June 30, 2023, the publication year filter was used from January 2013 to January 2023. When the publications belonging to 2023 were removed from the dataset, the number of publications dropped to 264.

Screening

This phase included selection according to the inclusion/exclusion criteria and the eligibility process. The inclusion and exclusion criteria of the studies were as below:

- The screening was limited to the title, abstract, and keywords of the documents.
- Articles published between January 2013 and January

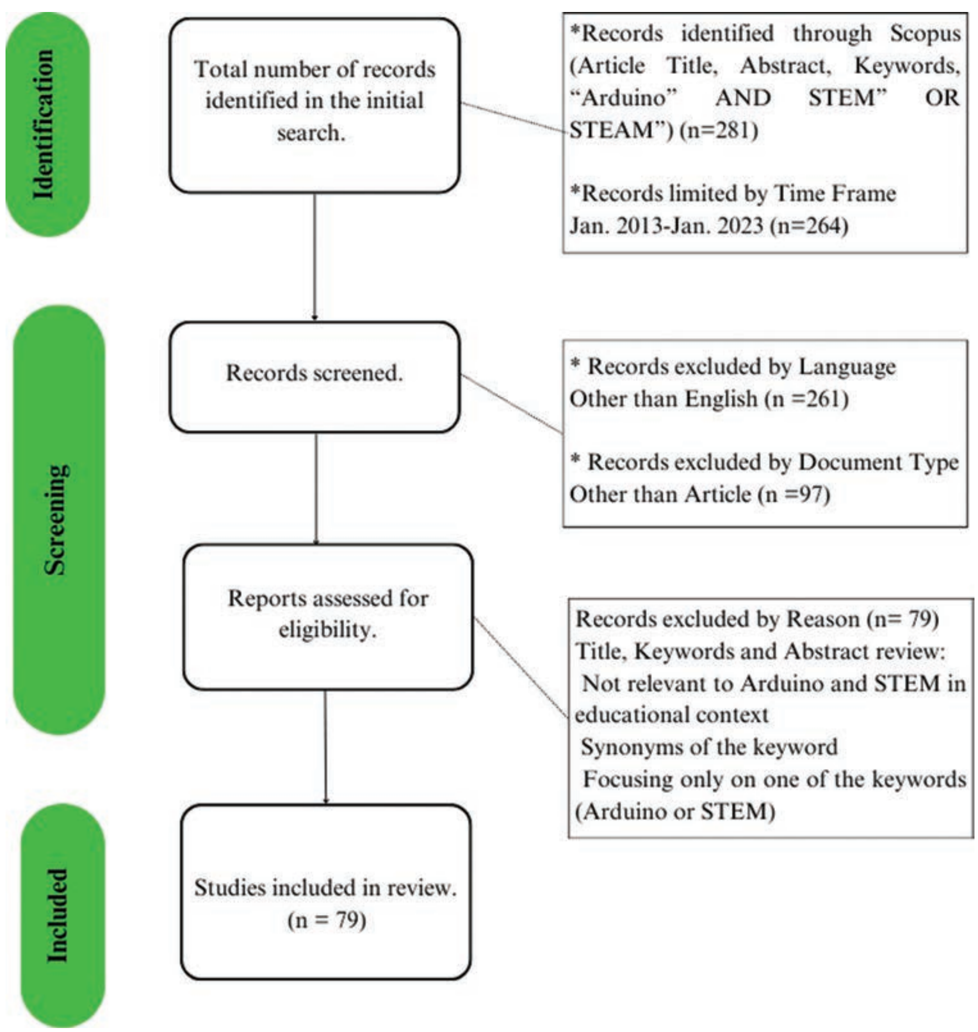

Figure 1: PRISMA flow diagram for the data selection (adapted from PRISMA [2020])

2023 were included in the study.
- In document types, other than the journal articles are excluded (i.e., proceeding papers, book chapters, editorial materials, meeting abstracts).
- Languages other than English are excluded due to addressing the international publications.
- Early access publications are excluded from the study.
- The documents must focus on using Arduino boards in STEM Education.

As presented in Figure 1, removing the languages other than English left 261 publications. In terms of the document type, having selected the article as the only type, 97 publications appeared. The reason behind this selection is these "journal papers" are deemed reliable because of peer review. Then, to ensure that they are eligible for the study, these 97 articles were perused regarding the abstract as well as the titles by the two authors. On perusing the articles, two main issues were used as a filtering process: Homonyms and words that are part of another word. For instance, the article named "A heat-pulse method for measuring sap flow in corn and sunflower using 3D-printed sensor bodies and low-cost electronics" was removed from the dataset because in this article the word STEM was used as "stem diameter", in the literal sense of the chosen word. In line with this given situation, other articles with similar usages of stem that are irrelevant to STEM education were dismissed from the database. Such usages in these articles are listed as follows; "stem stroke", "stem growth", "stem respiration" "stem of pepper cavity seedlings" "stem cell", "steam turbines" "steam pump", and "steam valves". In addition to these, one other article was eliminated because Scopus identified the word "system" as "stem" in the abstract.

Included

After reading and screening 97 articles, 79 of them were deemed eligible in the final data analysis as the last phase of the PRISMA (2020) protocol, Inclusion.

Data Analysis

In the present study, two prime bibliometric procedures (Performance analysis and Science/Bibliometric mapping) were used to reveal the research trends of using Arduino technology in STEM education. Performance analysis is an established quantitative method for assessing academic output for productivity, quality, and scientific impact by detecting principal contributors. Science or bibliometric mapping analysis illustrates the structural and dynamic aspects of the data extracted from the research (Börner et al., 2003; Small, 1999). In the current study, we used several software tools to get meaningful data from the 79 articles. For instance, MS Excel was used as one of the tools to conduct some fundamental tasks, e.g., to reveal publications and citation trends. Vosviewer and Biblioshiny were employed in data visualization and in discovering the relations in citations, co-authorship, and bibliographic coupling.

RESULTS AND DISCUSSION

Overview of the Analyzed Data Set

Table 1 shows the information on 79 articles published in the period 2013 and 2022, which was extracted from the Scopus database. All articles were published by 45 different journals and 191 authors, who used 222 different keywords. Average number of co-authors in each document is 2.85. This value shows a contrast to other disciplines where the most common authorship numbers consist of more than three authors (Saleem et al., 2021). The reason behind this value can be ascribed to a limited number of research publications in this study. However, considering the results obtained from Average citations per doc (7.709), we can say that "using Arduino in STEM education" is a topic that has begun to attract academic interest.

Research Productivity in Terms of Publications and Citations

Scopus was used to investigate the distribution of the number and citations of the articles per year. The annual research productivity is demonstrated in Figure 2. According to this graph, the first article appeared in 2013 and was cited 30 times. Despite the absence of publications in 2016 as seen in Figure 1, there seems to be a considerable increment in the coming few

Table 1: Descriptive statistics of the articles in the dataset

Description	Results
Timespan	2013:2022
Journals	45
Articles	79
Annual growth rate %	44.22
Document average age	2.81
Average citations per doc	7.709
Author's keywords (DE)	222
Authors	191
Co-authors per doc	2.85
International co-authorships %	7.595

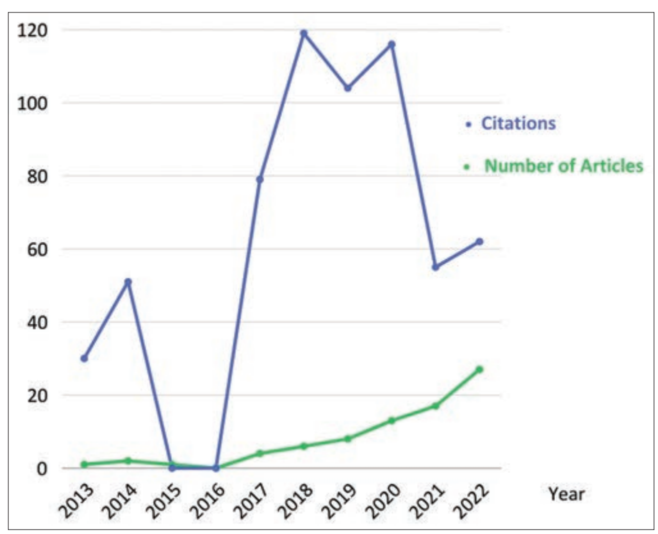

Figure 2: Number of publications and citations per year

years. The highest number of publications (n = 27) occurred in the year 2022, while the highest number of citations (N = 119) were received in the year 2018. Moreover, the number of articles produced between 2020 and 2022 constituted 72.15% of total publications. It seems that most of the articles have been published in the last few years. Furthermore, during the same time, the articles accounted for 86.85% of the total received citations. This finding is also supported by the Annual growth rate of 44.22% and the Average Age of the articles as 2,81 (Table 1).

Leading Countries

The total number of countries that have contributed to the studies conducted on the subject was twenty-nine. Out of these countries, Figure 3 depicts the research productivity of the most productive countries in terms of publications and citations.

Findings identify that the most productive countries were Turkey (n = 20), USA (n = 14), Taiwan (n = 7), and Spain (n = 4). The rest of the countries had three or fewer publications. Figure 2 also shows that Turkey (n = 83), USA (n = 227), Taiwan (n = 85), and Spain (n = 51) have the highest citations in the related field. Thus, it can be said that these four countries are the leading countries in Arduino and STEM publications. We investigate the descriptive statistics of these four countries as presented in Table 2 to better understand the unequal distribution of publications and citations among the countries (Figure 2).

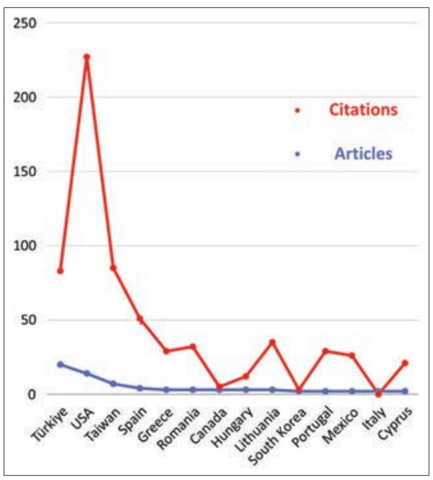

Figure 3: Trends of publications and citations of the countries

Table 2: Descriptive statistics for Turkey, USA, Taiwan, and Spain

Countries	Turkey	USA	Taiwan	Spain
Documents	20	14	7	4
Sources	13	12	6	3
Timespan	2019–2022	2013–2022	2018–2022	2017–2022
Document average age	1.95	4.53	2.57	3
Average citations per documents	4.81	17.13	12.29	13
Annual growth rate	91.29%	16.65%	10.67%	14.87%
Authors	26	54	16	14
Single-authored documents	4	3	1	0
Co-authors per documents	2.05	3.67	2.57	3.5
International co-authorship	4.762%	6.667%	0%	25%

With the highest number of documents (20), Turkey has the highest number of sources (13). As expected, producing the least number of documents (4), Spain has the fewest number of sources (3). "Document Average Age" for these four countries ranges from 1.95 (Turkey) to 4.53 (USA). This shows that Turkey only started to publish on this topic in 2019, relatively much later than others. On the contrary, USA-addressed articles have made connections between Arduino and STEM education since 2013. Therefore, since the USA has been the first country to publish these, this data could be accepted as a contributing factor to the unequal distribution between the USA and Turkey in terms of citation numbers shown in Figure 2. In parallel to this, the USA has the highest number of "Average Citations per document". Moreover, when we focus on the Annual Growth Rate values, the growth rate of Turkey (91.29%) can be seen to be much higher than other countries.

The average rate for the co-author per document numbers found for all the countries that participated in the dataset was 2.85. This number is 3.64 for the USA and 3.5 for Spain, which is significantly higher than the average. Thus, this illustrates that the cooperation in publications in these countries is higher than in the remaining 27 countries. The same rate for Turkey and Taiwan is lower than the average rate. Indeed, Figure 4 shows the authorship pattern in publications that originated in Turkey. As seen in this figure, the top authorship patterns were two authors (11 articles) and one author (6 articles) for Turkey. Finally, when we compare the International Co-Authorship rates, while Spain emerges as the leader with 25%, Taiwan does not have any international collaboration in their publications for this specific area.

Leading Institutions

Figure 5 shows Yeditepe University as the most productive with nine papers published in the dataset. Following closely, the second place belongs to Dokuz Eylül University with 6 papers, and in the third place is National Taiwan Normal University with 5 papers. In terms of total citation number, the first three countries are as follows; Becker College (n = 80) from USA; National Taiwan Normal University from Taiwan (n = 54) and Vilniaus University (n = 35) from Lithuanian. Yeditepe (n = 33) and Dokuz Eylül (n = 33) universities from Turkey rank in the fourth and fifth position with the citations that they have received.

Among the ten leading institutions illustrated in Figure 4, four of these institutions are in Turkey. Yeditepe University (n = 9) and Dokuz Eylül University (6) are placed in first and second positions. This shows that the number of publications per institution is high and concentrated in a few schools in Turkey. A total of 20 publications in Turkey came from 13 different institutions, whereas 14 publications from the USA came from 13 different affiliations. This also explains why there are only two institutions from the USA in Figure 5. Indeed, only two universities (Stanford and Becker) from the USA could publish two publications compared to others with only one publication, thereby entering the top ten productive institutions in Figure 5.

Among the institutions presented in Figure 5, Becker College received the highest number of citations per its publications with 80. The two publications in this college received 30 and 50 citations, and both had a common author named Galeriu (Table 3). Among a total of 191 authors, this author has received the highest number of citations for his publications in the dataset. His study published in 2013 is the first study to recommend using Arduino microcontroller as an ideal tool for integrated STEM projects. Moreover, his study titled "An Arduino Investigation of Simple Harmonic Motion", published in 2014, is the most cited publication in this dataset. In this study, the authors proposed a STEM activity that integrates electronics, computer programming, physics, and mathematics.

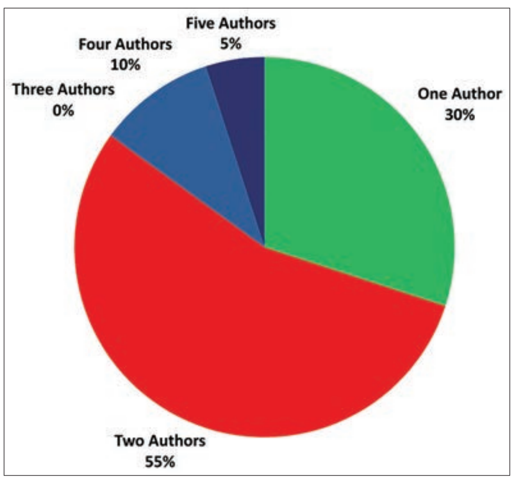

Figure 4: Authorship pattern of Turkey-addressed articles

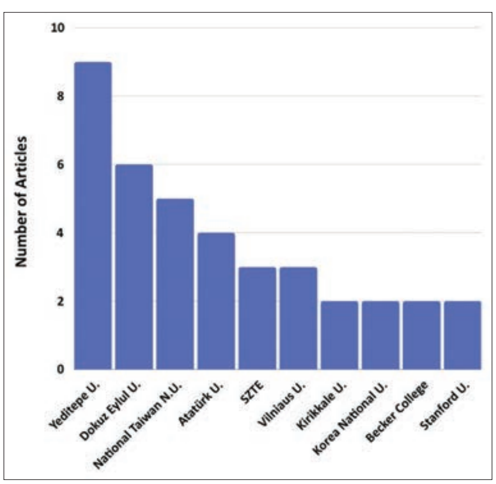

Figure 5: Number of publications of the leading institutions

Most Productive Authors

Table 4 shows the institution affiliated with the most productive authors, the total number of publications by each author (TP), the total citations associated with these publications (TC), and the h-index (h). As shown in Table 4, only two authors out of 191 authors published more than three papers on the topic, the rest of the authors published three or fewer articles. The most productive authors were Çoban, A. (N = 7+2) from Yeditepe University and Erol, M. (N = 5) from Dokuz Eylül University. In terms of Scopus, Coban, A. (two articles) and Çoban, A. (seven articles) are listed as different authors. However, they are the same person. Because of the Turkish characters in the author's last name, Scopus identified them as two different authors. After scrutiny, we have seen that these studies belonged to the same author, and we have made the necessary adjustments to calculate the h-index for the author's nine publications. It can be seen in Table 4 that Galeriu and Çoban have the highest impact with an h-index of three, that is, each author has three papers with at least three citations each, which means that the author has been included in at least nine publications (Table 4). In Table 4, Galeriu is listed as affiliated with Mark Twain International School; however, the same author is listed to be affiliated with Becker College in 2013 and 2014 (Table 3). While preparing the data, we used the school's name that he/she is currently working at in Table 4, yet the author's affiliation credential was listed as Becker College to demonstrate where he/she was working when he/she wrote the article.

The top three authors' production over time is shown in Figure 6. It is seen that Çoban, A. started publications in 2020. His most prolific year with four papers is in 2021. The second most productive author, M. Erol published his five papers with Çoban, A. in 2021 and 2022. Moreover, Galeru C. is the first author to mention Arduino and STEM at the same time in his paper. He has publications in 2013, 2014, and 2018.

Table 3: Becker college-addressed articles

Title	Authors	TC*
An Arduino Investigation of Simple Harmonic Motion	Galeriu et al.. (2014)	50
An Arduino-Controlled Photogate	Galeriu (2013)	50

*TC: The total citations associated with these publications

Table 4: Top contributing authors

Author	TP	Affiliation	h index	TC*
Çoban	9	Yeditepe University	3	33
Erol	5	Dokuz Eylül University	2	9
Galeriu	3	Mark Twain International School	3	91
Gingl	3	Szegedi Tudományegyetem (SZTE)	2	12
Juškevičienė	3	Vilniaus University	2	35
Makan	3	SZTE	2	12
Mingesz	3	University of Szeged	2	12
Salar	3	Atatürk University	1	2

*TC: The total citations associated with these publications

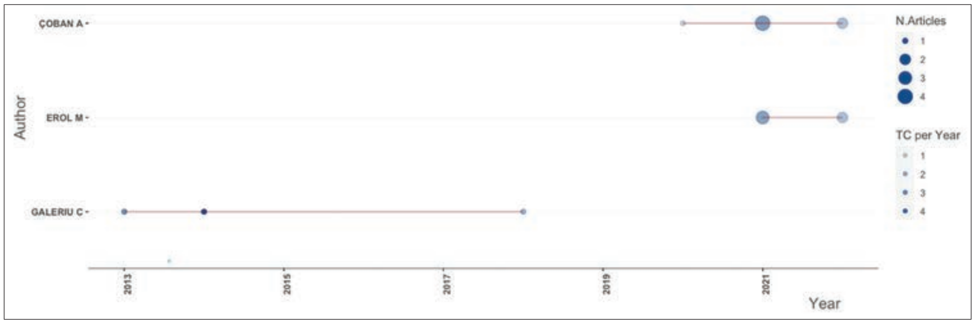

Figure 6: Top 3 Authors' production over time

Most Influential Journals

All 79 articles in the database were published by 45 different journals (Table 1). Table 5 presents the most influential journals with h-index over one. Thus, 38 other journals had h-indices of 1 that were not placed in Table 5. These seven top journals in Table 5 produced 47% of 79 articles in the database. When Table 5 is examined, it is seen that the most published journals belong to "Physics Education" (f = 13), "Physics Teacher" (f = 8), and "Electronics" (f = 5). Moreover, "Physics Education" and "Physics Teacher" are the most influential journals with an h-index of 4. H-index refers to that h publications of the journal that have been cited h times. That is, an h-index of 4 implies that four publications have been cited at least four times. Moreover, "Physics Teacher" has the first article in Arduino and STEM publications.

Most Frequently used Words in the Dataset

Of 222 author keywords were detected in 79 articles in the dataset (Table 1). Figure 7 presents a visualization of the top 10 words that appeared most frequently in the database. The word cloud illustrates words in various sizes depending on how frequently they appear. While the words are placed on the illustration somewhat randomly, the prominent words with a larger font size are placed in the middle so that they are more visible. The most repeatedly used keywords were "Arduino" (f = 31), "STEM" (f = 17), "STEM education" (f = 13), "computational thinking" (f = 10), "physics education" (f = 8), "physical computing" (f = 5), educational robotics (f = 5), and "project-based learning" (f = 3).

To visualize the top five keywords' frequency over time, Figure 8 was developed using the Biblioshiny with precise graphical parameters: field as "authors' keyword", occurrences "per year" with no confidence interval with the top five keywords considering their maximum frequencies. Each keyword is denoted with an individual color to distinguish in the graph, which are, respectively: Arduino (Red), STEM (dark violet), STEM education (fuchsia), computational thinking (light green), and physics education (blue). As seen in Figure 8, the oldest authors' keyword was Arduino, which was used for the first time in the article published in 2015. The use of Arduino as the author's keywords in publications seems to have increased dramatically especially after 2019 with a peak in 2021. Besides Arduino, other authors' keywords whose frequency has increased are: "STEM" and "STEM Education".

Table 5: Top contributing journals

Journal name/Source	h	NP	TC	PY-start
Physics Education	4	13	42	2019
Physics Teacher	4	8	103	2013
Computer Applications In Engineering Education	3	3	58	2019
Electronics (Switzerland)	3	5	31	2019
Eurasia Journal of Mathematics, Science and Tech. Educ.	3	3	84	2018
IEEE Access	2	3	14	2019
Romanian Reports in Physics	2	2	21	2020

Co-authorship Network Map

Biblioshiny software was employed to conduct a visual analysis of the authors' collaboration network. For this analysis, Figure 9 illustrates authors who co-wrote at least two articles. As seen from the thickest linkage in Figure 9, Çoban, A., and Erol, M. have the strongest collaboration relationship. They collaborated on five papers together in the dataset. Then Mingesz, R., Makan, G., and Gingl, Z. have the second strongest collaboration. They have three papers together. The other authors connected in Figure 10, have only two papers together.

Collaborative Networks between Countries

Vosviewer software was utilized to visualize the analysis of cooperation relations between countries, and the results are presented in Figures 10 and 11. Each country is signified by a circle, the size of which depends on the number of connections produced in that country. As indicated by the color red, Cyprus is the most collaborative country in the dataset of this study; hence, given the largest circle. The curve linking the two circles denotes the cooperation between the two connected countries. The thicker the curve is, the stronger the cooperation between the two countries. For this analysis, the minimum number of articles for a country was determined as one. The 23 clusters developed from 29 countries (Figure 10). The first cluster, the most crowded one, contained three countries (Cyprus-Greece-Turkey). The network in the countries belonging to this cluster is presented in Figure 11. Clusters 2, 3, 4, and 5 had two countries inside. These coupled countries in these clusters are as follows, respectively; Canada-United States (Cluster 2);

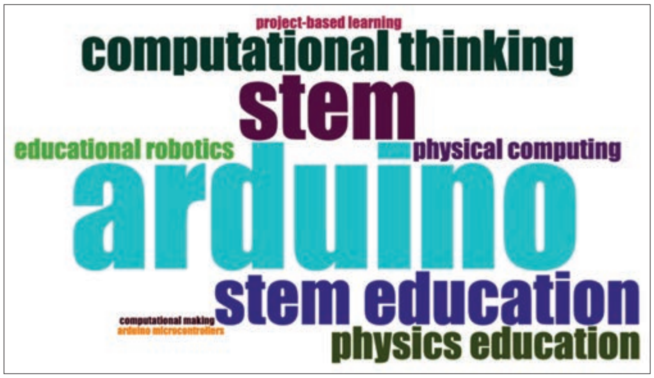

Figure 7: The word cloud of the author's keywords

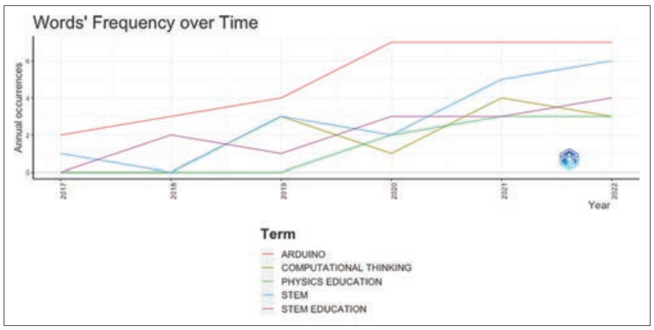

Figure 8: Mapping the word growth of the top 5 keywords based on the annual occurrence

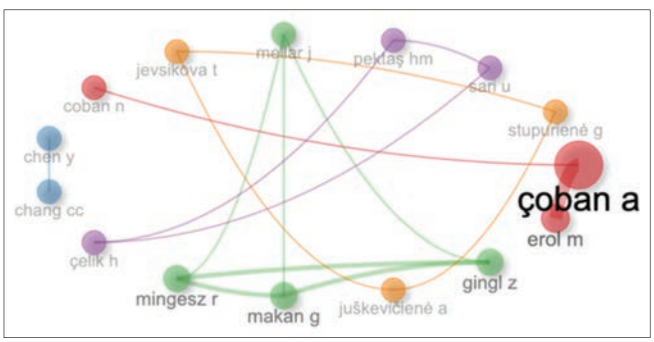

Figure 9: Co-authorship network map (min. edges: 2)

Netherlands-Romania (Cluster 3); Portugal-Spain (Cluster 4); Saudi Arabia-Tunisia (Cluster 5). The remaining 18 clusters consist of only one country.

Bibliographic Coupling of Countries

Figure 12 gives the bibliographic coupling of countries in the dataset. Bibliographic coupling of countries occurs when publications from two countries reference publications from a third country. Countries with a minimum of one document or more were included in the study; 29 of 29 countries meet the criterion. Countries are clustered as one for their close relations in content; clusters' connections are categorized using quantitative network indicators. Bibliographic couplings of counties in the dataset were classified into six clusters. Turkey is placed along with Italy, Taiwan, Hungary, and Brazil in cluster 1 (red cluster). The United States is in cluster 2 with Canada, and Mexico (green one). Chile and Lithuania are in Cluster 3. Cyprus and Greece are placed in cluster 4. Moreover, Cluster 5 contains Romania and the Netherlands. Lastly, Portugal is with Spain in Cluster 6. Countries with the top bibliographic coupling action included the US (74 total link strength); Cyprus (67 total link strength); and Turkey (65 total link strength).

Co-occurrence Network Mapping

With the Vosviewer program, "co-occurrence" and "author keywords" were chosen as the analysis unit. Then, when the minimum repetition count was selected as two for keywords, 26 keywords met this threshold. The network structure of the relationship between authors' keywords is presented in Figure 13. Each circle refers to a keyword. The size of a circle indicates the frequency of the keyword. Clusters of keywords are represented with different colors. Lines refer to co-occurrence links between keywords and the thickness of the line refers to the strength of the relationship between them. Six clusters were observed after the analysis. These clusters were composed of three–six keywords. The largest circle of each cluster indicates the dominant keyword. Arduino for the purple cluster, STEM for the blue cluster, "STEM education" for the green cluster, "Project-based Learning" for the red cluster, and "computational thinking" for the yellow cluster were the dominant keywords. For the light blue cluster, there are no dominant keywords because all keywords (low-cost, open-source, and "Raspberry Pi" have the same frequency as two. The words "Arduino," "STEM," "computational thinking," "STEM education" and "physics education" are situated at the center of Figure 12 because they have the highest connections with others. The total link strengths are as follows respectively; 46, 29, 21, 19, and 14.

CONCLUSION AND RECOMMENDATIONS

The results revealed that the first article that mentioned Arduino and STEM in an educational context appeared in 2013 and was written by Galerio, C. from Becker College, USA. In his study, Galerio recommended using Arduino microcontrollers in STEM projects. One year later, Galerio and his colleagues proposed a STEM activity including Arduino technology in their article (An Arduino Investigation of Simple Harmonic Motion), and it became the most cited article in the dataset. Moreover, both highly cited articles were published in Physics Teacher, one of the most influential journals in the dataset. Therefore, it appears that being a pioneer researcher and being published in an eminent journal is a useful way to become a distinguished author in the related field. Also, this data could be accepted as a contributing factor to the highest citation numbers of Becker College and USA among the institutions and countries. Despite the first articles appearing in 2013, a considerable increment could only be seen after 2016. Especially for the period between 2020 and 2022, a more dramatic increase in Arduino and STEM education studies has been detected. This increase after 2020 has also been recognized by more recent studies on Arduino-related

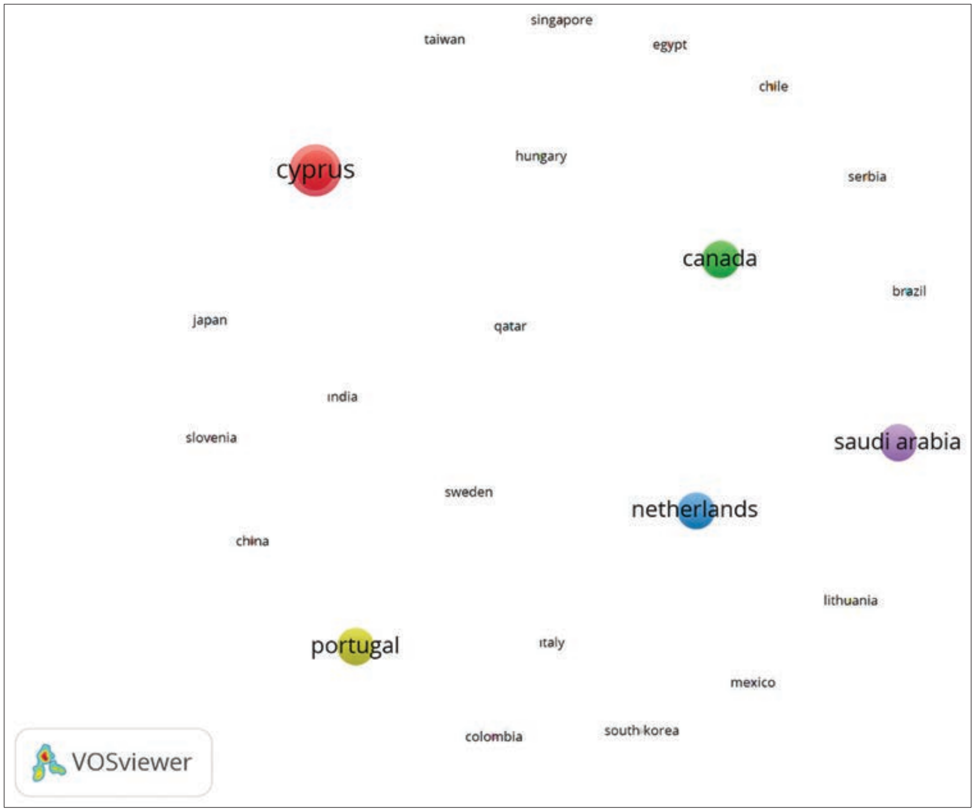

Figure 10: The co-authorship across all countries

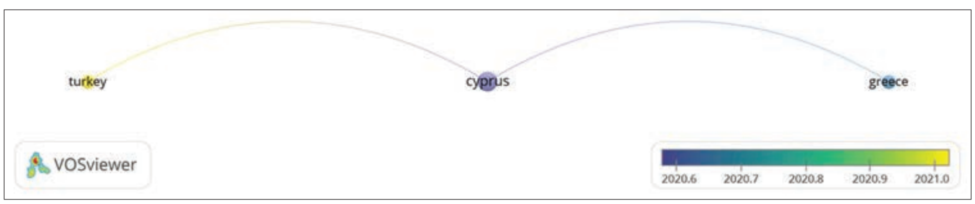

Figure 11: The co-authorship across Turkey, Cyprus, and Greece

Figure 12: Bibliographic coupling of countries

science application (i.e., Sulimro et al. 2023, Prabowo and Irwanto 2023). There could be a wide range of reasons behind why the number of articles experienced a slow start only to upsurge later. First, originally Arduino was not designed to be used for educational settings. Instead, it was designed and marketed toward hobbyists and designers who were interested in developing DIY (do-it-yourself) electronic circuits. This is why at first it was seen as difficult to implement Arduino into the class environment. However, several pioneering studies on how to implement Arduino-based applications in educational programs (i.e., Wong, 2015) encouraged more and more researchers to use Arduino in science and then STEM education. For instance, when the new term ChemDuino (a portmanteau of Chemistry and Arduino) was coined in 2015,

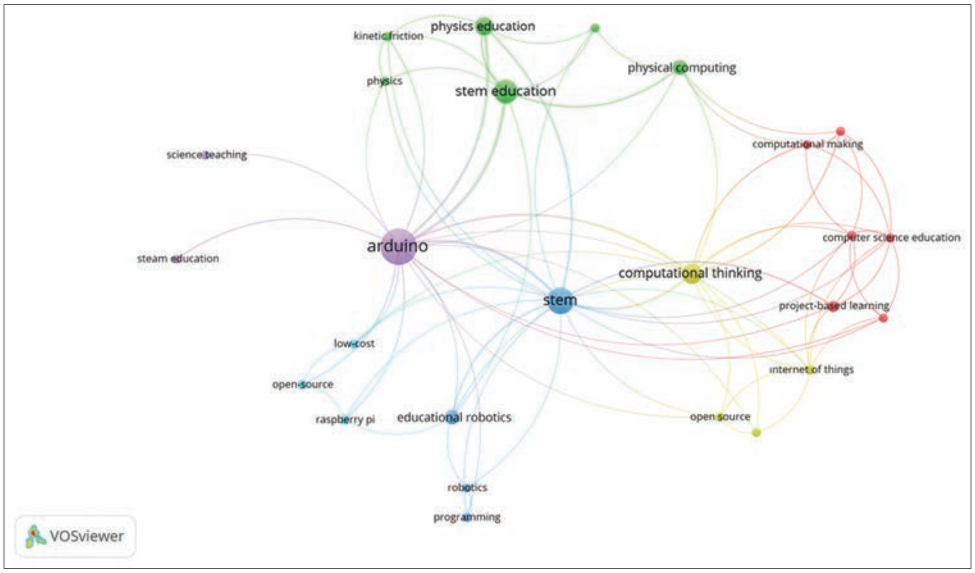

Figure 13: The co-occurrence of the authors' keywords

it was quickly welcomed in literature in the following years (Kubínová and Šlégr, 2015; Walkowiak and Nehring, 2016; Küçükağa et al., 2022). Moreover, using block-based coding (e.g., Scratch, Code.org) in the programming of Arduino hardware facilitated the use of Arduino at every level of education including the elementary level. Köksaloğlu (2022) found that an increase was observed in research articles focusing on the use of block-based coding tools in K-12 education in 2019. The reason behind this trend can be due to the growing emphasis on computational thinking which is accepted to be closely related to STEM subjects. Thus, the increasing trend of block-based coding environments and computational thinking could have contributed to the rapid growth in the number of Arduino and STEM studies after 2020.

Results of the present study further indicate that Turkey has had the most publications, but the USA has had the highest citations in Arduino and STEM-related articles. Because Turkey started its publications much later than the USA and the overall number of Turkey-addressed publications has exhibited noteworthy growth recently, it is anticipated the number of citations per document for Turkey will increase further soon.

The findings of the current study also indicate the need for a rise in national and international collaboration in this area. For instance, out of 29 countries contributing to the dataset, only 11 of them made international collaboration. Cyprus was determined as the most internationally collaborative country only because it cooperated with two other countries (Greece-Turkey). Another 8 countries which contributed to the study and collaborated internationally formed pairs in their studies. These pairs have been usually observed to be neighboring countries (e.g., Canada-United States, and Portugal-Spain). This could be due to the geographical vicinity and ease of travel to scientific meetings in nearby countries. This may indicate that more researchers would be inclined to collaborate with other countries if provided the means to travel to other researching countries, which in turn may prevent the risk of monopolization in this area.

With regards to the recommendations of the study, we suggest that researchers interested in using Arduino in STEM education follow the publications of the most influential authors and journals. The prospect of a wide-spread influence of the journal is a likely reason for authors to publish their papers in this journal rather than the other educational ones. Acknowledging the most influential journals, authors, and institutions can be a useful reference for researchers working on this topic. Moreover, being aware of conceptual (co-occurrences), intellectual (bibliographic coupling), and social (collaboration network) networks could help researchers find a partner or fund for their project related to this area.

Being a pioneer bibliometric study about using Arduino technology in STEM education, the current study will assist the researchers in identifying the research trends and research gaps. As a result of the analysis, five keywords stood out in terms of frequency which are Arduino, STEM, STEM education, computational thinking, and physics education. This can mean that computational thinking will continue to be an essential part of studies focusing on Arduino and STEM. Furthermore, there are plenty of studies mentioning using Arduino and STEM within the scope of physics subjects. However, with the promising potential of STEM education and Arduino for other subjects such as Biology, Chemistry, and Mathematics, there emerges a need for more publications and applications to be made. All these findings and the research indicate that it is necessary to encourage scholars to research and integrate Arduino into STEM education for science classrooms.

Limitations

The present study has some limitations. First, it only focused on articles obtained from the Scopus database and was limited to the time until 2023, meaning that changes and developments are highly likely to continue considerably in the future due to the short lifespan of this topic. Other data sources besides the Scopus database may be used in future studies. Furthermore, the bibliometric analysis in this study was not based on the detailed content analysis. This study is also limited to a correlational and quantitative nature. Future research may be supported with a core content analysis of bibliographic data. Furthermore, the inclusion–exclusion criteria may have impacted the analysis results. Altered criteria may bring about a different perspective of the research area. Future studies may include other document types, such as proceedings.

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