STEM Education

STEM Education, 6(3): 418–438
DOI: 10.3934/steme.2026018
Received: 14 November 2025
Revised: 14 March 2026
Accepted: 27 March 2026
Published: 13 April 2026

https://www.aimspress.com/journal/steme

Research article

Enhancing online mathematics learning through self-regulated and peer-support strategies

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Academic Editor: Zlatko Jovanoski

Abstract: This study examined the impact of integrating self-regulated learning strategies, including self-evaluation, goal setting, and peer-support strategies such as peer tutoring and collaborative problem-solving, on learners' satisfaction and academic achievement in an online mathematics environment. These strategies were introduced to address challenges faced by students learning mathematics without the physical presence of instructors, such as lack of motivation, lower achievement, and reduced interaction, which is a very critical problem and a key limitation in online learning. Quantitative data was collected. The randomized controlled trial involved a pre-test and post-test design. The sample consisted of 101 undergraduate students (both male and female), who were randomly assigned to two groups. The experimental group consisted of 57 respondents, while the control group consisted of 44 respondents. An independent sample t-test was used to analyze the two-group result. The two groups were taught using the same online learning mode for seven weeks. The experimental group received an intervention that combined self-regulated and peer-supported strategies during the online learning period. The study used a questionnaire to collect participant data during the learning period. The findings of this study show that students in the experimental group reported higher satisfaction and achievement scores. Additionally, the experimental group's results improved after receiving the intervention, which showed a better result than that of the control group. It is suggested that learning strategies are very effective. These findings provide evidence that integrating self-regulated and peer support can enhance online mathematics learning, particularly in fostering student autonomy and collaborative engagement.

Keywords: self-regulated learning, peer-support learning, online learning satisfaction, academic achievement in online mathematics

1. Introduction

In recent years, technological advancements have helped facilitate online learning as a novel learning approach [1,2]. This learning approach provides more flexibility and convenience for students. Learners can assess different types of learning materials, including course content, videos, and audio, which are the standard features of online learning platforms. These allow students to learn online without time and place limitations [3]. The online learning method can improve students' learning, make them more active, innovative, and student-centered, and provide more time and convenience for all learners [4]. Online learning refers to learning experiences that occur in synchronous or asynchronous contexts, where peers and instructors are not physically present but are accessed via the internet and a computer [5]. Some researchers have indicated that online learning course contents and materials can enhance students' learning experience [6]. Among the benefits of online learning is that learners do not need to travel long distances to interact with peers and facilitators, allowing them to gain or acquire knowledge conveniently without any time constraints [7]. This is due to the convenience and flexibility attributed to online learning. Students can interact with their peers and get instructor feedback on the online course material, videos, and audio, which can be easily accessed [8].

Despite the promises of online learning success, learners face many challenges specific to the online learning context, such as learning difficulties, lack of motivation, and engagement, which can lead to anxiety, frustration, and procrastination [9]. This might result in a high dropout rate or a lack of motivation to complete the online course [10]. Some research has identified challenges that learners face within the online learning context, including a lack of learners' desire to use online learning tools, a lack of instructors' skills, and inadequate monitoring of learners' activity [11].

Teaching and learning mathematics can be facilitated through online learning platforms, including web-based, e-learning, and mobile learning [12]. Mathematics is a core subject that many learners try to avoid due to its abstract nature; there also seems to be a phobia of learning mathematics online [13]. Teaching mathematics online requires not only instructors' content knowledge in any online learning platform but also the ability to overcome the problems that characterize the online learning environment [14]. Therefore, there is a need for all mathematics online instructors to facilitate the use of effective learning strategies in the online learning environment to avert learning difficulties [15]. Online learning satisfaction is another factor that motivates students to continue learning in an online environment [16]. Research has proposed enhancing mathematics online learning with the most appropriate learning strategies to avert many students' learning difficulties in their online mathematics problem-solving skills [17]. This can only be achieved if learners use effective learning strategies to develop problem-solving skills in mathematics during their online learning [5]. Such learning strategies, using self-regulated learning and peer-support strategies, collaboration in sharing knowledge among other peers, and instant feedback, can significantly improve learners' performance in mathematical online learning [18].

Self-regulated learning has been acknowledged as one of the most crucial learning strategies, comprising goal setting, self-evaluation, task-strategy, help-seeking, time management, and environmental structuring. Students are required to develop such strategies in order to foster and maintain their online learning [19]. The dynamic nature of learners' interaction with the learning environment is reflected in the constructs of SRL behavior when dealing with tasks [20]. Self-regulated learning encompasses learners' metacognition, motivational practices, behavioral strategies, and active learning approaches during the study process [21].

Numerous studies have indicated that self-regulated learners are active participants and possess specific skills, such as monitoring their learning process, goals, and tasks [22]. SRL has also been shown to enhance students' online academic achievements [23]. In addition, when learners use peer-support learning strategies during online mathematics learning, they can collaborate and fine-tune their understanding of learning difficulties [14]. Peer-support learning strategies, such as peer tutoring, peer feedback, collaborative problem-solving, and mutual interaction, enable learners to work together and improve their understanding of learning difficulties [24]. Peer learning can be defined as a learning process in which peers of the same social group assist each other to attain learning goals, while simultaneously enhancing their own understanding [25]. Combining these two learning strategies, SRL and PLS, in online mathematics instruction can positively impact students' metacognition [26]. However, learning mathematics is challenging for all students, as they often become frustrated due to its abstract nature [27]. Effective learning strategies are therefore essential; without them, student motivation will be low, and learning outcomes will be poor [28].

Consequently, it is crucial to design online mathematics teaching and learning activities that incorporate effective strategies, such as SRL and peer support, to stimulate students' problem-solving skills in online environments [1]. These two distinctive learning strategies can enhance learning outcomes by assisting students in integrating knowledge and applying that knowledge when solving online mathematics problems. Furthermore, as the number of learners in online environments continues to grow, learning strategies such as peer learning and self-regulated learning have gained prominence in mitigating the social isolation often associated with online learning [29].

2. Literature review

2.1. Learning mathematics online

Research in mathematics has shown the importance of using learning strategies for teaching and learning in an online learning environment to enhance students' comprehension [30]. To better understand the teaching and learning of mathematics online, effective learning strategies and the use of technology can help teachers and students address arising problems [13]. Some research has indicated that learning mathematics online is a challenging task for learners due to its complex nature, namely resulting in a lack of engagement and motivation [31]. This problem may arise from students' lack of self-confidence, limited physical interaction, inadequate problem-solving skills, and difficulties with online class management, all of which are associated with learning mathematics online [32]. Online learners of mathematics may quickly develop negative feelings that lead to anxiety and depression due to a lack of interaction between students and teachers or not obtaining any feedback when required [17]. However, learning mathematics online has a significant positive effect across all educational stages, including self-directed learning in primary schools [33], secondary schools [34], and in University when combined with an effective learning strategy [35]. It has been demonstrated that an online mathematics environment significantly assists and motivates learners to learn mathematics effectively [27]. This online learning using a learning strategy facilitates and helps learners of mathematics improve their problem-solving skills and higher-order thinking through the use of virtual instructors, allowing learners to engage interactively with mathematical tasks [36]. For online mathematical learning to be effective, it must be integrated with learning strategies such as SRL and PSL. This research highlights the importance of a learning strategy in online mathematics, leading to a more effective learning environment. This present research provides valuable insight into self-regulated learning and peer-support learning and into how learning supported by an effective learning strategy can significantly enhance students' learning outcomes and learners' success in online mathematics education [11].

2.2. Self-regulated learning and online mathematics

Past literature has widely acknowledged that learners' ability to self-regulate their learning is crucial in online mathematics. This involves goal setting, self-evaluation, environmental structuring, and help-seeking. Such skills enhance students' self-centeredness, support undergraduate students' online learning in mathematics, and improve learning outcomes [37]. SRL can be described as the learners' ability to control their learning environment in order to achieve a learning goal [22]. This is supported by extensive research over the past decade highlighting the importance of SRL in education [38]. The use of learning strategies has shown promising outcomes for mathematics students in online environments and has become crucial for learners. These strategies enhance their self-concept, improve problem-solving skills, and encourage their participation in online learning environments [39]. This approach is critical in the implementation of online courses, including mathematics learning [40]. In addition, there is a need for learners to adopt effective learning approaches that increase satisfaction and academic achievement [37]. Such approaches can positively change learners' attitudes toward online mathematics learning and deepen their understanding of the subject [41]. Research also indicates that students' achievement and satisfaction in online learning is a driving force of their willingness to continue learning mathematics online [42]. Additionally, peer-support learning and collaboration have been identified as significant factors in enhancing learners' SRL, leading to improved learning outcomes [43].

2.3. Peer-support learning and online mathematics

Peer-support learning, which includes peer tutoring, collaboration, and mutual interaction, is essential for learning and developing learners' metacognition during online learning [44]. When learning mathematics, seeking assistance and collaborating with peers are instrumental in improving learners' engagement with both the material and the online environment [18]. Peer-support learning involves a group of peers from similar social backgrounds working together to collaborate, without relying on expert or professional teachers, to achieve common goals and share knowledge [45]. It can also be described as the sharing of knowledge, ideas, concepts, and experiences among peers [46]. This approach has proven to be an effective method for improving students' academic achievement and learning in online mathematics [47].

Peer motivation can help reduce the stress and anxiety associated with online learning [48]. Moreover, it fosters collaborative and interactive learning, leading to improved learning outcomes [49], supports learners' metacognition and judgment during online mathematics learning [50], and enhances students' critical thinking skills when interacting with one another during virtual learning [51]. These learning methods facilitate peer collaboration and improve peer-to-peer tutoring, reducing instructors' workload [25]. However, certain factors, such as negative attitudes, culture, and students' lack of experience or confidence, can hinder the effectiveness of peer learning in online mathematics [14]. In some cases, peers may act as competitors, which can negatively affect performance [46,52]. Nevertheless, integrating self-regulated learning with peer-support strategies can significantly increase learning achievement and satisfaction in online mathematics [53].

2.4. Online learning satisfaction

Learners' satisfaction with online mathematics learning has become an important area of investigation, given its critical role in student motivation and success in higher education [20]. Learners' satisfaction generally determines the effectiveness of any e-learning environment [54], predicting the quality of online learning environments, and making it essential for higher educational institutions to assess the level of student learning [55]. Online learning satisfaction is a complex concept that involves several dimensions, including learners' participation, communication, workload, flexibility, teachers' pedagogical skills, feedback, and technological support [56]. Another critical factor in the online learning environment is learners' engagement. Integrating various tools to engage learners and provide timely positive feedback is crucial to increasing learners' satisfaction and achievement [57]. Research has shown that learning satisfaction is crucial in enhancing learners' engagement and promoting students' learning motivation [16]. For example, learners' engagement in peer interaction and communication can be improved through online class discussion forums, peer review, message boards, blogs, and chat rooms, enhancing social learning interactions among students [58]. Effective learning strategies further enable learners to plan, monitor, and organize their activities during the learning process [59].

The primary focus of this research is to address existing gaps by critically examining self-regulated learning and peer-support strategies, particularly their impact on learning processes and outcomes in linear algebra. The study also aims to provide practical implications for educators to enhance learners' academic achievement in online mathematics.

2.5. The present study

This research employs an experimental design using a randomized controlled trial (RCT), in which participants are randomly assigned to either the experimental or the control groups in an online linear algebra learning environment. This study investigates the effects of integrating two learning strategies, self-regulated learning and peer-support learning, on academic achievement and satisfaction. Two research questions (RQs) were formulated based on literature findings: (RQ 1) Does the use of self-regulated learning and peer-support learning interventions in linear algebra lead to higher academic achievement in the experimental group compared to the control group? (RQ 2) Does the use of self-regulated learning and peer-support learning in linear algebra increase students' learning satisfaction in the experimental group, in contrast with the non-intervention group (control group)?

The study aims to test the following specific hypotheses based on the research questions:

H_{01}. There is no significant difference in learning achievement between the experimental and control groups at the pre-test.

H_{02}. There is no significant difference in learning linear algebra between the experimental and control groups at the post-test.

H_{03}. There is no significant difference in learning satisfaction between the experimental and control groups.

2.6. Research framework

Following a review of the existing literature, the conceptual framework for the research was designed, as illustrated in Figure 1 below. The conceptual framework consists of self-regulated learning strategies, peer learning as independent variables, and learning satisfaction and achievement as dependent variables.

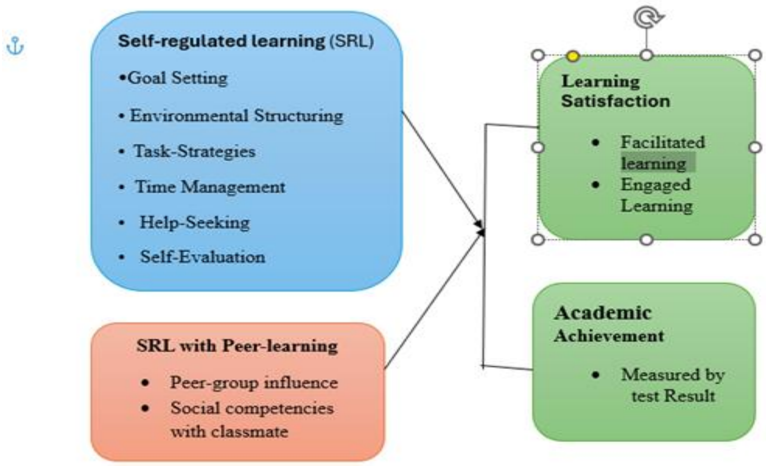

Figure 1. The conceptual framework of the study.

3. Methodology

3.1. Experimental research design

All students provided written informed consent before participating in the experimental study, and the research received approval from the relevant university authorities. The university's ethical committees approved all study procedures and the data collection method.

3.2. Participants

In this study, the participants were undergraduate students at the University Putra Malaysia, Malaysia, in the Department of Mathematics and Statistics. The sample consisted of 101 undergraduate students (both male and female), with an average age ranging from 17 to 20. A randomized controlled trial (RCT) was used. The two classes were randomly assigned to two groups. The study participants were randomly assigned to experimental and control groups, and participants and experimenters were blind to the assignment of participants. This helps to avoid bias and extraneous variables. The experimental group comprised 57 students, and the control group comprised 44 students. Both classes were taught using the same learning mode (online learning). The experimental group received an intervention, while the control group did not. The two classes were scheduled to use the same learning materials, learning content outline, and the same learning time; each class was taught for two hours. Two instructors with the same experience in teaching linear algebra taught the two classes. The two instructors were carefully observed by the researcher during the teaching activity to avoid any instructor effects on any group.

3.3. Experimental procedure

Figure 2 illustrates the 7-week experiment. A longer period of time might likely affect the study participants during the experimental process. This study agreed with the rules and guidelines of Universiti Putra Malaysia and the Department of Mathematics and Statistics; being conducted over seven weeks, this study taught students the topics of linear algebra.

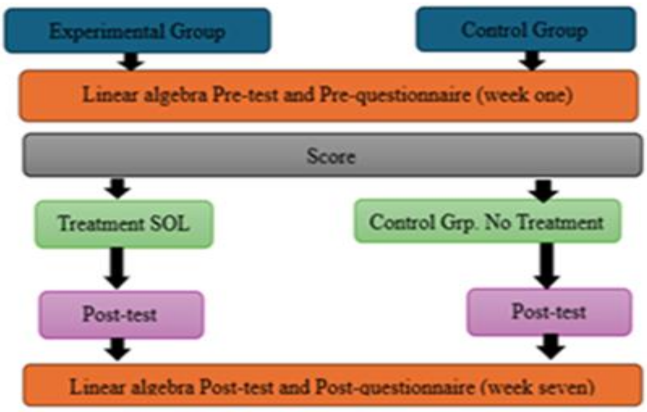

Figure 2. Experimental process of learning activities.

Students in the experimental and control groups used the same online learning mode, learning material, and online notes. The experimental group received the learning intervention, whereas the control group received no intervention during the learning of linear algebra.

After the students completed this 7-week program, they all participated in a post-test on linear algebra and filled out a post-questionnaire on SRL strategies, peer-support learning, and satisfaction with online learning.

3.4. Measurement instrument

The study employed a set of measurement instruments encompassing self-regulated learning strategies, peer learning, and online learning satisfaction.

The linear algebra test items for both the pre-test and post-test were prepared by two experienced lecturers who have taught the subject for many years. The scoring criteria were also designed and validated by two experienced lecturers to ensure the validity of the written test questions. The pre-test aimed to assess the students' prior knowledge of linear algebra in both the experimental and control groups. The pre-test consisted of six open-ended questions. We used SPSS to analyze the reliability of the pre-test questions. The pre-test Cronbach alpha value was 0.75, showing an acceptable internal consistency for the pre-test questions. The post-test questions were also analyzed using SPSS for reliability. Cronbach’s alpha value was 0.94, indicating an acceptable level of internal consistency for the post-test questions. After seven weeks of the experiment, a post-test written test was administered to the experimental and control groups, again with six open-ended questions. An instructor-developed rubric was designed to score students' performance. The maximum score for both the pre-test and post-test was 30 marks, which served as a measure of students’ knowledge of linear algebra.

3.4.1. Online self-regulated learning questionnaire

Barnard et al. (2009) developed a 27-item self-regulated learning strategies questionnaire [60] on a five-point Likert scale, ranging from 1 to 5 (strongly disagree, disagree, somehow agree, agree, and strongly agree). The items in the questionnaire consist of goal setting (6 items), environmental structuring (4 items), task strategy (4 items), time management (4 items), help-seeking (5 items), and self-evaluation (5 items). The questionnaire had a Cronbach's alpha value of 0.87, showing good reliability in internal consistency.

3.4.2. Peer learning

The peer-learning questionnaire, developed by Gladys Uzezi and Dennis Deya [61], presents nine items; a social competence scale with peers in online learning, developed by Shen et al. [62], has five items. In total, there are 15 items, and the questionnaire has a 5-point rating scale, ranging from 1 to 5 (strongly disagree, disagree, somehow agree, agree, and strongly agree), with a Cronbach’s alpha value of 0.71. This demonstrates good reliability in internal consistency.

3.4.3. Online learning satisfaction

The online learning satisfaction questionnaire, based on the Sloan Consortium model developed by Dziuban et al. [63], consists of 16 items: nine items for facilitated learning and seven items for learning engagement. The Cronbach alpha value is 0.85, which indicates good reliability in its internal consistency. Responses were recorded on a 5-point rating scale, ranging from 1 to 5 (strongly disagree, disagree, somehow agree, agree, and strongly agree).

4. Experimental results

This study examines the impact of combining two learning strategies, SRL and PSL, on students' learning achievement in a linear algebra online learning environment. An independent sample t-test was used to analyze the results.

In addition, the effect size (Cohen’s d value) measures the magnitude of the differences between two variables or the size of the difference between groups. For the experimental and control groups, results from the pre-test and post-test were calculated. The comparison between pre-test and post-test for the experimental group showed a Cohen’s $d = 1.255$, and that for the control group had a Cohen’s $d = 0.922$. This result indicates a large effect size for the sample. All research questions were at a significant level (α) = 0.05 with a 95% confidence interval, which allows a deeper understanding of the entire data. The Levene’s test for homogeneity of variance for the pre-test of the two groups clearly confirms homogeneity of variances (P = 0.086 > 0.05). For the post-test, Levene's test showed equal variances between both groups for learning achievement (P = 0.332 > 0.5). For learning satisfaction, Levene's test clearly shows homogeneity of variances between the two groups (P = 0.788 > 0.05).

4.1. Learning achievement of linear algebra

The independent sample t-test on the pre-test scores shows that the experimental group students have a mean value of *M* = 16.07, while the control group has a mean value of *M* = 16.02 ($t = 0.046, df = 99, p = 0.963 > 0.05$). This shows that both groups had equivalent knowledge, as indicated by their test scores at the beginning of the experiment.

Table 1. T-test result of learning achievement for the experimental and control groups' pre-test.

Test	Groups	N	Mean	SD	t	df	Sig
Pre-test	Experimental	57	16.07	4.85	0.046	99	0.963
	Control	44	16.02	5.45			

The post-test results show differences between the experimental group's mean score value ($M = 24.04, SD = 3.97$) and the control group's mean value ($M = 20.09, SD = 7.26$), ($t = 3.481, df = 99, p = 0.007 < 0.05$). The post-test results reveal that the SRL and PSL intervention was highly effective during the learning process, with a significant difference between the two groups, as shown in Table 2. The test scores of the experimental group improved after receiving treatment to a greater extent than those of the control group.

Table 2. T-test result of learning achievement for the experimental and control groups' post-test.

Test	Groups	N	Mean	SD	t	df	Sig
Post-test	Experimental	57	24.04	3.97	3.481	99	0.007
	Control	44	20.09	7.26			

4.2. Learning satisfaction analysis

An independent sample T-test was used to analyze the difference in learning satisfaction between the two groups. The mean scores were *M* = 195.01 for the experimental group and *M* = 160.36 for the control group. The experimental group's mean score was ($M = 195.01, SD = 22.72$), while the control group had a mean score of ($M = 160.36, SD = 78.65$), ($t = 10.29, df = 99, p = 0.001 < 0.05$). These results demonstrate that the experimental group was more satisfied with learning linear algebra during the learning process.

Table 3. T-test result of learning satisfaction.

Groups	N	Mean	SD	t	df	Sig
Experimental	57	195.01	22.72	010.29	99	0.001
Control	44	160.36	78.65			

5. Discussion and conclusions

In recent years, online learning has become increasingly popular. Many studies have shown that online learning environments are beneficial for students, particularly for self-directed learning. However, there is a pressing need to integrate practical learning strategies to enhance the learning experience in these environments [1,37]. Many researchers believe that SRL is an essential strategy for guiding students' learning when engaging in online learning environments during their learning activities [64,65]. Additionally, when learners refer to their peers' self-regulated learning methods, they can make more informed decisions about goal setting and the selection of appropriate learning strategies [66].

Research has shown that when low-achieving students employ self-regulated learning strategies effectively during their learning process, they become high achievers and more satisfied due to the impact of self-regulated learning on their cognition [26]. This research aligns with previous studies that demonstrated the impact of SRL on student achievement and satisfaction with mathematics during online learning [41,42]. Another study supporting this research indicates that self-regulated learning strategies are highly effective in enhancing learning achievement and satisfaction among mathematics students during online learning [67]. Studies have shown that effective learning strategies incorporating peer collaboration can significantly enhance peers' academic achievement and learning satisfaction [53].

Moreover, peer-support learning is another crucial factor in developing students' critical thinking skills and motivation through collaborative learning within a social group [51]. Self-regulated learning, when integrated with a peer-supporting learning process, effectively reduces the burden on instructors and enables learners to adopt the instructor's role during learning [29]. Research has shown that both self-regulated learning and peer support learning are highly effective in fostering collaborative learning in online environments [68]. The findings indicate that integrating SRL with PSL benefits learners by enhancing their cognitive and metacognitive learning abilities, encouraging more active learning, and granting them greater control over their learning process in any learning environment [52]. Another study, in line with this present study, indicates that peer learning and self-regulation are crucial combined learning strategies that improve learners' achievement in any learning context [69].

Peer learners are empowered to be both facilitators of their learning and active learners during the learning process [70]. When peers interact in a collaborative learning environment, they can better understand their learning and improve their learning experience [49]. In addition, it has been revealed that peers improve each other's critical thinking, ideas, and motivation, enhancing their ability to address learning challenges [25]. Therefore, this research incorporates two learning strategies: a self-regulated learning strategy and a peer-support learning strategy to help and guide students to learn effectively during their learning process. This results in learners referring to their peers' SRL methods and learning goals in online learning environments.

This study randomly assigned students to two different groups. The experimental group incorporated two learning strategies, self-regulated learning and peer-support learning, into their online learning. In contrast, the control group students were taught in the same online learning environment without any additional strategies. The mean score of learning achievement of students in the experimental group, who applied these two distinct learning strategies, was significantly higher than that of the control group.

Learning satisfaction, analyzed using an independent sample t-test, was higher for students in the experimental group. These results indicate that support through SRL and PSL interventions results in higher learning satisfaction. This research is consistent with previous studies that have found higher satisfaction for learners who employ effective learning strategies during their learning process [71,72] and studies that demonstrated the effectiveness of self-regulated learning strategies combined with peer-support learning in online mathematics, improving students' satisfaction with the learning content [55]. Future studies should consider learners' satisfaction with different types of online learning environments over extended periods and use other research designs, such as mixed methods, correlational, or design approaches.

In conclusion, this study identified the effectiveness of incorporating two learning strategies, self-regulated learning and peer-support learning, during online learning, by comparing learning achievement and satisfaction of two different learning groups using the same online learning environment. Future research can benefit from the suggestions made below.

5.1. Contributions

This study's findings indicate that the intervention was effective primarily due to the integration of self-regulated learning and peer-support learning, which can improve online mathematics learning, particularly in fostering students' autonomy and collaborative learning engagement. This study's findings offer practical implications regarding the role of self-regulated learning and peer support in enhancing students' learning performance, particularly for novice learners. When designed with clear goals, directives, structure, and mechanisms for peer feedback, such learning environments can increase students' performance and achievement in online mathematics. Self-regulated learning and peer-support learning in online mathematics courses can be operationalized by turning abstract, independent studies into structured interactions with socially shared regulation. These provide more measurable actions that foster metacognition and collaboration among learners. In an online mathematics environment, these can be achieved through specific tools, such as digital whiteboards, interactive forums, and learning management systems. This requires students to watch videos, spend time on a specific topic, share their group work, discuss different methods, and share problem-solving skills. These approaches help to create an effective learning environment that enhances learning outcomes. Finally, this research contributes to the existing knowledge in the literature on learning strategies, interventions in self-regulated learning, and peer-support learning by providing further evidence of the impact of this intervention approach on improving online mathematics.

5.2. Limitation

This study used self-reported measures to collect data, which might lead to bias when answering the questionnaire; some low-achieving students might over-rate their achievement [73].

Future studies can utilize data mining and log data to investigate students' activities in the online learning environment, with a focus on self-regulated learning and peer support in collaborative learning.

To understand the effects of incorporating self-regulated learning strategies with peer-support learning strategies in online learning environments, future studies should conduct long-term experiments to observe changes in students' activities using the same online learning platform. Further studies can also utilize larger sample sizes, which can significantly increase the power of the evidence.

This present study did not consider gender and age. Further studies can observe differences in gender and age of the different participants and their background when using learning strategies in online learning environments.

To improve the data collection process, future studies can use other means of assessment, such as observations and interviews; these could be used to triangulate the data.

This present study is limited to mathematics learning; future studies could be conducted among students from other areas to further strengthen the research.

To fully understand the effect of SRL and PSL in online learning environments, future research should conduct long-term experimental studies on various online learning platforms to observe changes in learners' satisfaction when engaging in different online learning environments. This study made use of the quantitative design method. Future studies should attempt mixed-methods approaches, longitudinal designs, action research designs, and exploratory designs.

Table 4. Example pre-test and post-test questions.

Questions
1. a) Give the definition of **subspace.** b) Let $W = \{ax^2 + 3x - 2 \mid a \in \mathbb{R}\}$, and $V = P_2$. Determine **whether** the given set W is a **subspace** of the vector space V.
2. Let $\bar{u}$ and $\bar{v}$ in vector space $\mathbb{R}^2$. Prove that $span(\bar{u}, \bar{v}) = \{\bar{w} = k_1\bar{u} + k_2\bar{v} \mid k_1, k_2 \in \mathbb{R}\}$ is **subspace** of $\mathbb{R}^2$.
3. Let $\bar{u}, \bar{v}$ and $\bar{w}$ be vectors such that $\langle \bar{u}, \bar{v} \rangle = 3$, $\langle \bar{v}, \bar{w} \rangle = -2$, $\langle \bar{u}, \bar{w} \rangle = 7$, $\|\bar{u}\| = 2$, $\|\bar{v}\| = 5$ and $\|\bar{w}\| = 8$. Calculate $\langle 2\bar{u} + \bar{v}, \bar{v} - \bar{w} \rangle$.
4. Find a basis for the Null space of the following system: $x_1 - 3x_2 + x_3 + x_4 = 0,$ $-8x_2 + 2x_3 = 0,$ $10x_2 - 5x_3 - 5x_4 = 0.$

Table 5. Activities of the experimental group during the intervention.

Week	Days	Intervention	Lesson
Week 1	Same days	Experimental group (self-regulated learning and peer support learning)	Pre-test for linear algebra problem solving, self-regulated learning, satisfaction with online learning
Week 1	Same days	Control group (no intervention)	Pre-test for linear algebra problem solving, self-regulated learning, satisfaction with online learning
Week 2	Tuesday Thursday	Experimental group (self-regulated learning and peer support learning); students learn from each other through collaborative learning, shared discussion, peer to peer tutoring, and assignment activities that encourage goal setting, task strategy, self-monitoring, help-seeking, and time management	Victor space associated with matrices Null space

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Week 2	Tuesday Thursday	Control group (no intervention)	Victor space associated with matrices Null space
Week 3	Tuesday Thursday	Experimental group (self-regulated learning and peer support learning); students learn from each other through collaborative learning, shared discussion, peer to peer tutoring, and assignment activities that encourage goal setting, task strategy, self-monitoring, help-seeking, and time management	Row space and column space
Week 3	Tuesday Thursday	Control group (no intervention)	Row space and column space
Week 4	Tuesday Thursday	Experimental group (self-regulated learning and peer support learning); students learn from each other through collaborative learning, shared discussion, peer to peer tutoring, and assignment activities that encourage goal setting, task strategy, self-monitoring, help-seeking, and time management	Rank and nullity
Week 4	Tuesday Thursday	Control group (no intervention)	Rank and nullity
Week 5	Tuesday Thursday	Experimental group (self-regulated learning and peer support learning); students learn from each other through collaborative learning, shared discussion, peer to peer tutoring, and assignment activities that encourage goal setting, task strategy, self-monitoring, help-seeking, and time management	Orthonormal bases and Gram–Schmidt process; orthogonal matrices

Continued on next page

Week 5	Tuesday Thursday	Control group (no intervention)	Orthonormal bases and Gram–Schmidt process; orthogonal matrices
Week 6	Tuesday Thursday	Self-regulated learning and peer support learning; students learn from each other through collaborative learning, shared discussion, peer to peer tutoring, and assignment activities that encourage goal setting, task strategy, self-monitoring, help-seeking, and time management	Orthogonal matrices; change of bases
Week 6	Tuesday Thursday	Control group (no intervention)	Orthogonal matrices; change of bases
Week 7	Tuesday Thursday	Experimental group (self-regulated learning and peer support learning); students learn from each other through collaborative learning, shared discussion, peer to peer tutoring, and assignment activities that encourage goal setting, task strategy, self-monitoring, help-seeking, and time management	Eigenvalues and eigenvectors; post-test for linear algebra problem solving, self-regulated learning, satisfaction with online learning
Week 7	Tuesday Thursday	Control group (no intervention)	Eigenvalues and eigenvectors; post-test for linear algebra problem solving, self-regulated learning, satisfaction with online learning

Author contributions

Ahmed Alhassan Abdulrahman: writing, original draft, editing and data analysis. Sharifah Kartini Said Hussain: conceptualization, project administration. Malathi Letchumanan: methodology and execution. Faridah Yunos: Design and data collection. Sharifah Osman: writing review, proofreading and interpretation of the study.

Use of generative AI tools declaration

In this present study, we declare that we did not use any Artificial Intelligent (AI) tools in the creation of this article.

Acknowledgement

This work was funded by Universiti Putra Malaysia, through the Putra research Grant GP-IPM/2022/9732000.

Conflict of interest

All authors declare No conflict of interest in the article.

Ethics declaration

This research involves human subjects. Ethical approval for all the experimental procedures and protocol was granted by the Universiti Putra Malaysia, Malaysia. Reference number JKEUPM-2024-266.

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