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# Self-Regulated Learning in STEM Education: A Bibliometric Mapping Analysis of Research Using Scopus Database

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## Abstract

Considering SRL is one of the key aspects that determines an individual's success in STEM learning, knowing the development of research related to this topic is crucial. This research aims to conduct a bibliometric mapping analysis of research published in Scopus-indexed journals from 2013 to 2023. The search yielded 1683 publications, which generally showed an increasing trend. The analysis results showed the distribution of publications based on document type, year of publication, and geographical area. Then, the co-authorship analysis results showed publication collaboration among countries and among authors. In addition, the citation analysis results provided information on the most influential authors, journals, and publications. In relation to the co-occurrence analysis results, the most popular research focuses were the relationship between SRL and "e-learning" and "engineering education". The topics that are quite popular are related to "mathematics", and those that are less popular are related to the terms "stem (science, technology, engineering and mathematics)" or "stem" and "science" or "science education". Regarding trending topics, several keywords that have been popular recently are "covid-19", "online learning", "major clinical study", "technology", "human experiment", "student learning", and "academic achievement". Several recommendations are also provided based on the findings and limitations of this research.

## Introduction

The ability to self-regulate is one of the determinants of a learner's success in achieving their learning goals. This concept is known as Self-Regulated Learning (SRL), which continues to be studied in an effort to help students become independent learners. SRL is a learning process in which a learner takes control of their learning so that their learning goals can be achieved (Garcia et al., 2018). According to Zimmerman (1989), a learner is said to be a self-regulated learner when he begins and directs the process of acquiring certain knowledge and skills independently and does not depend on the help of other people (such as teachers or parents). What needs to be emphasized is that self-regulation is not essentially a mental ability or academic skill but rather a process in which a learner independently directs himself to turn his mental abilities into academic skills (Zimmerman, 2002).

In the self-regulation process, there are several components that need to be managed. Zimmerman (1989) states that learners are considered capable of self-regulation when they are actively involved in the learning process metacognitively, motivationally, and behaviorally. Similarly, Usher and Schunk (2018) say that self-regulation is a learner's effort to achieve learning goals by systematically organizing their thoughts, feelings, and actions. It can be concluded that SRL is a process in which learners actively and independently regulate their thoughts, feelings, and actions to achieve their learning goals.

SRL is a crucial factor in the success of an individual's learning process, especially in learning that requires student independence, one of which is STEM (science, technology, engineering, and mathematics) learning. STEM learning, which is naturally designed to develop divergent thinking with limited external direction, requires students to autonomously construct meaning, regulate the pace of learning, make decisions, and evaluate learning outcomes (Li et al., 2020). Apart from that, SRL is also crucial for a learner in completing various tasks in STEM learning which are naturally interdisciplinary (Zheng et al., 2020). Furthermore, the connection between SRL and STEM learning can also be seen from the perspective of educators and learners. Through STEM learning, SRL encourages students to regulate their learning process, and teachers who are experienced in STEM subjects are more likely to help these students improve their SRL skills (Nu'man & Retnawati, 2021).

The importance of SRL in STEM education makes it crucial to understand the development of research related to this topic. One thing that can be done is to carry out bibliometric mapping analysis, which can be used to determine trends in the development of research related to SRL in STEM education. There are several studies that use the bibliometric mapping analysis method to examine SRL topics. For example, bibliometric mapping analysis of SRL in general (Sulistiawati et al., 2023), SRL in the context of basic education (Sökmen et al., 2023), and SRL in the context of online learning (Cai & Lombaerts, 2023). There are also various studies that use bibliometric mapping analysis method related to STEM education, such as those related to the Engineering Design Process for STEM education in K-12 (Ali & Tse, 2023), the use of simple spectrophotometer in STEM education (Shidiq et al., 2021), STEM education in the ASEAN region (Ha et al., 2020), and STEM education in general (Assefa & Rorissa, 2013; Özkaya, 2019; Talan, 2021; Tas, 2022; Yu et al., 2016).

While numerous bibliometric analysis studies have been conducted on self-regulated learning (SRL) and a substantial body of literature exists on the application of this method in STEM education, no research has been identified that investigates the intersection of these two areas concurrently. Therefore, this study focuses on bibliometric mapping of publication data related to SRL in STEM education in the period from 2013 to 2023. This research seeks to analyze the research landscape related to this topic through the following research questions (RQ):

RQ 1. What is the distribution of publications based on type of document?
RQ 2. What is the distribution of publications based on year of publication?
RQ 3. What is the distribution of publications based on geographical area?

RQ 4. What is the co-authorship status?
RQ 5. Who are the most influential researchers?
RQ 6. Which are the most influential publications?
RQ 7. Which are the most influential journals?
RQ 8. What are the research focuses based on keywords used in the publications?
RQ 9. What are the trending topics based on keywords used in the publications?

## Method

### Research Design

The research design used in this research was bibliometric mapping analysis, or also known as science mapping (Goksu, 2021; Kaban, 2023). A map of science can be defined as a spatial representation of various disciplines, fields, specialties, and individual papers or authors, which can be likened to a geographic map that shows the relationships between physical features of the earth's surface (Small, 1999). This method was used in this research because it can help quantify the literature and evaluate current topics so that researchers in any field can discover existing trends (Kasemodel et al., 2016). Awareness of the importance of regularly monitoring publications related to a discipline in an effort to identify existing trends has existed for several decades (Van Doren & Heit, 1973). Therefore, this research focuses on research results published in the last decade in an effort to determine the latest trends.

### Meta-Data Collection Method

To obtain meta-data, it is necessary to search for scientific publications contained in a particular database. In this study, the Scopus database was chosen for several reasons. First, Scopus is one of the academic databases commonly used in bibliometric studies (Bahri et al., 2022; Phan et al., 2022). Second, even though the Scopus collection is not larger than Google Scholar, Scopus has the advantage because its publications undergo a peer review process so that it becomes the most extensive database for peer-reviewed publications (Julius et al., 2021). Third, although other databases such as Web of Science allow researchers to obtain meta-data for bibliometric analysis, Scopus has a wider range of documents than Web of Science for educational disciplines (Hallinger & Chatpinyakop, 2019). Based on these three reasons, Scopus was chosen as a database to obtain meta-data related to SRL in STEM education.

The Boolean operators (AND & OR) were used in the search process so that the keywords used were ["self-regulated learning" AND (stem OR science OR technology OR tech OR engineering OR mathematics OR math)]. The search, which was conducted in June 2023, aimed to find these keywords in the title, abstract, or keywords of publications indexed by Scopus. Only research published between 2013 and 2023 was included in this study.

### Data Analysis

After the data obtained from the Scopus database had been exported into CSV files, the data was then processed using Microsoft Excel and VOSViewer. To determine the distribution of publications based on document type, year of publication, and geographical area, the analysis process was performed using Microsoft Excel. The analysis processes that required the VOSViewer program were co-authorship analysis (to analyze collaboration between authors), citation analysis (to analyze influential authors, publications, and journals), and co-occurrence analysis (to analyze developments in the research field from time to time, including hotspots in certain fields) (Goksu, 2021). The VOSViewer software developed by Van Eck and Waltman (2010) has proven useful for carrying out the analyses required in bibliometric studies (Ali & Tse, 2023; Bahri et al., 2022; Goksu, 2021; Kaban, 2023).

## Results and Discussion

### The Distribution of Publications Based on Type of Document

The search conducted in June 2023 produced 1683 publications, which were divided into ten types of documents, as shown in Table 1. Based on Table 1, the majority of publications were 952 (56.57%) articles and 493 (29.29%) conference papers. Meanwhile, the other 3 types of documents, namely book chapter, review, and conference review, accounted for less than 10% each. The five documents, namely book, editorial, erratum, note, and short survey, were very small in number, with less than 1% each.

Table 1. The Distribution of Publications Based on Type of Document

| Rank | Type of Publication | F | % |
|---|---|---|---|
| 1 | Article | 952 | 56.57 |
| 2 | Conference Paper | 493 | 29.29 |
| 3 | Book Chapter | 119 | 7.07 |
| 4 | Review | 51 | 3.03 |
| 5 | Conference Review | 38 | 2.26 |
| 6 | Book | 15 | 0.89 |
| 7 | Editorial | 6 | 0.36 |
| 8 | Erratum | 5 | 0.30 |
| 9 | Note | 2 | 0.12 |
| 10 | Short Survey | 2 | 0.12 |

This finding is in line with the results of a bibliometric study carried out by Özkaya (2019) who studied STEM education in general, and Ha et al. (2020) who studied STEM education in ASEAN countries. In those two publications, the number of article-type publications was greater than that of conference papers and was the largest among other types of publications. However, this finding is different from another bibliometric study in the field of education conducted by Goksu (2021), which analyzed research in the field of mobile learning, as there were more conference papers (59.53%) than articles (36.37%). It should be noted that studies conducted by González-Alboand Bordons (2011) and Zhang and Glänzel (2012) found that articles received more citations and had a higher impact than proceeding papers.

**The Distribution of Publications Based on Year of Publication**

The distribution of these publications based on year of publication is presented in Figure 1. It is clear that in general the number of studies related to this topic is increasing gradually, with the highest number in 2023 at 245 publications. Even though there were declines, namely from 2013 to 2014 and from 2020 to 2021, the declines were not significant, only seven and six publications, respectively. Meanwhile, in 2023, the number only reached 116 because the data was taken in mid-2023.


Figure 1. The Distribution of Publications Based on Year of Publication

This increasing trend can be seen as a positive thing considering that apart from STEM learning, which naturally demands learner autonomy (Li et al., 2020), online learning, which is increasingly popular today, also requires individuals to become autonomous learners. In other words, if STEM learning is carried out in an online environment, then support for students' SRL will become increasingly crucial. Support for students' SRL can increase academic success in online learning, which demands a high degree of autonomy (Wong et al., 2019).

**The Distribution of Publications Based on Geographical Area**

In this study, it was found that there were 92 countries that published research related to the topic of SRL in STEM education. Based on Figure 2, it is apparent that publications on this topic were not evenly distributed across all countries. It is clear that in the list of 10 countries with the most publications, the United States (US) was the country with the highest number of publications, with 443 (26.32%) publications, followed by Germany (121 = 7.19%), Spain (117 = 6.95%), Australia (107 = 6.36%), Indonesia (106 = 6.30%), Canada (97 = 5.76%), the United Kingdom (UK) (92 = 5.47%), China (91 = 5.41%), Taiwan (81 = 4.81%), and the Netherlands (66 = 3.92%). This finding confirms findings from previous STEM-related bibliometric studies, which found the USA to be the country with the most publications (Ali & Tse, 2023; Yu et al., 2016). Another finding that is similar to the findings of the two studies is that among the top 10 countries, there were always representations from four continents, namely America, Asia, Australia, and Europe.

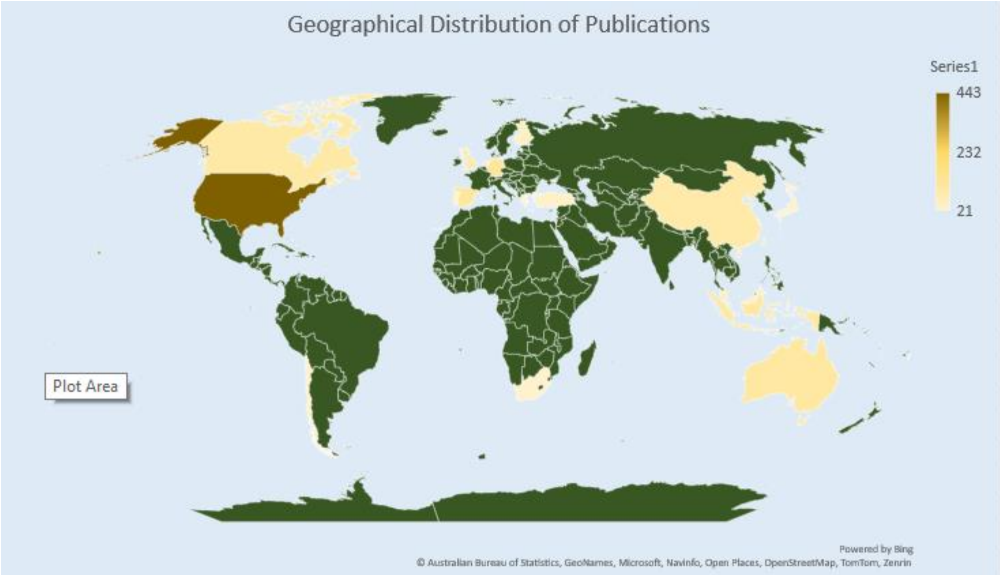


Figure 2. The Distribution of Publications Based on Geographical Area

**The Co-Authorship Status**

After analyzing the distribution of publications based on geographical area, the analysis process in this research also produced data regarding collaboration between researchers based on their country of origin. In co-authorship analysis using VOSViewer, it was found that there were 39 countries with a minimum of 10 publications collaborating with each other. They form seven clusters, as shown in Figure 3.

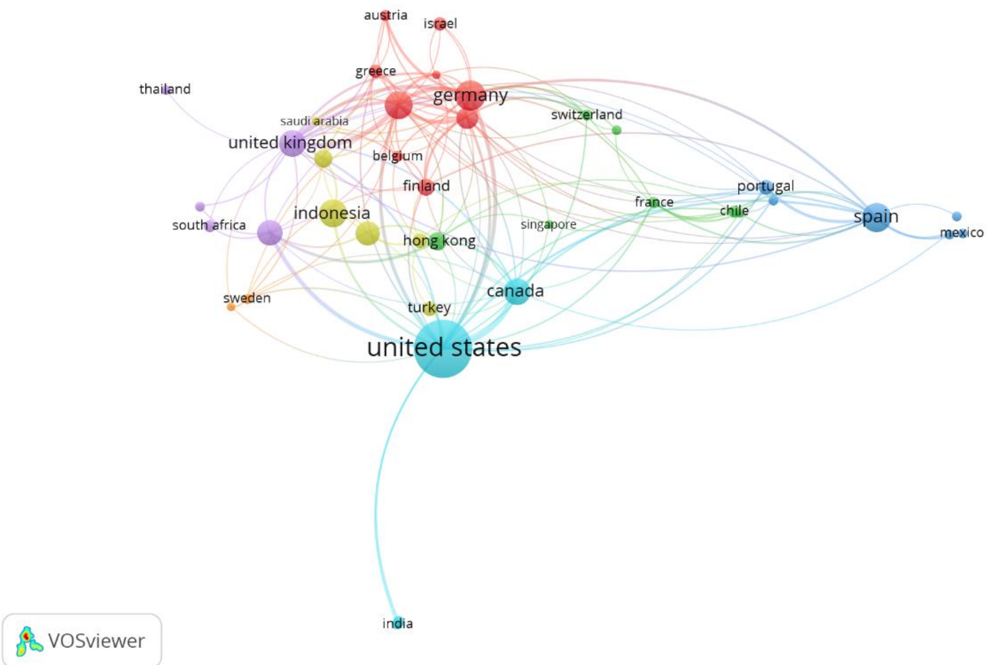


Figure 3. Country Co-Authorship Visualization on SRL in STEM Education

The size of the circles can indicate the number of publications originating from those countries, and the closeness of the circles indicates cooperation (Goksu et al., 2021). Another thing that needs to be noted, and will be used to interpret co-authorship results, is the total link strength (TLS), which can indicate the number of co-occurrences of a node (or circle) with other nodes, including repeated co-occurrences (Y. J. Huang et al., 2022). In other words, TLS can indicate the total strength of a particular aspect (such as the number of co-authorship links of one author to other authors) (Au-Yong-Oliveira et al., 2021).

Figure 3 shows that although the US had the highest TLS (122) in the cyan cluster, it was not in the largest cluster. The red cluster was the largest cluster containing nine countries, with three countries, namely Germany (highest TLS = 90), Australia (TLS = 89), and the Netherlands (TLS = 66), were included in the list of 10 countries with the most publications. The countries with the highest TLS in other clusters were as follows: Chile (green; TLS = 22), Spain (blue; TLS = 46), Malaysia (yellow; TLS = 15), the United Kingdom (purple; TLS = 80), and Sweden (orange; TLS = 11). Meanwhile, countries that were far from the cluster (such as India) were countries with minimal cooperation (Goksu et al., 2021).

Furthermore, co-authorship analysis also produced a visualization of cooperation between individual researchers as shown in Figure 4. Authors with a minimum number of five publications on the topic of SRL in STEM education were included in the analysis process. Of the 80 authors who met this criterion, only 45 were connected to each other. This means that almost half of the authors did not collaborate with each other.

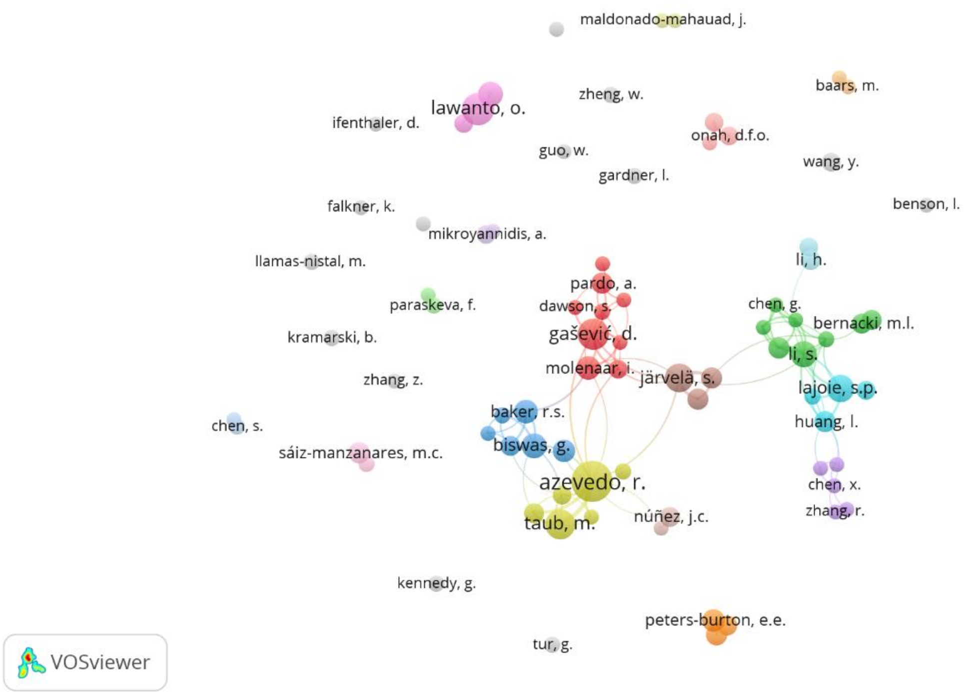


Figure 4. Co-Authorship Visualization on SRL in STEM Education

Figure 4 illustrates that even though R. Azevedo (yellow cluster) from the US was the author with the highest TLS (50), he was not in the largest cluster. The red cluster as the largest cluster contained nine authors with D. Gašević (TLS = 30) as the author with the highest TLS. Other authors with the highest TLS in other clusters (which had at least 5 authors) were as follows S. Li. (green; TLS = 31), G. Biswas (blue; TLS = 22), X. Chen (yellow; TLS = 7). Apart from these clusters, there was one cluster with four authors, four clusters with three authors, eight clusters with two authors, and fourteen clusters with one author (a total of 32 clusters). Based on the findings related to co-authorship, it is hoped that there will be more collaboration between authors and countries because co-authorship can increase academic productivity (Ductor, 2015) and the quality of research papers (Kumar & Ratnavelu, 2016).

**The Most Influential Researchers**

To determine the most influential researchers, the number of citations can be an indicator of how influential an author is in their field (Goksu, 2021; Kaban, 2023). Although the number of publications can indicate how much productivity and contribution a researcher has in their field, what is more essential is how interesting and effective these publications are (Goksu, 2021). Therefore, the number of citations was chosen as an indicator of the most influential researchers rather than the number of publications. Table 1 presents the results of the citation analysis which shows the ten most influential researchers with a minimum of five publications ordered based on the number of citations they received.

Table 2. Top 10 Most Influential Researchers on SRL in STEM Education

| Rank | Author | Institution | Country | Publications | Citations |
|---|---|---|---|---|---|
| 1 | D. Gašević | Monash University | Australia | 26 | 2231 |
| 2 | R. Azevedo | University of Central Florida | US | 35 | 694 |
| 3 | S. Järvelä | University of Oulu | Finland | 17 | 637 |
| 4 | J. Malmberg | University of Oulu | Finland | 10 | 511 |
| 5 | A. Pardo | University of South Australia | Australia | 10 | 491 |
| 6 | H. Järvenoja | University of Oulu | Finland | 9 | 363 |
| 7 | M. Taub | University of Central Florida | US | 18 | 323 |
| 8 | S. P. Lajoie | McGill University | Canada | 16 | 267 |
| 9 | M. Bannert | Technical University of Munich | Germany | 7 | 255 |
| 10 | P. H. Winne | Simon Fraser University | Canada | 11 | 243 |

The results of the citation analysis showed that there were 80 authors who had at least five publications. Table 2 shows that D. Gašević was the author with the most citations, even though his number of publications was less than R. Azevedo. Furthermore, Table 2 also shows that D. Gašević, R. Azevedo, and S. Järvelä were the three most influential authors. These findings confirm several results from previous studies. For example, a study conducted by Sulistiawati et al. (2023) found that R. Azevedo was one of the authors with the most publications when reviewing the development of research on SRL over the last three decades. Similarly, a study conducted by Cai & Lombaerts (2023) also found that D. Gašević was one of the most influential authors on the topic of SRL in online learning contexts. Another thing that should be noted is that the ten most influential authors came from Australia, Europe, and the US. There were no authors from Asia even though there were three Asian countries, namely Indonesia, China, and Taiwan, which were included in the list of 10 countries with the most publications.

**The Most Influential Publications**

To discover the most influential publications, a citation analysis was carried out to determine the number of citations an article received, as was done in several previous bibliometric studies (Bahri et al., 2022; Goksu, 2021; Kaban, 2023; and Merigó et al., 2015). Taking into account the number of citations is one of the most popular methods that is often used in bibliometric studies (Merigó et al., 2015). One of the benefits of knowing the number of citations from a publication is to assess the magnitude of the influence of the publication (Bahri et al., 2022). Table 3 shows the 20 most influential articles related to SRL in STEM education based on the number of citations and citations per year.

Table 3. Top 20 Most Influential Publications on SRL in STEM Education

| Rank | Year | First Author | Publication Title | Cit | Cit/Year |
|---|---|---|---|---|---|
| 1 | 2015 | D. Gašević | Let's not forget: Learning analytics are about learning | 496 | 62.00 |
| 2 | 2014 | Y.-C. Kuo | Interaction, Internet self-efficacy, and self-regulated learning as predictors of student satisfaction in online education courses | 444 | 49.33 |
| 3 | 2016 | D. Gašević | Learning analytics should not promote one size fits all: The effects of instructional conditions in predicting academic success | 395 | 56.43 |
| 4 | 2013 | C.-H. Wang | Students' characteristics, self-regulated learning, technology self-efficacy, and course outcomes in online learning | 362 | 36.20 |
| 5 | 2019 | J. Wong | Supporting self-regulated learning in online learning environments and MOOCs: A systematic review | 229 | 57.25 |
| 6 | 2013 | D. A. Cook | Mastery learning for health professionals using technology-enhanced simulation: A systematic review and meta-analysis | 218 | 21.80 |
| 7 | 2014 | A. S. Donker | Effectiveness of learning strategy instruction on academic performance: A meta-analysis | 217 | 24.11 |
| 8 | 2014 | D. Gašević | Where is research on massive open online courses headed? A data analysis of the MOOC Research Initiative | 212 | 23.56 |
| 9 | 2014 | M. Bannert | Process mining techniques for analysing patterns and strategies in students' self-regulated learning | 195 | 21.67 |
| 10 | 2013 | W. Ahmed | Emotions, self-regulated learning, and achievement in mathematics: A growth curve analysis. | 189 | 18.90 |
| 11 | 2015 | A. Lepp | The relationship between cell phone use and academic performance in a sample of US college students | 189 | 23.63 |

| Rank | Year | First Author | Publication Title | Cit | Cit/Year |
|---|---|---|---|---|---|
| 12 | 2018 | J. Maldonado-Mahauad | Mining theory-based patterns from Big data: Identifying self-regulated learning strategies in Massive Open Online Courses | 178 | 35.60 |
| 13 | 2018 | Z. Sun | The role of self-regulated learning in students' success in flipped undergraduate math courses | 163 | 32.60 |
| 14 | 2015 | N. Hood | Context counts: How learners' contexts influence learning in a MOOC | 160 | 20.00 |
| 15 | 2015 | M.-H. Cho | Self-regulated learning: The role of motivation, emotion, and use of learning strategies in students' learning experiences in a self-paced online mathematics course | 141 | 17.63 |
| 16 | 2015 | M.C. Duffy | Motivation matters: Interactions between achievement goals and agent scaffolding for self-regulated learning within an intelligent tutoring system | 140 | 17.50 |
| 17 | 2017 | J. Malmberg | Capturing temporal and sequential patterns of self-, co-, and socially shared regulation in the context of collaborative learning | 127 | 21.17 |
| 18 | 2016 | A. Pardo | Combining university student self-regulated learning indicators and engagement with online learning events to predict academic performance | 125 | 17.86 |
| 19 | 2014 | J. León | Self-determination and STEM education: Effects of autonomy, motivation, and self-regulated learning on high school math achievement | 125 | 13.89 |
| 20 | 2015 | K. G. Nelson | Motivational and self-regulated learning profiles of students taking a foundational engineering course | 121 | 15.13 |

Of the 20 articles with the highest number of citations, almost half of the articles focused on SRL in technology-mediated or supported learning, including online learning (Gašević et al., 2014; Gašević et al., 2015; Gašević et al., 2016; Maldonado-Mahauad et al., 2018; Pardo et al., 2016; C. H. Wang et al., 2013; Wong et al., 2019), technology-enhanced simulation (Cook et al., 2013), and hypermedia learning (Bannert et al., 2014). Another study related to SRL and technology was a study conducted by Lepp (2015), which made SRL a significant predictor in the process of assessing the relationship between mobile phone use and academic performance.

Meanwhile, several studies that investigate SRL in the context of STEM learning are related to SRL in mathematics learning (Ahmed et al., 2013; Cho & Heron, 2015; León et al., 2015; Malmberg et al., 2017; Sun et al., 2018), biology learning (Duffy & Azevedo, 2015), data science learning (Hood et al., 2015), both math and science learning (Donker et al., 2014), instructional technology learning (Kuo et al., 2014), and engineering-tailored foundational computer science courses (Nelson et al., 2015).

These findings indicate that half of the 20 highest cited articles found in the search process were more related to the relationship of SRL to technology and not to technology learning as part of STEM. Therefore, more efforts are needed to ensure more influential publications regarding SRL in various STEM subjects.

### The Most Influential Journals

Citation analysis, as one of the popular methods in bibliometric studies (Merigó et al., 2015), was also used as an indicator to determine the most influential journals, as in previous bibliometric studies (Djeki et al., 2022; Kaban, 2023; Koçak & Soylu, 2022). The top 10 most influential journals related to SRL in STEM education with a minimum of 10 publications are presented in Table 4.

Table 4. Top 10 Most Influential Journals on SRL in STEM Education

| Rank | Journal | Publications | Citations |
|---|---|---|---|
| 1 | Computers & Education | 25 | 1256 |
| 2 | Metacognition and Learning | 24 | 825 |
| 3 | Computers in Human Behavior | 20 | 806 |
| 4 | Learning and Individual Differences | 16 | 465 |
| 5 | Learning and Instruction | 10 | 433 |
| 6 | Lecture Notes in Computer Science | 52 | 387 |
| 7 | Frontiers in Psychology | 37 | 279 |
| 8 | Journal of Computer Assisted Learning | 10 | 262 |
| 9 | Interactive Learning Environments | 18 | 254 |
| 10 | ACM International Conference Proceeding Series | 40 | 236 |

Based on the results of the citation analysis, it was found that there were 24 journals that had at least 10 publications. Table 4 shows that "Computers & Education", which focused on how digital technology could enhance education, was the most influential journal with 1256 citations, even though it was not the journal with the largest number of publications. In second place was "Metacognition and Learning" which specialized in research on metacognition and self-regulation. The results of further investigation also showed that although the search focused primarily on SRL issues in STEM education, half of the journals included in the 10 most influential journals revolved around the use of computer technology, such as "Computers & Education", "Computers in Human Behavior", "Lecture Notes in Computer Science", "Journal of Computer Assisted Learning", and "ACM International Conference Proceedings Series". Another thing to note is that there were no journals that focused on STEM education on this list.

### The Research Focuses Based on Keywords Used in the Publications

To discover the focuses or topics of research related to SRL in STEM education, one method that can be used is keyword co-occurrence analysis (Goksu, 2021; Suseelan et al., 2022). From a total of 1683 publications identified, there were a total of 5745 keywords. After setting the threshold for the minimum number of occurrences of a keyword at 20 and filtering to ensure the relevance of the keywords to this research topic, there were 74 keywords that met the requirements. Figure 5 shows a network visualization of the co-occurrence of these keywords, which were divided into five clusters, where each cluster can reflect one research focus (Suseelan et al., 2022). However, no description can fully explain the richness of each cluster (Kaban, 2023). The size of the circles or nodes in Figure 5 represents the frequency of the co-occurrence, which means the higher the frequency, the larger the size (Bahri et al., 2022; Kaban, 2023). The distance between circles or nodes indicates the strength of the relationship between them; the closer they are, the stronger their relationship is likely to be (Bahri et al., 2022).

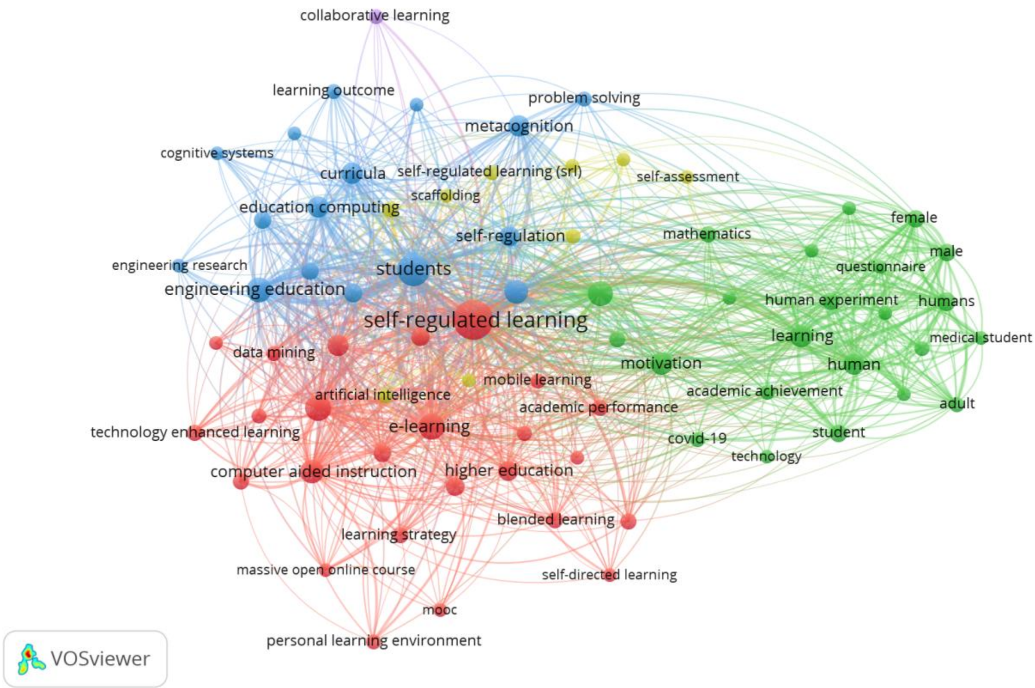


Figure 5. Network Visualization of The co-occurrence of Keywords

Figure 5 illustrates that some of the most frequently used words were “self-regulated learning” (1024 occurrences), “students” (453 occurrences), “e-learning” (230 occurrences), “learning systems” (211 occurrences), and “engineering education” (199 occurrences). Meanwhile, if we look at the clusters, the keywords that appear most often in each cluster were "self-regulated learning" in the red cluster (1024 occurrences), "education" in the green cluster (171 occurrences), "students" in the blue cluster (453 occurrences), “scaffolds” in the yellow cluster (44 occurrences), and “collaborative learning” in the purple cluster (33 occurrences).

Based on the network visualization shown in Figure 5, several interpretations can be made. Firstly, the most popular research topic was related to students' SRL in the context of e-learning (230 occurrences), such as related to students' SRL processes during an e-learning course (Cerezo et al., 2020), how to support SRL in an e-learning learning environment (Zhao & Chen, 2016), SRL strategy use in English learning supported by e-learning tools (Bai et al., 2021), how network centrality and self-regulation influence learning in a social network awareness-related e-learning environment (Lin et al., 2015), and the techniques and tools used to measure SRL in e-learning environments (Araka et al., 2020). Furthermore, in the red cluster, where the keywords "self-regulated learning" and "e-learning" were located, there were many other terms related to the use of technology for education, such as learning analytics, online learning, blended learning, data mining, mobile learning, flipped classroom, personal learning environment, massive open online course, and learning management system. There were many keywords related to technology in education in this research because the keyword "technology" was used in the search process. Research regarding the relationship between SRL and e-learning is crucial. This is because even though technology is useful for helping students determine their learning goals and monitor their learning process, flexible learning and a variety of multiple e-learning resources often lead to the emergence of poor self-regulation behaviors, which ultimately make them unable to organize knowledge and manage their learning processes independently (Lai & Hwang, 2021).

Secondly, another popular research focus was related to SRL in engineering education (199 occurrences), which is one of the STEM subjects. Several topics studied were, for example, related to students' SRL behaviors in engineering education (Concannon et al., 2018; Nelson et al., 2015; Zheng et al., 2020), SRL in the context of digital technology-supported learning (de Oliveira Fassbinder et al., 2017; Manganello et al., 2019; Rocha et al., 2020; Schettig et al., 2022), and the effect of self-assessment on students' SRL skills (El-Maaddawy, 2017).

Thirdly, besides engineering education, the co-occurrence analysis also showed "mathematics" as a quite popular research focus related to SRL in STEM education, with 43 occurrences. There were various topics related to SRL and mathematics, such as how SRL influenced mathematics achievement (Cleary & Kitsantas, 2017; Cleary et al., 2017; Říčan et al., 2022; Yıldızlı & Saban, 2016) and the role of students' SRL in online mathematics learning (Cho & Heron, 2015; Dai et al., 2022; Fung et al., 2014).

Meanwhile, the terms "stem (science, technology, engineering and mathematics)" and "stem" only occurred 15 and 10 times, respectively. Consequently, these terms were not visible in the network visualization because they were less than 20. Research on the relationship between SRL and STEM learning was carried out in the context of primary education (Sáiz Manzanares et al., 2020), secondary education (Han, 2017; Li et al., 2020; Q. Wang et al., 2022; Zheng et al., 2020), and higher education (Jackson, 2018; Kryshko et al., 2022; Pelch, 2018; Taub et al., 2018; Zheng et al., 2019). Similarly, the terms "science" and "science education" each only occurred 13 times, so they were also not visible in the network visualization. Several studies related to SRL in science learning, for example, related to science learning in secondary education (Sagun & Prudente, 2023) and higher education (Arcoverde et al., 2022; Hashemyolia et al., 2015; X. Huang et al., 2022).

**The Trending Topics Based on Keywords Used in the Publications**

Besides network visualization, which can describe research focuses, co-occurrence analysis can also produce overlay visualization, which provides information about trending topics related to a particular issue (Bahri et al., 2022; Goksu, 2021; Kaban, 2023). In this type of visualization, while blue nodes indicate keywords that occurred closer to the beginning of the period (2013), yellower colors indicate keywords that occurred closer to the end of the period (2023); thus, what topics have been most discussed recently can be determined (Bahri et al., 2022). Figure 6 shows the distribution of 74 keywords with a minimum of 20 occurrences based on the average year of their occurrence.

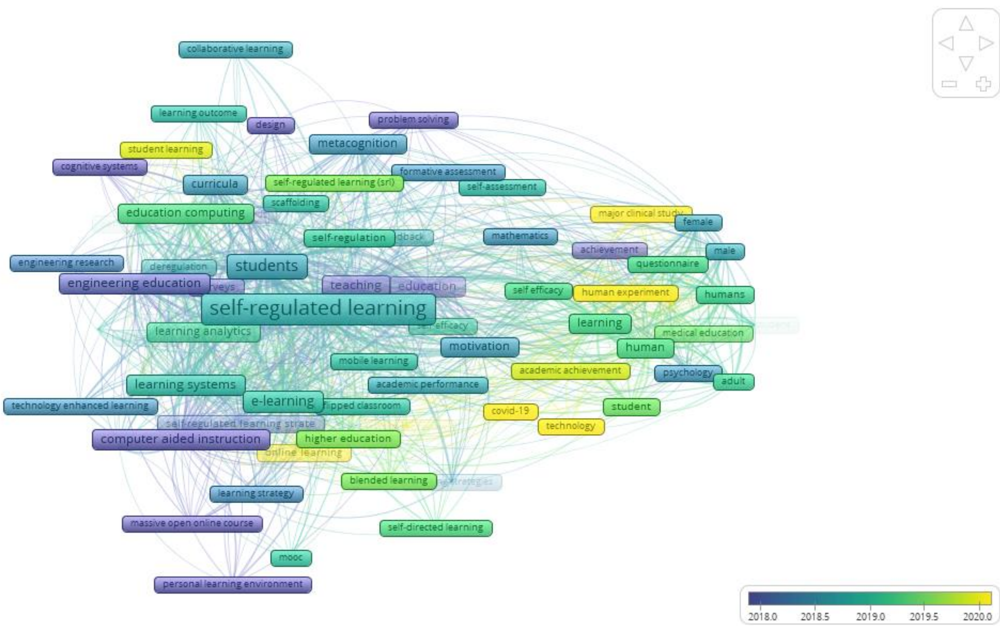


Figure 6. Overlay Visualization of the Co-Occurrence of Keywords

Based on Figure 6, several keywords that have been popular recently include "covid-19", "online learning", "major clinical study", "technology", "human experiment", "student learning", and "academic achievement". The terms "covid-19" and "online learning" have become the two most trending terms recently considering the COVID-19 pandemic that has hit the entire world, making many studies related to SRL focus on these things. For example, research related to these keywords was research conducted by Dai et al. (2022), which investigated junior high school students' SRL profiles in the context of online mathematics learning during the COVID-19 pandemic. Another example is research carried out by Ishartono et al. (2022), which examined the use of GeoGebra for improving students' SRL ability in online mathematics learning during the COVID-19 pandemic.

## Conclusions

SRL is one of the essential aspects that determines a learner's success in learning various things, including STEM subjects. This is because STEM learning often demands learning autonomy from a learner. This research is crucial considering that studies on SRL in STEM education continue to develop, so analysis is needed to determine research developments related to this topic. This research was carried out using the bibliometric mapping analysis method for research published in Scopus-indexed journals. A meta-data search was carried out using the keywords ["self-regulated learning" AND (stem OR science OR technology OR tech OR engineering OR mathematics OR math)] and by limiting the year of publication from 2013 to 2023. The data obtained was then analyzed to determine the distribution of publications based on document type, year of publication, and geographical area. In addition, the VOSViewer, a software for processing and visualizing bibliometric networks, was used to perform co-authorship, citation, and co-occurrence analyses.

The results of the analysis of data obtained in June 2023 showed that there were 1683 publications divided into ten types of publications, with articles becoming the largest type of publication at 952 (56.57%). In general, research related to this topic showed an increasing trend from 2013 to 2023. The reason why the number of studies in 2023 was quite low compared to previous years was probably because data collection was performed in the middle of 2023. In terms of distribution of publications based on geographic area, of the 92 countries identified, the US became the country with the most publications, with 443 publications (26.32%). Furthermore, the results of the co-authorship analysis showed that among countries that had a minimum number of publications of 10, there were 39 countries that collaborated. In addition, co-authorship analysis also showed that of the 80 authors who had at least five publications, only 45 were linked to other authors. This means that around half of the authors did not cooperate with each other in carrying out publications.

Furthermore, the results of the citation analysis produced several findings. Firstly, regarding the most influential authors, there were 80 authors who had at least 5 publications, with D. Gašević as the author with the most citations, and followed by R. Azevedo, and S. Järvelä. What needs to be noted is that in this research, one of the keywords used was "technology", so that many studies regarding the relationship between SRL and technology were included in the data obtained. Therefore, D. Gašević was the author with the most citations in this research because he was one of the most influential authors on the topic of SRL in technology-supported learning. Furthermore, even though there were three Asian countries in the top 10 countries with the most publications, not a single author from Asia was included in the top 10 most influential authors. Secondly, regarding the most influential publications, of the 20 articles with the highest number of citations, almost half of the articles focused on SRL in technology-mediated or supported learning. Several studies that investigated SRL in the context of STEM education were related to SRL in mathematics learning, biology learning, science learning, data science learning, and engineering-tailored foundational computer science course. Lastly, regarding the most influential journals, of the 24 journals that had at least 10 publications, "Computers & Education" was the most influential journal with 1256 citations, even though it was not the journal with the largest number of publications. In addition, among the top 10 most influential journals, there was no journal that focused on STEM education.

Furthermore, the results of the co-occurrence analysis revealed research focuses and trending topics based on keywords used in the publications. Of the total 5745 keywords, there were 74 that occurred at least 20 times and were relevant to this research. Regarding research focus, the findings based on the results of the co-occurrence analysis were: (1) the most popular research topic was related to students' SRL in the context of "e-learning" (230 occurrences); (2) another popular research topic was regarding SRL in "engineering education" (199 occurrences); (3) a quite popular topic was the relationship between SRL and "mathematics" (43 occurrences); (4) the keywords "stem (science, technology, engineering and mathematics)" (15 occurrences), "stem" (10 occurrences), "science" (13 occurrences), and "science education" (13 occurrences) were keywords that were less popular because they occurred less than 20 times. Regarding trending topics, several keywords that have been popular recently are "covid-19", "online learning", "major clinical study", "technology", "human experiment", "student learning", and "academic achievement".

## Limitations and Recommendations

The findings of this study have to be seen in light of some limitations. Firstly, this study only analyzed publications indexed in the Scopus database. Therefore, there might be many relevant studies published in other databases, which were not included in this study. Secondly, this study only utilized three bibliometric techniques, namely, co-authorship, citation, and co-occurrence analyses. There are other techniques that can be used, such as co-citation and bibliographic coupling analyses. Lastly, this study only analyzed research published between 2013 and 2023; thus, there might be certain research trends that are different if the time frame is different.

Considering the findings and limitations of this study, there are several recommendations for future studies. Firstly, more collaboration is needed between authors who focus on this topic to obtain more comprehensive findings that investigate this issue in various contexts. Second, there needs to be researchers from the Asian region who focus on this topic, considering that not a single author from Asia is among the top 10 most influential authors. Thirdly, research related to this topic needs to be continued and facilitated through journals that focus on STEM education in order to obtain articles that can become references for other researchers. Fourthly, more studies are needed regarding SRL in STEM education, especially those related to science education. Fifthly, research related to the trending keywords needs to be continued, considering that this is in accordance with current needs. Lastly, it is necessary to conduct research on publications indexed by databases other than Scopus using other bibliometric analysis techniques with different time frames in order to obtain even richer results.

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