SELF-REGULATED LEARNING IN MATHEMATICS ONLINE LEARNING ENVIRONMENT: A SYSTEMATIC REVIEW

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ABSTRACT

Learning mathematics in an online learning environment has unique challenges. Success in an online mathematics learning environment depends on a student's self-regulating ability. This systematic review provides the scholarly community with a synthesis of current self-regulated learning (SRL) strategies of students in the mathematics online learning environment. We looked at research from 2014 to 2022 regarding the approaches, purposes, outcomes, and limitations of these studies. Our findings indicate that most of the studies focused on the effect of SRL on student achievement. The results reveal that 88.2% of the studies used a quantitative approach and 41.1% employed high-school students as study samples. In addition, most of the studies used questionnaires to collect data and indicated that their limitation was the narrow study context. We encourage learning institutions to integrate SRL strategies in mathematics online learning environments to improve the quality of education.

Keywords: *self-regulated learning strategies, online learning environment, mathematics, quantitative approach*

INTRODUCTION

Mathematics is one of the core subjects at all levels of education. Studying mathematics is believed to produce students who can think critically and creatively (Roick & Ringeisen, 2018). Understanding basic mathematics topics forms a strong foundation for complex disciplines such as machine learning, networks, and mobile applications. In addition, mathematics also serves as the gatekeeper for occupations in fields such as science, engineering, medicine, and technology (Hegeman, 2015). Despite its benefits, many students state that learning and mastering the core concepts of mathematics carries the risk of failure that can lead to negative learning experiences and mathematics anxiety. Learning mathematics involves problem-solving skills, observing interrelationships between concepts, and applying deductive reasoning that arrives at a set of solutions.

Background and Aim of The Study

A meta-analysis of 86 articles on learning mathematics reported that many students face difficulties in solving mathematics problems and often show low self-esteem when encountering higher-level mathematics questions (Lima et al., 2019). Learning and understanding technical subjects such as mathematics becomes even more complicated when the teaching and learning activities are conducted online. This is because learning mathematics online establishes different means of interaction with instructors, utilizes other teaching pedagogy, and delivers learning materials in different ways during instructions (Enget al.,

2010). Researchers report concern over whether the online learning platform allows students to obtain substantial mathematical knowledge, skills, and capabilities (Kaino, 2012). Past studies also raise concerns over whether the online learning platform could enhance students' mathematical thinking and their ability to apply creative and innovative thinking to solve problems. In addition, whether students' capabilities to analyze mathematical challenges and deliver meaningful answers are the same as in traditional classrooms is also a serious concern among researchers when mathematics is taught online (Kaino, 2012). To increase students' mathematics achievement in an online learning environment, students are urged to adopt self-regulated learning (SRL).

It is crucial for students to self-regulate their learning process in an online learning environment because students' success in this environment greatly depends on their ability to self-regulate their learning process (Broadbent & Poon, 2015). According to Bandura (1986), SRL consists of self-efficacy and self-regulation. Self-efficacy refers to an individual's belief in their ability to achieve goals, while self-regulation involves an individual setting goals, and managing their behavior, and making plans to achieve them (Mou, 2023; Zimmerman, 1990). Self-regulation represents the metacognition, motivations, emotions, and active learning behaviors of students (Zimmerman, 2000). As reported by Panadero (2017), students usually will undergo three phases when studying in a traditional learning environment. In the preparatory phase, students plan and set goals for their learning activities based on the given task and the environment. In the performance phase, students simultaneously execute the task and monitor and control their cognition. In the appraisal phase, students regulate their SRL and reflect and adapt their process through self-reflection or evaluation by peers, teachers, or parents. Generally, SRL refers to a student's capability to plan, set learning goals, and execute the planned task while controlling and managing the progress of the task, and then evaluate the performance of the task either by using self-reflection or evaluation by friends or teachers. In an online learning platform, students should be able to learn independently to attain excellent results.

There is a range of established theoretical frameworks for SRL. Panadero (2017) concluded that the models created by Zimmerman (2000), Boekaerts (1996), Winne and Hadwin (1998), Pintrich (2000), Efklides (2011), and Hadwinet al. (2011) were theoretically and empirically supported. These six major frameworks of SRL highlight the significance of various facets of learning. For instance, Zimmerman (2000) stated that it is vital to integrate cognitive, motivational, social, and behavioral aspects of learning in his SRL framework. Thus, Zimmerman's model of SRL consists of three phases—forethought, performance, and self-reflection—that focus on all the learning aspects stated above. In the forethought phase, students evaluate the task, set a learning goal, and plan how to execute them based on predetermined goals and expectations. During the performance phase, students apply various self-control strategies and techniques to complete the given task while monitoring their progress. In the self-reflection phase, students evaluate their performance of and reaction to the task (Zimmerman, 2000).

Boekaerts (1996) also highlighted the importance of cognitive and motivational self-regulation and stated that cognitive self-regulation, which directs the learning process, and motivational self-regulation, which focuses on aspects such as effort and selection, work closely to determine the student's learning performance. Winne and Hadwin's (1998) framework emphasized the importance of cognitive and motivational self-regulation to achieve good academic outcomes. Similarly, Efklides' (2011) SRL model highlighted how metacognitive and affective self-regulation interact to determine student achievement. Pintrich (2000), highlighted the effect of motivation, emotions, and cognition on the learning performance of students. Finally, Hadwin et al. (2011) explored regulation in social and interactive learning features and emphasized the function of cognitive, motivational, and affective self-regulation in the student's learning performance. Panadero (2017) stated that the effect of learning aspects discussed in each theoretical framework for SRL varies according to the focus of the frameworks. Our review considered Zimmerman's (2000) theoretical model of SRL, which included all the primary learning aspects. In addition, most of the publications in our review discuss their SRL perspectives through the lens of Zimmerman's (2000) SRL framework.

Past studies show that SRL does not begin autonomously. There are a few strategies that students need to adopt to create a successful SRL

process. Past studies reported the existence of a positive connection between students' academic achievements and SRL strategies (ChanLin et al., 2015; Cho & Shen, 2013). These strategies are time management, online interaction, peer learning, metacognition, effort regulation, elaboration, organization, critical thinking, help-seeking, and self-learning management (Broadbent & Poon, 2015). This indicates that students who adopt effective SRL strategies could sustain their learning patterns and find effective solutions to obtain excellent learning performance (Broadbent & Poon, 2015). Researchers also highlighted that SRL students' SRL strategies, metacognitive knowledge, and procedures would differ based on their learning tasks and the academic domain (Wang & Sperling, 2020). Additionally, SRL in mathematics may also have distinct challenges that may increase when the instruction is conducted online. For example, Leite et al. (2022) identified the crucial and distinct role that SRL could play with teachers' orchestration in enhancing the online mathematics achievement of middle and high school students. Hidajat (2022) also acknowledged the need for creative mathematics teaching instruction to focus on SRL elements for improving students' mathematical thinking and achievement in the online learning environment.

Many reviews of SRL take place in various learning environments such as online, blended, flipped, Massive Online Open Course (MOOC), and computer based. Some reviews focused on the tools created to support the SRL process and discussed its relationship with learning performance (Perez-Alvarez et al., 2022). Other papers addressed measurement and intervention tools such as learner analytics and educational data mining (EDM) methods to assess and foster SRL strategies for students in the online learning environment (Araka et al., 2020). Several reviews presented their interest in specific methods such as metacognitive prompts (Guo, 2022), recommender systems (Du & Hew, 2022), and interventions or a combination of interventions observed to have a significant impact in supporting each phase of SRL (Edisherashvili et al., 2022). The reviews by Zhang, Tian et al. (2022) and Ceron et al. (2021) explained the supportive MOOC features for SRL. Lai and Hwang (2021) indicated how each strategy in the SRL phases could be applied effectively in the online learning environment. Gambo and Shakir (2021) conducted a review that explored empirical research that focused on models and design tools that support the SRL process in a smart learning environment. Ballouk et al. (2022) highlighted their review of the learning behavior of medical students in a blended learning environment to produce self-regulated learners. Another review by Silverajah et al. (2022) summarized self-regulated learning strategies in flipped classrooms.

Although these studies presented distinct perspectives on SRL, it is still challenging to get a comprehensive view of the SRL of students in technical courses such as mathematics in the online learning environment. Hence, our study aimed to analyze the current literature on SRL in mathematics online learning environments. Our review takes a broad approach to SRL in an online learning environment by identifying the general characteristics, research purposes and outcomes, and limitations in the studies related to SRL in a mathematics online learning environment. We also provide an overall view of the importance of SRL in improving the academic outcome of students in mathematics online learning environments.

Previous Systematic Reviews on SRL in the Online Learning Environment

Several systematic reviews addressed the range of SRL literature and provided us with a helpful reference point and context for our current systematic review. The focus of the systematic reviews about SRL varies. Perez-Alvarez et al. (2022) reviewed the tools developed to support the SRL process and determine its relationship with academic achievements. They concluded that the impact of tool functionalities on SRL processes is seldom elaborated, and only a few tools evaluated the effect of the SRL process on students' academic achievement. Meanwhile, Araka et al. (2020) discussed measurement and intervention tools such as learner analytics and EDM methods to assess and foster SRL strategies for students in the online learning environment. They asserted that traditional techniques are being adopted to evaluate SRL in elearning environments, though few studies have used learner analytics and EDM methods.

Some reviews showed an interest in specific methods that significantly support each SRL phase (Edisherashvili et al., 2022). For instance, Guo's (2022) review highlighted that metacognitive stimulus substantially improved SRL tasks and learning

results. Meanwhile, Du and Hew (2022) found that diverse attributes of recommender systems were constructed to foster SRL strategies, and students exhibit positive attitudes towards applying recommender systems to assist them in self-regulation. Similarly, Edisherashvili et al. (2022) reported that SRL supports interventions to improve the implementation of SRL.

Reviews conducted by Ceron et al. (2021) and Gambo and Shakir (2021) focused on models and design tools that support the SRL process. Ceron et al. (2021) highlighted that SRL MOOCs are an emerging area of study. Most studies on SRL in the MOOCs environment used the Zimmerman model as their theoretical framework. Meanwhile, Gambo and Shakir (2021) reported that SRL strategies such as setting goals, seeking help, managing time, and conducting self-evaluations are frequently discussed approaches in the literature. They also reported that limited theoretical models were developed to explore SRL in a smart learning environment.

There is also a review of how each strategy in the SRL phases could be applied effectively in the elearning platform (Lai & Hwang, 2021). The authors reported that more than half of the articles ignore this approach for individual SRL stages. In addition, some of the articles did not explicitly indicate how SRL could be used in a real-time environment.

Finally, some reviews also highlighted the effect of SRL on students' academic performance. For instance, Silverajah et al. (2022) reviewed the impacts of SRL on academic and nonacademic results and the conditions that affected the results. Generally, the review highlighted that implementing SRL strategies improves students' academic and nonacademic outcomes. Four factors, namely, frequency of access to learning resources, use of online features in SRL, adoption of SRL strategies, and motivation, all affect the academic and nonacademic results. Similarly, Ballouk et al. (2022) reported that SRL improves medical students' academic achievement in the blended learning environment.

REVIEW QUESTIONS

While there has been increased research focusing on SRL in online learning environments, we did not utilize previous systematic reviews that focused on the SRL of students in technical courses such as mathematics in online learning environments. Hence, our study aimed to analyze the current literature on SRL in mathematics online learning environments. As such, we asked the following research questions:

RQ1: What are the characteristics of the studies related to SRL in mathematics online learning environment?

RQ2: What are the research purposes and outcomes of the studies of SRL in mathematics online learning environment?

RQ3: What types of limitations exist in the research on SRL in mathematics online learning environments?

This review contributes to and advances knowledge regarding SRL in mathematics online learning environments in two ways. First, it highlights the use of SRL strategies in online mathematics learning environments that support effective learning outcomes (Hwang et al., 2021; Leite et al., 2022; Rienties et al., 2019). Maintaining learning in courses such as mathematics in an online environment is the most substantial challenge for students. The learning process in this environment requires students to continuously reflect, assess, revise, and observe their learning approaches. Usually, students with low self-regulation have difficulties adjusting to online learning (Silverajah et al., 2022). The evidence from this review could enhance readers' understanding of how students could effectively apply SRL strategies in an online learning environment, which could lead to similar learning advantages as those experienced in face-to-face classes for mathematics students. Second, the review also highlights the research approaches, other main research purposes, outcomes, and limitations in the selected publication about SRL in mathematics in an online learning environment. Thus, it exposes a research gap and focus for future research.

METHOD

A systematic review aims to conduct a review that is rigorous and transparent in a systematic manner to create an outcome that is reproducible and updateable (Zawacki-Richter et al., 2020). This study performed a systematic review by following the PRISMA approach (Figure. 1; Moher et al., 2009). Resources for this systematic review are from the journal databases Scopus, Education

Research Information Center (Eric), Science Direct, SpringerLink and Proquest.

Search Strategy

The review process was conducted in December 2022. First, we identified keywords for the search process based on past studies using keywords related to SRL, mathematics, and the online learning environment. Table 1 shows the four concepts, along with the keywords, we used.

Table 1.
Concepts and the Keywords Used

Concept 1	Concept 2	Concept 3	Concept 4
self-regulated self-control SR SRL Self-regulated learning	*online learning* *technology-enabled learning* *computer-based learning* *web-based learning* *elearning* *digital learning*	*learning* *instruction*	*mathematics*

We refined the keyword string through pilot searches by entering different combinations of keywords in the title, abstract, and keyword fields across various databases to determine if relevant articles could be discovered. Results were obtained for publications on various aspects of SRL adoption in online learning environments for learning mathematics. For instance, the pilot search string revealed that key publications would be missed if web-based learning, elearning, and digital learning synonyms were not included in the title, abstract, or keyword search.

Based on the identified concepts and pilot search, the developed keywords were: [("self-regulat*" OR "self-control" OR "SR" OR "SRL" OR "self-regulated learning") AND ("online learn*" OR "technology-enabled learn*" OR "computer-based learn*" OR "web-based learn*" OR "e-learn*" OR "digital learn*") AND ("learning*" OR "instruction") AND (mathematics)].

For the first concept, SRL can be further categorized into categories such as cognition, metacognition, motivation, and emotion. However, we assumed that such an expansion was unnecessary based on the assumption that the term "self-regulated learning" would be sufficient for locating publications comprising various categories of SRL. We further diversified the second concept of online learning search words by including other terms such as technology-enabled learning, computer-based learning, web-based learning, elearning, and digital learning. We believed these keywords would locate all the publications where the learning sessions are conducted online. Generally, an online learning environment is an elearning environment used for teaching and learning activities through computer-mediated platforms.

The eligibility criteria included only peer-reviewed journal articles resulting in excluding articles not in peer-reviewed journals, review articles, book series, books, book chapters, and conference proceedings. In addition, our search focused only on publications available in English for nine years (2014–2022). Further, the studies included in this review addressed SRL research in online learning settings for learning mathematics. Finally, we included only studies with original research data that consisted of qualitative, quantitative, or mixed-method approaches and had recognizable Methods and Results sections. Review pieces, opinions, literature reviews, or conceptual papers were omitted. Table 2 summarizes the inclusion and exclusion criteria.

Table 2.
The inclusion and exclusion criteria

Criterion	Eligibility	Exclusion
Literature type	Peer-reviewed journal (research articles)	Non–peer-reviewed journals, review articles, book series, books, chapters in books, conference proceeding
Language	English	Non-English
Timeline	Between 2014 and 2023	Before 2014
Research environment	SRL research in online learning settings for learning mathematics	
Article type	Original research data Studies should include qualitative, quantitative, or mixed methods Studies with recognizable methods and result sections	Review pieces, opinions, literature reviews, or conceptual papers

The search criteria produced 1,012 articles. We double-screened the titles and abstracts of the articles based on the predetermined eligibility

measures. When we disagreed on the inclusion or exclusion criteria, we conducted consensus discussions. The interrater agreement was 91%, indicating a good agreement between us. This screening lowered the number of articles substantially. Next, we reviewed the full text for chosen abstracts to determine the eligible publications.

The quality of the included studies was assessed based on Dybå and Dingsøyr's (2008) quality criteria, which has three main criteria: rigor, credibility, and relevance. We applied eight quality criteria based on the Critical Appraisal Skills Programme (CASP) and related works (Dybå & Dingsøyr, 2008).

Thematic Analysis

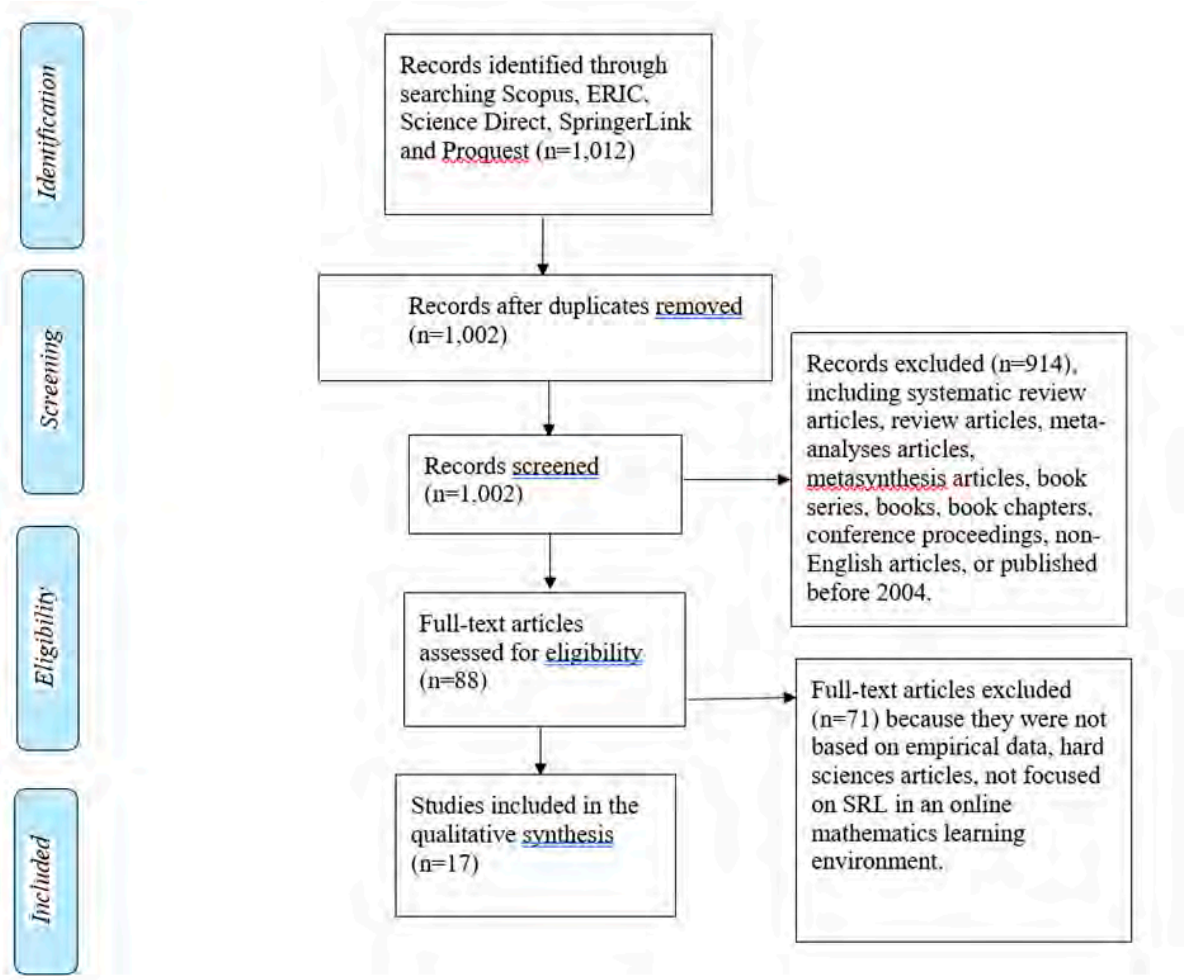
We used the inductive lens to identify common themes as proposed by Braun and Clarke (2006). This process has six processes, including data familiarization, data coding, theme searching, theme review, defining themes, and naming themes. Data familiarization was attained through screening and full-text and quality review processes. Then, we coded each manuscript and combined the data to determine the common themes.

RESULTS AND DISCUSSION

RQ1: What are the Characteristics of the Studies?

Seventeen (17) articles from various countries were selected for the final review. Table 3 shows the characteristics of the selected articles. The majority of the publications were from the United States (n = 3), the Netherlands (n = 3), China (n = 3), followed by Taiwan (n 1), Indonesia (n = 1), Germany (n = 1), Spain (n = 1), Bosnia and Herzegovina (n = 1), Malaysia (n = 1), South Korea (n = 1), and one comparative study conducted

Figure 1.
Review Process



among several countries. The reviewed articles showed that research related to SRL in mathematics online learning environment was conducted in North America, Asia, Europe, and Oceania, but no research has been conducted in the Middle East.

Most studies reported a quantitative method (n = 15) compared to one that utilized mixed methods and one that utilized secondary data. The research design employed by the studies was experimental (n = 5), quasi-experimental (n = 1), correlational (n = 1), cross-cultural (n = 1), cross-sectional (n = 1), and descriptive (n = 1). In contrast, seven studies did not specify the study design. The analysis also showed that undergraduates (n = 6), graduates (n = 1), both undergraduates and postgraduates (n = 1), diploma students (n = 1), high school students (n = 7), and middle and high school students (n = 1) were the student samples applied in the reviewed studies. The sample size of the reviewed studies ranged from 53 to 105,430 students.

Most of the studies (n = 14) used a questionnaire to collect data because it is economical to send and process the results (Roth et al., 2016). In addition, some of the studies also used analysis of numerical examination student grades (n = 6) and Learning Analytics (log data details) (n = 5). Log

Table 3.
Summary of Findings

No	Study (year)	Country	Research Method	Study Design	Respondents (n)	Duration
1	Hwang et al. (2021)	Taiwan	Quantitative	Experimental	High School students (62)	7 weeks
2	Leite et al. (2022)	USA	Quantitative	Not mentioned	Middle and High School students (6,174)	14 weeks
3	Rienties et al. (2019)	Netherlands	Quantitative	Not mentioned	Undergraduates (1,075)	7 weeks
4	Hidajat (2022)	Indonesia	Quantitative	Quasi-experimental	High School students (53)	10 weeks
5	Bellhäuser et al. (2022).	Germany	Quantitative	Experimental	Undergraduates (136)	4 weeks
6	Dai et al. (2022)	China	Quantitative	Not mentioned	High School students (428)	Not mentioned
7	Cueli et al. (2017)	Spain	Quantitative	Experimental	High School students (624)	Not mentioned
8	Dunn (2014)	USA	Quantitative	Not mentioned	Undergraduates and Graduates (101)	Not mentioned
9	Ejubovic & Puska (2019)	Bosnia and Herzegovina	Quantitative	Not mentioned	Undergraduates (375)	Not mentioned
10	Bruso et al. (2020)	USA	Mixed	Correlational	Graduates (452)	Not mentioned
11	Yahya et al. (2021)	Malaysia	Quantitative	Not mentioned	Diploma students (67)	Not mentioned
12	Raaijmakers et al. (2018)	Netherlands	Quantitative	Experimental	High School students (122)	100 minutes
13	Yu et al. (2020)	China	Quantitative	Descriptive	High School students (468)	5 weeks
14	Kim et al. (2018)	South Korea	Quantitative	Not mentioned	Undergraduates (284)	Not mentioned
15	Chen et al. (2021)	Hong Kong, Japan, Macau, Singapore, South Korea, Taipei, Australia, Denmark, Finland, Germany, Ireland, New Zealand, Sweden, United Kingdom, and United States	Secondary data	Cross-cultural	High School students (105,430)	Not mentioned
16	Zhang, Zou et al. (2022)	China	Quantitative	Cross-sectional	Undergraduates (799)	Not mentioned
17	van Harsel et al. (2022)	Netherlands	Quantitative	Experimental	Undergraduates (147)	116 minutes

data provides the students' engagement trends and learning approaches that are absent in traditional classrooms (Wang, 2019). Learning Analytics techniques have a low risk of bias as they can obtain and keep students' learning patterns precisely (Ahmad Uzir et al., 2020). Meanwhile, two studies used semistructured interviews and secondary data from the PISA database.

In terms of study duration, there were several classifications: 4 to 6 weeks (n = 2), 7 to 10 weeks (n = 3), and 11 to 14 weeks (n = 1). Raaijmakers et al. (2018) and van Hansel et al. (2022) were conducted for 100 minutes and 116 minutes, respectively, while the remaining nine publications did not indicate the study duration. Conducting a longitudinal study is a good alternative for studies related to SRL for its ability to capture students' SRL strategy patterns precisely (Silverajah et al., 2022).

RQ2: What are the Research Purposes and Outcomes of the Studies?

To explain the progress in the research area of SRL in mathematics online learning environment over the past nine years, we examined the research purposes and outcomes of the reviewed articles.

Research purposes

By analyzing the research purposes of the chosen articles, we categorized them into the following groups:

a. Investigating the effect of SRL strategies on learning performance. Articles in this classification assessed students' learning performance differences after implementing SRL strategies.
b. Investigating factors that influence the adoption of SRL strategies. Articles in this category determined the factors that influence the adoption of SRL strategies.
c. Investigating the influence of interventions such as web-based training and hypermedia tools on implementing SRL strategies. Articles in this category examined the improvement in adopting SRL strategies after attending training.
d. Investigating the adoption of SRL strategies based on individual differences. Publications in this category examined the variation in SRL strategy implementation based on individual characteristics.

The findings of the four categories are shown in Figure. 2. Most studies (n = 8) investigated the effect of SRL strategies on learning performance. Students' learning performance was evaluated based on academic (cognitive), behavioral, and affective learning outcomes. For example, Hwang et al. (2021) investigated students' learning performance in terms of academic and motivational learning outcomes. Leite et al. (2022) examined the academic performance of middle and high school students by determining their SRL strategies through log data patterns. Rienties et al. (2019) determined the undergraduates' academic performance through their distinct behavioral engagement in the SRL environment. Hidajat (2022) analyzed the mathematical creativity (affective) of or ability to provide a specific set of solutions by high school students. Dai, Li and Jia (2022) and Dunn (2014) investigated the behavioral (engagement and passive procrastination) outcome of students. Passive procrastination refers to characteristics of students who delay a task even after deciding. This is self-destructive because it is accompanied by self-doubt, anxiety, and distress. Ejubovic and Puska (2019) examined academic and affective (satisfaction) learning outcomes. Meanwhile, Yahya et al. (2021) determined the diploma students' motivational and behavioral (class participation) learning outcomes.

Figure 2.
Results of the Category of the Research Purpose

Further, 17.6% (n = 3) of the selected articles investigated factors that could influence the adoption of SRL strategies. For example, Yu et al. (2020) explored the effect of social networking, such as connection sizes and relationship-establishing factors, on SRL strategies. Chenet al. (2021) examined

social media use in implementing SRL strategies. Zhang, Zou et al. (2022) analyzed the impact of teaching presence on SRL strategies.

In addition, three publications evaluated how training improves the implementation of SRL strategies. For instance, Bellhauser et al. (2022) investigated the differences in the implementation of SRL strategies after attending web-based training among undergraduate students. Raaijmakers et al. (2018) and Cueli et al. (2017) explored the effectiveness of self-assessment, task-based training, and hypermedia tool-based training in implementing SRL strategies.

Finally, three selected articles examined the adoption of SRL strategies based on individual differences. Bruso et al. (2020) investigated the individual differences based on Big 5 personality trait and their respective SRL strategies pattern. Kim et al. (2018) and van Harsel et al. (2022) examined the SRL strategies of students with various learning patterns.

Research outcomes

In this review, the research outcomes are discussed by classification according to the research purpose. Among the eight publications that studied the effect of SRL strategies on students' learning performance, four of them emphasized the crucial role of SRL strategies on academic achievement. The authors of the articles stressed that students who adopt a greater level of SRL strategies achieved higher academic performance (Ejubovic & Puska, 2019; Hwang et al.; 2021; Leite et al.; 2022, Rienties et al., 2019). Self-regulated students were active learners and looked for information relevant and conducive to their learning. These students applied various learning strategies such as highlighting, underlining, and note-taking that helped them to select the critical information to process and retain in their memory. The cognitive self-regulated students also actively explained ideas and participated in the question-and-answering section in classes (Barak et al. 2016). In addition, these students had good organizational strategies and critical thinking skills that enabled them to perform better in their academic tasks. Thus, these students had abilities to achieve higher academic performance in mathematics, which was taught via the online mode.

Hwang et al. (2021), Yahya et al. (2021), Hidajat (2022), and Ejubovic and Puska (2019) indicated that the implementation of effective SRL strategies had positive and significant effects on students' affective domain. For instance, Hidajat (2022) highlighted that high school students demonstrated increased creativity in solving mathematics problems in the SRL learning environment. Similarly, students were reported to have higher rates of learning satisfaction in the SRL learning environment (Ejubovic & Puska, 2019). The affective domain in SRL is believed to influence students emotionally. Affective learning is required for the successful acquisition of knowledge in the classroom and involves the feelings that arise during learning that influence a student's emotional state. This emotional state is believed to influence students' learning progress (Tyng et al., 2017). In the mathematics online learning environment, Hidajat (2022) and Ejubovic and Puska (2019) indicated that adopting the SRL strategy increased the creativity and satisfaction level of the students. Thus, students form a positive attitude towards learning mathematics that significantly influences their academic achievement.

Dai et al. (2022), Hwang et al. (2021), and Yahya et al. (2021) concluded that the implementation of SRL strategies resulted in learners having better learning motivation. Students in an online SRL environment could continue to work diligently because they believed they could make further, adequate progress (Tzeng & Nieh, 2015). These students enjoyed performing the given task and valued the obtained result. Thus, they were more motivated to execute the task in an online SRL learning environment. Motivation was an important learning aspect of learning mathematics, as students found mathematics to be a challenging subject. Mathematics students who engage in SRL online learning environment could improve their motivation level and perform better in mathematics.

Dunn (2014) and Yahya et al. (2021) highlighted the significant effect of SRL strategies on behavioral outcomes. The authors concluded that students in the SRL learning environment demonstrated higher learning engagement, greater class participation, and more passive procrastination. The behavior learning aspect is considered one of the crucial learning aspects in the SRL online learning environment as it can ensure the students achieve their learning goals. In the mathematics online

learning environment, the behavior learning aspect is one of the critical elements that can determine students' learning performance. Students' learning behavior would give a clear picture to the instructors about their understanding of the subject. Thus, based on students learning behavior, the instructors could make some valuable changes to increase students' learning engagement in classrooms and find ways to implement effective SRL. Kizilcec et al. (2017) found that students who report a higher degree of engagement in the SRL online learning environment liked to revisit the learning materials several times. This enabled them to understand the course material and actively participate in the classroom and avoid the attitude of delaying a task.

Furthermore, three publications focused on exploring the factors that contribute to the SRL strategies adoption. These three discussed factors such as social networking or social media use and teaching presence. For example, Yu et al. (2020) indicated that larger connection sizes or the number of connections and higher ability to establish relationships online influenced effective SRL implementation. Similarly, Chen et al. (2021) concluded that social media use, such as frequency of use, contributed positively to SRL strategies. In addition, Zhang, Zou et al. (2022) stated that teaching presence factors, such as clear guidelines on the course material, could influence an individual's SRL strategies and consequently affect their learning performance.

All three articles that determined the effectiveness of training on SRL implementation concluded that training programs effectively improve the adoption of SRL among students. For instance, Bellhauser et al. (2022) reported that web-based self-regulation training significantly improved students' SRL knowledge and self-reported SRL behavior. Similarly, Cueli et al. (2017) highlighted that training via hypermedia tools increased students' awareness of adequate self-regulatory strategies and enabled them to recognize the absence of SRL strategies in their learning activities. In addition, Raaijmakers et al. (2018) concluded that students who obtained self-evaluation and task choice training were better at implementing SRL strategies.

Finally, three publications that examined the adoption of SRL strategies based on individual differences concluded that the implementation of SRL strategies entirely depends on students' personal characteristics. Students who are open-minded, self-disciplined, assertive, cooperative, organized, and have higher self-efficacy abilities implement SRL strategies effectively in the online learning environment. Students' personal characteristics determine the choice of activities and arrangements that need to be made to successfully regulate their online learning activities to achieve the preidentified goals. In addition, these students could develop strong survival skills to confront adverse situations during their learning process. For example, Bruso et al. (2020), who adopted the Big 5 personality traits, suggested that students high in openness, conscientiousness, extraversion, and agreeableness could self-regulate effectively. Students with personality trait openness used goal setting and environmental structuring regularly. Similarly, students with the personality trait of conscientiousness frequently employed goal setting, environmental structuring, and time management. Students with the personality trait of extroversion used help-seeking and self-evaluation strategies, while those with the personality trait of agreeableness demonstrated frequent use of task structuring and help-seeking. Kim et al. (2018) highlighted that students who begin learning earlier are dedicated to adopting all the SRL strategies. In addition, van Harsel et al. (2022) concluded that most students show similar characteristics when selecting tasks from the beginning to the end of a course. The students start a task with a lower complexity level and begin with an example study before completing a task in the SRL environment.

RQ3: What types of Limitations Exist in the Research?

Table 4 shows the types of limitations of the reviewed publications. We noticed that the limited study context in terms of the study site and type of respondents was the most common limitation in the 17 articles (n = 7). Next, adopting a weak study design was highlighted as one of the major limitations in the articles (n = 6). This is followed by other limitations such as formulation of the aims and objectives of the research (n = 3), limited sample size (n = 2), lack of reliable data (n = 1), and limited study time frame (n = 1). Further, 12 publications had more than one research limitation, while two selected publications did not specify the research limitation.

Table 4.
Type of limitations of the selected investigations

No	Investigation	Type of limitation
1	Hwang et al. (2021)	Not mentioned
2	Leite et al. (2022)	Adoption of study design Lack of instrument validity
3	Rienties et al. (2019)	Limited study context Implementation of the data collection method
4	Hidajat (2022)	Limited study context in terms of the study site and type of participants Implementation of the data collection method
5	Bellhäuser et al.(2022)	Adoption of study design Limited study context in terms of the study site and type of participants
6	Dai et al.(2022)	Adoption of study design Limited study context in terms of the type of respondents
7	Cueli et al. (2017)	Duration of study Sample size Formulation of the aims and objectives of the research
8	Dunn (2014)	Limited study context in terms of the type of participants Formulation of the aims and objectives of the research
9	Ejubovic & Puska (2019)	Sample size Limited study context in terms of the type of participants
10	Bruso et al. (2020)	Self-reported data.
11	Yahya et al. (2021).	Not mentioned
12	Raaijmakers et al. (2018)	Implementation of the data collection method
13	Yu et al. (2020)	Implementation of the data collection method
14	Kim et al. (2018)	Limited study context in terms of the study site and type of respondents Adoption of study design
15	Chen et al. (2021)	Adoption of study design Formulation of the aims and objectives of the research
16	Zhang, Zou et al. (2022)	Adoption of study design Limited study context in terms of the type of respondents
17	van Harsel et al. (2022)	Implementation of the data collection method Formulation of the aims and objectives of the research

LIMITATIONS

This systematic review is a description of publications from Scopus, Education Research Information Center, Science Direct, SpringerLink, and Proquest journal databases over the past nine years (2014–2022). First, this review only examined the articles from these specified databases; therefore, not all the existing articles on the issue were included. Second, we examined the articles published in English and did not include articles about SRL in mathematics online learning environments published in other languages. Third, we focused on only peer-reviewed journal articles to analyze scientifically sound studies.

CONCLUSION

This systematic review provides an overview of the current research on SRL in mathematics online learning environments regarding research approaches, purposes, outcomes, and limitations. It explains the development and trends in research related to SRL in mathematics online learning environments over the past nine years. A total of 17 articles were analyzed.

First, a general finding about the research approach adopted in this line of research was investigated through RQ1. Most of the studies were conducted in North America, Asia, Europe, and Oceania, but research has yet to be undertaken in the Middle East. Research from other parts of the world would enrich the data and provide meaningful interpretations based on the respondents' identities.

The findings also revealed that the reviewed articles included a large variety of study samples from middle school to university levels. The majority (n = 15) of the studies also adopted the quantitative method. In addition, most of the studies used self-reported (questionnaire) data. Interestingly, many articles used Learning Analytics techniques to identify the students' SRL behaviors. Learning Analytics techniques provide precise information on student activities in an online learning environment and raise the trustworthiness of the reported data (Silverajah et al., 2022). Most of the articles did not report the study duration. However, five studies were conducted within a short time of 4–10 weeks. Only, one study was conducted for 14 weeks.

The findings for RQ2 show that research on SRL in mathematics online learning environments mainly focused on investigating the effects of SRL strategies on students' learning performance. Exploring the factors influencing students to use SRL strategies in mathematics online learning environments is still in the initial stage, as only three studies investigated the factors. The factors influencing students to use SRL strategies in mathematics online learning environments should be investigated because the output from such a study will provide meaningful and key aspects to an educational institution to implement SRL strategies successfully. In addition, only three studies focused on the effectiveness of training to guide students to implement SRL strategies. These studies indicate the importance of SRL training to students. Finally, three studies investigated the differences in SRL implementation based on individual differences.

We also examined the research outcomes as they highlighted the progress made for nine years. SRL strategies have generally increased students' academic performance, motivation, and affective and behavioral outcomes. Students' mathematics achievement has increased, and they show more positive attitudes toward learning mathematics in the online learning environment. Several factors, such as social networking or social media use and teaching presence, were found to influence the success of SRL strategies in online mathematics learning environments. On top of that, training is an important key aspect that improves students' SRL strategies in the online learning environment. The implementation of SRL strategies also varies according to students' characteristics. Students who are forward thinkers successfully employed SRL strategies in mathematics online learning environments.

The most common limitations to these studies were the limited study context regarding the study site and the type of respondents. Future studies should include more study sites and more respondent categories.

Past studies have reported that SRL is of greater importance in online learning environments due to its more autonomous nature (Dabbagh & Kitsantas, 2004). In the face-to-face learning environment, instructors guide students throughout all learning phases—planning and preparation, monitoring and supporting, and providing swift feedback. In online learning, students need to take responsibility for their learning process and regulate their cognition, motivation, and behaviors to perform well. Our current review suggests that adopting SRL techniques in the mathematics online learning environment enhances students' performance, creative thinking, motivation, and learning satisfaction. In addition, it is essential to highlight that proper and adequate training sessions are necessary to develop students' SRL competence in the online learning environment to attain good academic and nonacademic results.

In summary, the evidence from the current literature suggests that SRL in mathematics online learning environment remains a topic for

increasing research in the near future. Thus, this review is valuable for researchers to understand the implementation of SRL in online learning environments in mathematics and to realize the gaps in the literature.

This systematic review discovered gaps in the research and provided research prospects on SRL strategies in mathematics online learning environments. Future studies should consider applying Learning Analytics techniques that provide room for real-time observation of students' SRL competence and learning performance. In addition, the results of this review show that many publications employed only one research method. Thus, future research should use mixed methods to capture rich data sets about SRL in mathematics online learning environments. We also recommend that future research adopt qualitative research methods such as interviews and focus groups and that the influence and effect of instructor support on the SRL strategies of mathematics students in the online learning environment be investigated.

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