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Research article

Understanding the interplay of peer learning, self-regulation, and gender in shaping learning engagement in online mathematics classes

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Abstract: Learning mathematics in an online environment can be challenging, as it requires an effective learning strategy. Self-regulated learning (SRL) can play a crucial role in helping students achieve success in mathematics within an online learning environment. SRL studies also indicate that support characteristics, such as peer learning, increase and maintain students' online academic behaviors and engagement. Additionally, gender is also perceived to moderate the relationship between peer learning and SRL. Thus, this study aimed to identify the effects of peer learning on learning engagement, the mediating roles of SRL, and the moderating effect of gender on the relationship between peer learning and SRL in the mathematics online learning environment. A total of 112 mathematics students from two public universities in Malaysia participated in this study. Descriptive analysis and partial least squares structural equation modeling (PLS-SEM) were used to analyze the data. The results revealed that peer learning had no significant effect on learning engagement. However, online SRL (OSRL) has a direct influence on the students' learning engagement. The results also suggest that peer learning is a key antecedent of OSRL, and OSRL fully mediates the relationship between peer learning and learning engagement. Additionally, it was found that gender did not moderate the relationship between peer learning and SRL. This study could provide practical guidance for scholars on the role of peer learning, SRL, and gender in determining higher learning institution students' learning engagement in online mathematics classrooms.

Keywords: self-regulated learning, peer learning, learning engagement, university, mathematics, gender

1. Introduction

Higher learning institutions around the world prefer to use online learning even after the lockdown. This different learning environment forced students to quickly adapt to new learning styles. An online learning environment (OLE) has been reported to influence students' learning performances [1]. For instance, a recent study reported that learning online or from home can lead to academic decline among students [2]. As online learning has become a regular teaching method, students may have fewer opportunities to interact with their facilitators and peers than in traditional physical learning environments [3]. This may result in a significant decline in students' learning effectiveness and engagement.

Many higher-learning institutions consider teaching and learning mathematics courses challenging and report that students face significant issues in mastering their mathematics skills [4]. Accordingly, educators strive to address learning difficulties and any ambiguities that students may encounter, thereby helping them learn mathematics effectively [5]. However, empirical research reveals that students quickly become bored and irritated while facing difficulties in learning mathematics [4,6]. Furthermore, teaching mathematics online is challenging as it requires suitable supporting tools, effective time allocation, and a well-defined teaching and learning strategy [7]. In addition, students are not always skillful in handling their learning activities effectively when using online learning platforms [8]. In an OLE, students have more autonomy; this requires that students self-regulate their learning activities. Self-regulated learning (SRL) is believed to enhance students' learning engagement when they face more complex learning activities and environments.

SRL is an individual's ability to plan, manage, and observe the learning process to attain predetermined learning goals [9]. SRL involves the application of cognitive, metacognitive, and resource management approaches to manage the behavioral and motivational learning process [10]. Feedback is considered one of the essential ingredients for SRL behaviour. Receiving and evaluating feedback enables students to achieve their desired learning goals [11]. SRL is a learning process that increases students' motivation to promote learning engagement [12]. Learning engagement is a "constructive, enthusiastic, willing, emotionally positive, and cognitively focused participation with learning activities" [13]. Learning engagement is considered a significant measure for determining students' academic performance in online education [14]. Student engagement could be categorized into behavioral, emotional, and cognitive engagement [15]. Behavioral engagement involves students' participation in academic tasks [15]. Emotional engagement is defined as students' attitude and perception toward academic tasks [16,17]. Meanwhile, cognitive engagement highlights students' involvement in all academic processes, characterized by a positive psychological status [18]. Students who employ SRL strategies have established learning goals and adopt appropriate techniques to achieve better academic results and remain engaged with their learning activities [19].

SRL studies also indicate that support characteristics develop students' online academic behaviors [9]. Similarly, past research has reported on the significance of a supportive environment, including peers, in developing SRL [20,21] and learning engagement [22]. Peer learning is a process where peers assist and facilitate the learning of other students. Peer learning occurs among students from similar educational or social backgrounds who collaborate to enhance one another's learning [23]. Peer learning assists students in acquiring the necessary SRL skills in online classes [19] and offers more opportunities for peers to interact with each other, which leads to help-seeking behavior. This subsequently contributes to the practice of self-regulatory skills such as self-reflection [19]. Interactions between peers are also believed to promote online learning engagement. For instance, participating in formal and informal collaborative learning facilitates students to brainstorm and actively engage in the learning process, thereby remaining engaged in their learning activities [24].

The role of gender has also been examined as a potential moderating factor in the relationship between peer learning and SRL. Exploring gender differences in this context may provide valuable insights for instructors in designing instructional materials and delivery modes that are responsive to the needs of diverse learners [25]. For example, Cui [26] reported a significant moderating effect of gender on the relationship between collaborative learning and SRL, highlighting differential patterns for male and female students. Such findings are useful for both instructors and policymakers in identifying instructional designs that maximize learning benefits across gender groups. In contrast, Almasri [25] found that male students tended to participate more actively in online discussions in STEM-related courses, thereby strengthening their regulation strategies compared to their female counterparts. These inconsistent results underscore the need for further research to clarify the moderating role of gender in the link between peer learning and SRL.

Past studies have investigated many issues related to online self-regulated learning (OSRL). However, only a few have explored the relationship between mathematics higher learning institution students' self-regulation and engagement in OLE with support characteristics of peer learning [23,27] and the moderating effect of gender on the relationship between peer learning and SRL. In addition, scholars have also highlighted that the online peer-learning self-regulation technique has been considered an underutilized approach, despite claims of its significant pedagogical benefits [28,29]. Hence, this study aims to determine the effects of peer learning on learning engagement, the mediating effects of OSRL on the relationship between peer learning and learning engagement, and the moderating effect of gender on the relationship between peer learning and SRL in mathematics OLE in higher learning institutions through a partial least squares approach (PLS). The study could provide practical guidance for scholars on the role of peer learning, gender, and SRL skills in determining the learning engagement of students in higher education institutions in online mathematics classrooms.

2. Literature review and hypothesis

2.1. The relationship between peer learning and learning engagement

The biggest challenge in OLE is supporting social interaction with students to enhance learning engagement [30]. Students in this learning environment felt isolated and bored by the complexity of reaching other classmates and sustaining two-way interaction [31]. As a result, students demand more interactive group activities that promote interaction and collaboration among students to improve their online learning experience [22].

Empirical studies based on social constructivist theories have confirmed that social relationships among students or peer learning can overcome the negative effects, such as burnout, exhaustion, isolation, and boredom, experienced by students in online classes [32,33]. Online peer learning enables students to utilize social networks to connect virtually and exchange ideas and valuable information about their academic activities [34]. This helps students overcome the negative experiences they encountered in online classes. In addition, peer learning also enhances students' learning interaction and improves their potential learning skills [34]. Havnes et al. [35] reported that peer learning expands students' time management skills, motivates students to use critical thinking skills, and invokes greater expectations among students of the topics being learned.

The interaction between peers enhances students' understanding of the topic and allows giving and receiving feedback and evaluating their own learning [36]. This challenges students to apply better communication and bilateral skills. In this case, it has been reported that learning with peers increases students' self-motivation to perform and engage with their learning. Additionally, support from peers can have a profound influence on students' learning engagement. This is because peer support enhances students' confidence levels, leading to increased learning engagement [37]. Furthermore, the quality of students' peer interaction is another important criterion for developing learning engagement. Terlektsi et al. [38] highlighted that quality friendship will protect students against being rejected and bullied. This will help students study without worrying about being isolated, which in turn enhances their engagement in the learning process. Additionally, Nerantzi [39] believed that peer learning in online classes motivates students to learn consistently, leading to seamless and active engagement in learning.

Thus, we propose the following:

H_1: Peer learning impacts (a) behavioral, (b) cognitive, and (c) emotional student engagement in an OLE.

2.2. The relationship between self-regulated learning and learning engagement

Unlike traditional learning environments, where educators can assist students in regulating their learning, OLEs provide students with high autonomy and low educator presence [40]. Consequently, students' SRL abilities become a profound factor in determining academic success in an online learning environment. Empirical studies highlighted that many students struggle to self-regulate effectively in OLEs, resulting in lower learning engagement [41]. Zimmerman [9] highlighted that the complexity of the OLE may be the reason that causes students to become easily disturbed and experience difficulties with self-regulation.

Usually, self-regulated learners know how to use time and resources effectively. These students possess high self-efficacy and employ various strategies to maintain focus on their learning activities [42]. Park and Yun [16] reported that students' learning engagement (behavioral engagement) levels improved significantly when they used various motivational regulation strategies. Highly self-regulated students often find solutions to their problems by seeking help from their peers or instructors. This helps students better understand the course content and demonstrate greater engagement with their subject matter. In addition, scholars such as Al Mutawah et al. [43] and Park and Yun [16] have highlighted that students' self-regulatory practices significantly influence their engagement in the learning process.

Thus, we propose the following:

H_2: SRL impacts (a) behavioral, (b) cognitive, and (c) emotional student engagement in an OLE.

2.3. The relationship between peer learning and SRL

Previous studies have reported that students often struggle to effectively regulate their online learning activities [40,44]. In the OLE, students tend to lose focus quickly and become distracted by the large number of online resources and their nonlinear structure. In addition, difficulties in effectively receiving facilitator support have been highlighted as another crucial factor affecting students' performance and self-regulation during online classes [40].

Empirical studies reported that peer learning significantly influences SRL in online classes [19]. Peer learning provides students with a sense of immediate community, where they interact with one another for help-seeking and help-giving, receiving swift responses and feedback from peers [45]. This bidirectional relationship internalizes their task strategies. This subsequently increases their self-regulated learning abilities [19]. In addition, in a peer learning environment, students usually disseminate and divide thinking responsibilities. This active task stimulates the help-seeking strategy in self-regulated learning.

Peer learning also affects students' resource management skills [46]. Students who receive high peer support often have access to numerous learning resources and effective time management skills. These students can engage more with their studies and improve their self-regulated learning skills [45].

Thus, we propose the following:

H_3: Peer learning impacts the SRL of students in an OLE.

2.4. The mediating role of SRL on the link between peer learning and (a) behavioral, (b) cognitive, and (c) emotional student engagement in an OLE

Social cognitive theorists emphasize that peer support assists students in acquiring SRL skills [47]. Students with a greater degree of SRL skills could assist students with a lower degree of SRL skills to regulate their learning process and sustain better learning engagement [19]. Similarly, students with a greater degree of SRL skills could diversify their self-regulation strategies with the support of peers to enhance their learning ability and engagement [48]. Consequently, the link between peer learning and learning engagement should be more robust for students with a higher degree of SRL skills. Therefore, this study proposes that SRL can mediate the potential relationship between peer learning and learning engagement. In this case, students' SRL skills could have a greater impact on their learning engagement in two ways: first, by a direct effect on their new improvement in learning engagement, and second, by diversifying and strengthening peer relationships, which may further contribute to their engagement.

Thus, we propose the following:

H_4: SRL mediates the relationship between peer learning and learning engagement of students in an OLE.

2.5. The moderating role of gender on the relationship between peer learning and SRL

A past study indicated that female students tend to exhibit greater confidence in online learning environments, as they are increasingly developing competence and autonomy as online learners [26]. Cui [26] reported that female students demonstrate higher self-efficacy in self-regulation compared to their male counterparts. Specifically, they demonstrate stronger abilities in planning homework, retrieving information from classes or textbooks, and actively participating in class discussions. Furthermore, female students are more likely to engage in group learning and seek peer support to enhance their understanding of course content [26]. These tendencies suggest that peer learning may play a significant role in strengthening their SRL skills. However, contrasting evidence exists in STEM disciplines, where male students have been found to participate more actively in group learning activities [25]. Given these inconsistencies between male and female students' peer learning and SRL practices in OLEs, it is crucial to examine whether gender moderates the relationship between peer learning and online SRL.

Therefore, we propose the following hypothesis:

H_5: Gender moderates the relationship between peer learning and SRL in an OLE.

The conceptual framework related to the hypotheses of this study is shown in Figure.1.

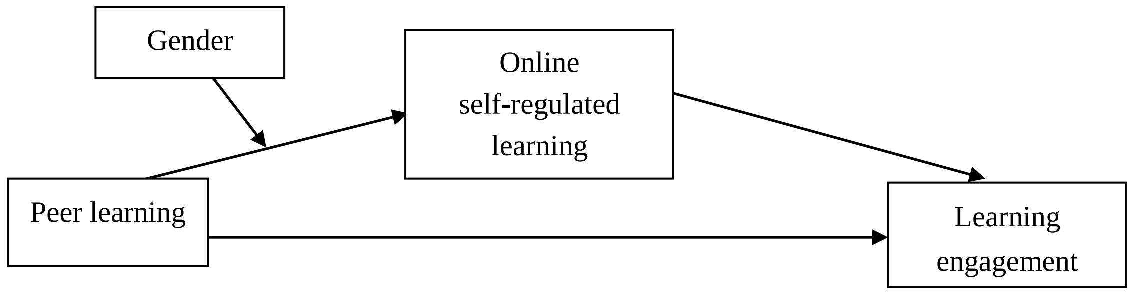

Figure 1. Conceptual model.

3. Method

3.1. Research design and study sample

The study applied a descriptive research design and a quantitative research approach. A total of 112 undergraduate students from the mathematics department, enrolled in online learning, participated in the study. For partial least squares structural equation modeling (PLS-SEM), Table 1 shows the sample sizes that should be used to get an 80% power level at different significance levels and minimum R-squared (R^2) values. The table helps to determine the appropriate sample size based on the number of arrows (indicators or items) pointing at a construct in their PLS-SEM model, significance levels, and minimum R-squared values. The findings from Table 1 indicate that a sample size of 33 (significance level of 5%, R^2 = 0.5) is required for the proposed model. This confirms that the sample size used in this research is sufficient for analysis. The respondents were from two public universities in Malaysia. The mean age of the respondents was 21.5 with a standard deviation of 0.90. There were 29.5% of males and 70.5% of females. Table 2 shows the demographic details of the participants.

Table 1. Sample size recommendation in PLS-SEM for a statistical power of 80%.

Maximum number of arrows pointing at a construct	Significance Level											
	1%				5%				10%			
	0.10	0.25	0.50	0.75	0.10	0.25	0.50	0.75	0.10	0.25	0.50	0.75
2	158	75	47	38	110	52	33	26	88	41	26	21
3	176	84	53	42	124	59	38	30	100	48	30	25
4	191	91	58	46	137	65	42	33	111	53	34	27
5	202	98	62	50	147	70	45	36	120	58	37	30
6	217	103	66	53	157	75	48	39	128	62	40	32
7	228	109	69	56	166	80	51	41	136	66	42	35
8	238	114	73	59	174	84	54	44	143	69	45	37
9	247	119	76	62	181	88	57	46	150	73	47	39
10	256	123	79	64	189	59	59	48	156	76	49	41

Source: Cohen [49]

Table 2. Respondents' demographic information.

Demographic item	**Categories**	**Frequency**	**Percentage (%)**
Gender	Male	33	29.5
	Female	79	70.5
Institution	A	80	71.4
	B	32	28.6
Semester	4	67	59.8
	5	30	26.8
	6	15	13.4

3.2. Data collection

Data for this study were collected using convenience sampling through the administration of an online questionnaire. An invitation to participate in the online questionnaire was sent to respondents after their email addresses were obtained from their respective lecturers. The respondents were allowed to withdraw their participation at any time. A total of 146 survey responses were received, of which 32 incomplete responses were excluded. As a result, the authors analyzed 112 survey responses.

3.3. Instrument

The online questionnaire had four sections. The first section gathered the respondents' demographic information, such as age, gender, name of university, and semester. The second section included a peer learning questionnaire with 10 items adopted from Uzezi and Deya [50]. The following section comprised an OSRL questionnaire (OSLQ) with 24 items adapted from Barnard et al. [51]. The fourth section included a learning engagement questionnaire with 13 items adapted from Wang et al. [52]. The questionnaire was administered with a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

3.3.1. Peer learning

The measurements for peer learning assessed students' perceptions of the support they receive from peers during online learning. The indicators in peer learning assessed the effect of peer group influence.

3.3.2. OSRL questionnaire (OSLQ)

The measurement of OSLQ was designed to assess the adoption of SRL strategies in OLEs. Six SRL strategies, namely goal-setting, environmental structuring, task strategies, time management, help-seeking, and self-evaluation, were measured to meet the study's purpose.

3.3.3. Learning engagement

The measurement of learning engagement was designed to assess the students' learning engagement level in OLEs. Three indicators of learning engagement were assessed: cognitive, behavioral, and emotional.

3.4. Data analysis

Descriptive analysis and partial least squares structural equation modeling (PLS-SEM) were used to analyze the data. PLS was used because it can maximize prediction capability and is applicable for analyzing small sample sets [53]. In addition, PLS-SEM is also considered a suitable technique for mediation testing, which is required in this study [54]. SmartPLS 4.0 was used for data analysis. At first, the validity and reliability of the measurement model were assessed. Then, the analysis of the structural model was performed.

4. Results

Prior to hypothesis testing, the measurement model was analyzed. Two items from peer influence, six items from OSRL, and three items from learning engagement were discarded because they generated low factor loadings. The other items with factor loadings higher than 0.5 were retained [55]. Composite reliability (CR) and Cronbach's alpha were used to determine the reliability of the constructs. The Cronbach's alpha value for all the constructs was higher than 0.7, the recommended value by Hair et al. [56] and Nunnally [57]. Additionally, all constructs exhibited average variance extracted (AVE) values greater than 0.50, indicating that convergent validity was achieved. Table 3 shows the loading of the items, CR, and Cronbach's alpha.

Discriminant validity of the constructs was tested using Fornell and Larcker's [55] and the Heterotrait–Monotrait (HTMT) ratio of correlations technique. Table 3 shows that the pairwise correlations between constructs were lower than the square root of AVE values (diagonal values). Additionally, the HTMT value of all the constructs was less than 0.85 [54]. Thus, discriminant validity was achieved. The overall model fit was measured using the standardized root mean square residual (SRMR). The SRMR was 0.07 (less than the recommended threshold value of 0.08 [58]).

Table 3. Descriptive and measurement assessment results.

Item	Item loadings	Cronbach's alpha	CR	AVE
Learning engagement				
LE1	0.734	0.944	0.944	0.627
LE2	0.795			
LE3	0.850			
LE4	0.891			
LE5	0.756			
LE6	0.775			
LE7	0.767			
LE8	0.861			
LE9	0.754			
LE10	0.718			
Online self-regulated learning				
OSRL1	0.757	0.949	0.947	0.503
OSRL2	0.573			
OSRL3	0.555			
OSRL4	0.642			
OSRL5	0.797			
OSRL6	0.770			
OSRL7	0.644			
OSRL8	0.840			
OSRL9	0.773			
OSRL10	0.819			
OSRL11	0.598			
OSRL12	0.634			
OSRL13	0.763			
OSRL14	0.681			
OSRL15	0.816			
OSRL16	0.690			
OSRL17	0.659			
OSRL18	0.655			
Peer learning				
PL1	0.785	0.902	0.896	0.522
PL2	0.681			
PL3	0.760			
PL4	0.793			
PL5	0.603			
PL6	0.686			
PL7	0.797			
PL8	0.648			

Table 4. Fornell-Larcker criterion results.

Factors	1	2	3
	LE	OSRL	PL
1 LE	**0.792**		
2 OSRL	0.610	**0.709**	
3 PI	0.518	0.524	**0.722**

Note: The square root of the average variance extracted is represented diagonally, and the other values represent the correlations. Key: LE, learning engagement; OSRL, online self-regulated learning; PI, peer influence.

Table 5. HTMT results.

Factors	1	2	3
	LE	OSRL	PL
1 LE			
2 OSRL	0.778		
3 PI	0.510	0.505	

Key: LE, learning engagement; OSRL, online self-regulated learning; PI, peer influence.

PLS-SEM analysis with 5000 bootstrap samples was used to test the structural relationships among the latent variables [59]. Figure 2 shows the structural model. H1 postulates that peer learning has a significant relationship with learning engagement. The results highlighted that peer learning did not significantly affect learning engagement ($\beta = 0.146$, $t = 1.158$, $p > 0.05$); hence, H1 was rejected. H2 postulates that SRL significantly predicts learning engagement. The results indicated that SRL had a significantly positive effect on learning engagement ($\beta = 0.709$, $t = 7.281$, $p < 0.01$), thereby supporting H2. In H3, the influence of peer learning on OSRL was tested. The findings demonstrated that peer learning has a significant influence on OSRL ($\beta = 0.524$, $t = 6.616$, $p < 0.01$), thereby supporting H3.

The R-squared (R^2) is the proportion of the variance in a dependent variable that is explained by an independent variable. Figure 2 shows that peer learning accounts for 41% of the variance in OSRL. Additionally, OSRL explained 63% of the variance in learning engagement. R^2 values of 0.67, 0.33, and 0.19 show substantial, moderate, and weak models, respectively [60]. According to Chin's recommendation, the predictive power of the research model of this study was moderate.

Effect sizes (f^2) were also tested. The effect size f^2 identifies the effect of exogenous latent constructs on endogenous latent constructs [61]. Effect sizes of 0.35, 0.35, 0.15, and 0.02 denote larger, medium, and small effects [62]. Table 4 shows that OSRL has a strong effect on learning engagement ($f^2 = 0.993$). Peer learning was also found to have a strong effect on OSRL ($f^2 = 0.379$). However, peer learning had a small effect on learning engagement ($f^2 = 0.042$).

The model's accuracy can be assessed using predictive relevance (Q^2). The Q^2 criteria suggest that the conceptual model is able to forecast the latent structure. In this study, Q^2 was tested using blindfolding techniques. Q^2 values greater than zero indicate that the model has predictive relevance [56]. Predictive relevance of 0.02, 0.15, and 0.35 is denoted as small, medium, and large, respectively. In this study, OSRL has a medium Q2 value of 0.21, and learning engagement also has a moderate Q^2 value of 0.19.

Mediation analysis was performed to determine the mediating role of OSRL on the link between peer learning and learning engagement. Table 5 showed that the indirect effect of peer learning → OSRL → learning engagement is significant (β = 0.372, t = 4.202, p < 0.01). Since there were no significant relationships between peer learning and learning engagement directly found in this study (β = 0.146, t = 1.158, p > 0.0.05), the indirect effect stated previously is full mediation. Furthermore, the moderation analysis revealed that gender did not significantly moderate the relationship between peer learning and SRL (β = -0.169, t = 1.803, p > 0.05). Therefore, Hypothesis 5 was not confirmed.

Additionally, the model was tested for the presence of multicollinearity to mitigate common method bias. The variance inflation factor (VIF) was used to determine multicollinearity [63]. Hair et al. [58] suggested that a VIF value exceeding 5 indicates the presence of multicollinearity. The VIF values in this study ranged from 1.000 to 1.324 (i.e., less than 5), indicating that the multicollinearity issue is absent (see Table 6).

Table 6. Structural assessment result.

Hypothesis	**Relationship**	**Std Beta**	**t-value**	**p-value**	**Decision**	**R^2**	**f^2**	**Q^2**	**VIF**
H1	PL → LE	0.146	1.158	0.247	Rejected		0.042		1.324
H2	OSRL → LE	0.709	7.281	0.000	Supported	0.63	0.993	0.19	1.324
H3	PL→ OSRL	0.524	6.616	0.000	Supported	0.41	0.379	0.21	1.000
H4	PL → OSRL → LE	0.372	4.202	0.000	Supported				
H5	Gender x PL →OSRL	-0.169,	1.803	0.071	Rejected				

Key: LE, learning engagement; OSRL, online self-regulated learning; PI, peer influence.

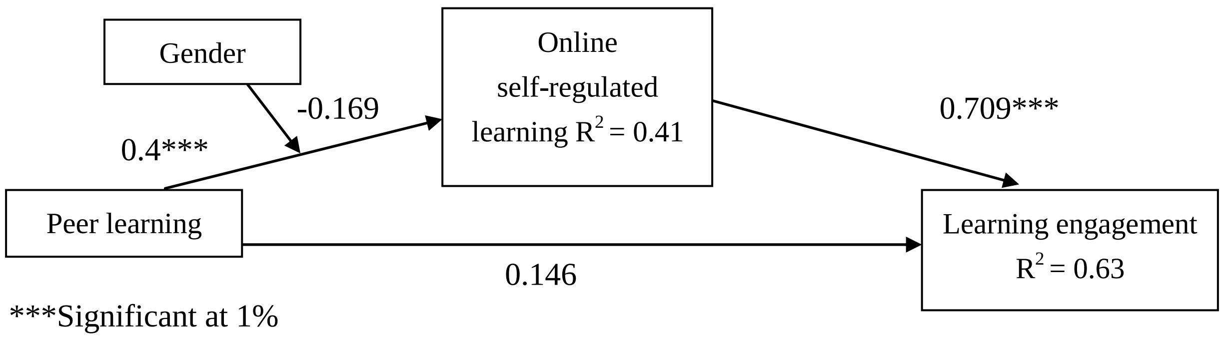

Figure 2. Hypothesis testing results.

5. Discussion

The focus of this study is to identify the effects of peer learning on learning engagement and the mediating effects of OSRL on the relationship between peer learning and learning engagement in online mathematics classes in higher learning institutions.

The findings show that peer learning had no significant effect on learning engagement. It suggests that peer support and influence in an online mathematics learning environment do not enhance students' learning engagement. This is somewhat surprising, as prior work has found a relationship between peer learning and learning engagement [32,39,64]. In addition, Gherghel et al. [22] theorized, through their concurrent test of the hypothesized model, that social interaction could promote emotional engagement significantly more than behavioral engagement. However, emotional engagement could mediate the relationship between social connection and behavioral engagement. This finding shows that social connection cannot guarantee the promotion of all learning engagement components in OLE. This is because, in an OLE, the quality of peer relationships is always compromised as compared to a face-to-face learning environment [65]. Additionally, students encountered challenges in forming a quality friendship within an OLE [66]. This leads to poor peer learning as students find it challenging to receive a clear response to their misconceptions and ambiguities. In mathematics, for instance, which involves more algorithms and formulas, a dedicated explanation is needed to enhance students' understanding and engagement. Additionally, a follow-up personal communication with the two instructors who taught the online classes also revealed that they may not have designed enough activities that require peer interaction. If activities that require peer interaction are limited, peer learning may have little or no effect on learning engagement. This may result in an insignificant relationship between peer learning and learning engagement [67]. Thus, instructors are encouraged to carefully design activities that require collaboration among peers in online learning. In addition, instructors are also encouraged to help students form peer groups that comprise students with diverse backgrounds and educational competencies, thereby leveraging the benefits of peer interaction. This finding aligns with previous work [68,69]. In those studies, the authors highlighted that peer interaction did not significantly contribute to increasing students' learning engagement in OLE. In addition, the finding resonates with social constructivist theory, which asserts that peer interaction contributes to engagement only when it entails deeper forms of collaboration. When instructional activities are not structured to encourage such collaborative practices, peer learning may become superficial, thereby limiting its potential to enhance students' engagement. This suggests that the impact of peer support on engagement is highly dependent on the quality of interaction and the extent to which the learning environment promotes interdependent learning [70].

OSRL directly influences students' learning engagement, which is consistent with the findings of Park and Yun [16], who reported that students' learning engagement increased significantly after using various self-regulated strategies in OLE. Past studies also reported that OSRL played an important role in increasing university students' learning engagement in STEM OLE [71]. This is because SRL has shown promising evidence in increasing students' motivation in OLE [72,73]. Motivation played an essential role in improving students' learning engagement and initiating meaningful, goal-directed activities. At the same time, SRL guides students to set goals, act strategically to achieve those goals, and evaluate and monitor their learning progress. Empirical studies reported that motivation serves as the driving force to increase students' enthusiasm and interest toward learning mathematics [74,75]. Thus, adopting OSRL in mathematics OLE fuels students' motivation and learning, which in turn enhances their learning engagement.

The results also suggest that peer learning is a key antecedent of OSRL. The result corroborates previous literature, which found that peer learning enhances students' OSRL [19]. In addition, a recent study by Hashmi et al. [76] also reported that learner-to-learner interaction profoundly influences university students' OSRL activities. This is because, in an online learning environment, peer interaction profoundly facilitates the sharing of perspectives, constructive feedback, and collaborative problem-solving, which is the foundation for self-regulatory skills [77]. Through peer support, students can set clear learning goals, control and manage their learning tasks, and create an environment that promotes progress in their learning activities. Thus, in this study, peer learning was found to influence mathematics students' OSRL significantly.

This study showed that OSRL fully mediates the relationship between peer learning and learning engagement. Similarly, it is understood that when mathematics students' self-regulated learning is increased through peer support, their learning engagement can be significantly enhanced. An online learning environment requires students to be independent learners. To achieve the desired success in their learning, students should self-regulate their learning process. Successful self-regulation increases students' motivation, which in turn leads to enhanced learning engagement. Here, peer learning serves as a catalyst to enhance further the outcomes obtained from OSRL. This is because dialogue with peers plays a crucial role in stimulating and enhancing the acquisition of self-regulatory skills [78]. Thus, OSRL mediates the relationship between peer learning and learning engagement. These results are generally congruent with those of Wu et al. [67]. The findings are also aligned with Zimmerman's social cognitive model and Bandura's triadic reciprocity theory [9,79] that posits that personal factors such as OSRL serve as central factors that influence students' motivation and strategic regulation in managing and accomplishing learning tasks successfully (behavioral factor) with the help of peer support (environmental factor). OSRL motivates students and enhances their ability to complete learning tasks in OLE, which significantly influences their learning attitudes and behaviors [80,81]. High OSRL generally promotes students' confidence and improves their learning strategies, which positively influences their learning engagement. This implies that future studies should account for mediating variables when examining the relationship between social factors and learning outcomes. The finding also indicates that self-regulation is a catalyst for translating peer collaboration into actual learning gains among students at higher learning institutions in OLE. This aligns with the findings of Broadbent [28] (2017) and Kizilcec et al. [82], who highlighted that strong self-regulator habits and autonomy could lead to successful learning gains in OLE.

This study demonstrates that gender does not significantly moderate the relationship between peer learning and OSRL. The effect of peer learning on OSRL is therefore consistent across genders, with no notable difference in how male and female students benefit from collaborative engagement in online mathematics classes. While this result contrasts with earlier studies that reported gender differences in online learning confidence [26], it aligns with findings of Kara et al. [83], suggesting that technological competence and collaborative learning behaviors are increasingly independent of gender. A plausible explanation is that male and female students now have comparable access to digital resources and similar levels of online learning experience, enabling them to participate equally in peer-supported activities that enhance SRL. Other factors, such as instructional design and group dynamics, may play a more significant role than demographic differences in moderating the relationship between peer learning and OSRL among university students [84].

6. Conclusions

This study contributes to the literature by highlighting the mediating effect of OSRL on learning engagement, as well as demonstrating the indirect effect of peer learning on OSRL to enhance learning engagement. Although the results did not reveal a direct relationship between peer learning and learning engagement, it was found that this relationship was mediated by the OSRL capacity of the students. This indicates that higher-learning mathematics students who are supported by peers and understand how to regulate their learning effectively would probably have a higher level of learning engagement in an online learning environment. The results indicate that peer learning may be a crucial factor in students’ self-regulated learning abilities. Students' tendencies to share and discuss learning-related issues with peers, such as course content and effective learning strategies, influence their attitude and behavior, which directly leads to the adoption and promotion of self-regulated learning. Thus, educators are recommended to design more activities that require peer interaction. Additionally, the study reported that gender did not moderate the relationship between peer learning and OSRL. This suggests that other contextual factors, such as instructional design and group dynamics, may moderate the effectiveness of peer learning on SRL. Thus, educators should create authentic collaboration opportunities and instructional activities that are inclusive and universal, rather than tailored to a specific gender.

From a practical point of view, this study suggests that SRL strategies could be a crucial factor in improving the learning engagement of mathematics students in higher learning institutions in OLE. These students need appropriate guidance to self-regulate their learning process. This is because past studies have reported that many students struggle to self-regulate successfully in online classes [40,41]. Thus, educators should take appropriate actions to support students’ SRL process in OLEs. As indicated by Bellhauser et al. [85], educators can provide web-based training to students to enhance their understanding of the underlying principles of SRL and increase their proficiency in SRL strategies.

This study has several limitations. First, this study is situated in two higher learning institutions and focuses on mathematics students. Future studies could be conducted among students from other faculties and other public and private higher learning institutions. Second, this study uses self-reported measures, which possibly introduce some bias, such as recall bias. To improve the data collection process, other means of assessment, such as learning analytics, observations, and interviews, could be used to triangulate the data in future studies. Third, other social factors such as teacher orchestration and parental support could be included in the model to increase its robustness. Fourth, this study used a convenience sampling method to collect data from mathematics students from two public higher learning institutions in Malaysia. The findings of this study may not be representative of all higher learning institutions in Malaysia, which consist of both public and private sectors. Thus, generalization of the findings should be approached with caution beyond a similar context.

In addition, this study was conducted among mathematics students, whose learning activities and syllabus structures differ from those in other STEM fields. Hence, the generalization of the findings to other STEM disciplines should be made with caution. Moreover, the study was carried out in a public higher learning institution, where the learning environment and facilities may differ from those in private institutions offering online mathematics courses, further limiting the transferability of the results. In Malaysia, the male-to-female enrollment ratio in public higher learning institutions is typically imbalanced, often ranging between 30:70 and 40:60 [86]. This distribution, however, may differ in other countries and within private higher education institutions. Accordingly, the generalizability of the findings to gender-balanced populations should be treated with caution. Finally, caution is also warranted when extending the results to students from different cultural contexts, as cultural variations may shape learning experiences in ways not captured in this study.

Author contributions

Malathi Letchumanan: writing—original draft and editing, conceptualization, data curation, data analysis, proofreading of the manuscript; Sharifah Kartini Said Husain: conceptualization, project administration; Ahmad Fauzi Mohd Ayub: methodology, writing—review and editing.

Use of Generative-AI tools declaration

We declare that we did not use Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare that there is no conflict of interest in this manuscript.

Ethics declaration

Ethical considerations were rigorously upheld to safeguard the rights and welfare of participants. Respondents were informed about the study's purpose, assured of confidentiality, and made aware that their participation was voluntary.

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