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Does Hybrid Mathematics Learning Evaluation Enhance Metacognitive Creative Problem-Solving? A Multi-Group Analysis by Gender

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Abstract

Mathematics learning evaluation in hybrid learning environments is not only viewed as an assessment approach but also as a pedagogical strategy that facilitates students' cognitive regulation and problem-solving processes. However, empirical evidence on the impact of hybrid mathematics learning evaluation on students' metacognitive engagement in creative problem-solving, particularly regarding gender differences, remains limited. This study aims to explore the structural relationship between hybrid mathematics learning evaluation and metacognitive creative problem-solving, including gender differences. A partial least squares structural equation modeling (PLS-SEM) approach was used to collect data from 147 undergraduate mathematics students. Overall, the findings indicate a positive relationship between hybrid mathematics learning evaluation and metacognitive creative problem-solving across the full sample. In terms of gender differences, although the relationship is significant for both groups, it is stronger for male students. However, multi-group analysis revealed no significant difference in structural relationships between males and females, indicating model invariance. This study highlights the value of developing hybrid mathematics evaluation strategies to support students' metacognitive abilities in creative problem-solving.

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INTRODUCTION

Gender differences in learning mathematics have remained an essential factor in influencing students' learning engagement, motivation, and cognitive strategies (Chiu, 2020; Zhang et al., 2024). Past research findings have shown that male and female students may use divergent learning strategies in learning mathematics (Almasri, 2022; Kwarikunda et al., 2022). These differences may be observed in hybrid or blended learning settings, where students are expected to learn to control their learning in both online and offline settings. Research findings have shown that students' learning outcomes in technology-mediated settings may differ by gender. For instance, Egara and Mosimege (2024) a significant gender difference was observed in retention scores for students who used a blended learning setting in learning mathematics, with female students showing higher scores than their male counterparts. Similarly, Idrizi et al. (2023) found gender differences in learning preferences and performance across instructional modes, with female students preferring read–write learning styles and showing stronger performance in traditional courses, while male students tend to favour kinesthetic learning and slightly outperform females in online learning environments.

It is important for mathematics education to recognize such differences, especially in developing an evaluation process with the goal of creating an inclusive education process. Research

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findings have also shown that male students have higher levels of metacognitive performance, whereas female students have a more consistent use of metacognitive strategies in the process of learning evaluation (Abedini, 2022; Lemieux et al., 2019). This study seeks to examine the role of gender in the interaction of hybrid learning evaluation of mathematics with metacognitive creative problem-solving.

From a theoretical point of view, this study is informed by three different, though complementary, theories. The first is Self-Regulated Learning Theory (Zeidner & Stoeger, 2019), which focuses on the active role that students play in controlling and regulating their cognitive, emotional, and behavioral strategies aimed at achieving academic goals. According to the self-regulated learning theory (Boekaerts, 1999), practices that focus on evaluative approaches and feedback, as well as reflection and process criteria, help students develop greater awareness and regulation of their cognitive strategies, thus improving metacognition in solving creative problems. (Angwaomaodoko, 2025). The second theory is Social Cognitive Theory (Bandura & Walters, 1977), which focuses on the interactive role that personal factors, behavioral factors, and environmental factors play in learning and motivational outcomes. The third theory is Expectancy-Value Theory (Wigfield & Eccles, 2000), which focuses on motivation as consisting of two major components. These are students' expectations for success and the value that students assign to learning tasks. The decision to participate in tasks, as well as the effort and motivation to carry out tasks, is influenced by students' beliefs about their ability and task value. Together, these theoretical lenses suggest that evaluation practices in hybrid learning environments may influence motivation indirectly through metacognitive processes, and that gender may moderate these relationships. Although hybrid learning has expanded rapidly, theoretical and empirical discussions about how gender interacts with hybrid mathematics evaluation remain limited.

On the basis of these theories, the context of evaluation in hybrid mathematics learning can be considered a significant area that affects metacognitive engagement and problem-solving. Hybrid learning, a combination of face-to-face and online learning, is becoming a common practice in higher education (Malonisio, 2023). Ideally, evaluation in a hybrid learning environment should not only assess procedural knowledge but also promote higher-order thinking, creativity, and metacognitive regulation. Studies have shown that a well-designed learning environment in a hybrid learning setting can increase engagement and improve flexible problem-solving skills (Abdulrahman & Rawf, 2022; Acosta-Gonzaga & Ruiz-Ledesma, 2022; Gamage et al., 2022; Yen & Lee, 2011). In addition, metacognition is a significant factor in creative problem-solving, as it allows learners to be flexible and adapt to any situation (Farida et al., 2024; Martinez, 2006). Previous studies have shown that evaluation positively affects metacognitive engagement, leading to a positive increase in learning motivation (An et al., 2024; Efremova et al., 2019). In mathematics education, learning evaluation extends beyond the measurement of achievement to actively shape students' cognitive engagement during problem-solving (Frick et al., 2010). Prior research also demonstrates that mathematics learning evaluations incorporating feedback on reasoning processes and strategic decision-making significantly improve students' abilities to plan, monitor, and evaluate their problem-solving approaches, particularly in open-ended and non-routine tasks (Smit et al., 2024; Ukobizaba et al., 2021).

Despite the progress that has been achieved in the learning of hybrid mathematics, there are still significant gaps in the literature. The majority of the existing studies have centered primarily on the direct relationships between learning evaluation and motivation, without considering the potential mediating role of metacognitive creative problem-solving. In addition, although gender differences in mathematics cognition and motivation are well documented, few studies have specifically examined whether gender moderates the structural relationships between hybrid evaluation, metacognition, and motivation. There are few studies that have examined the cognitive, affective, and contextual dimensions of learning within a single analytical framework. These gaps must be addressed to avoid any unintended bias toward certain groups of learners in a hybrid mathematics learning environment.

The need for this kind of research is compounded by the fact that there has been a rapid uptake of a learning mode referred to as a hybrid learning mode in higher learning institutions. A proper comprehension of the issue is necessary for the creation of a fair, engaging, and cognitively supportive mode of teaching mathematics in a hybrid mode.

This study seeks to contribute to the field by proposing and empirically testing a structural model that integrates hybrid mathematics learning evaluation and metacognitive creative problem-solving. Specifically, the study addresses the following research questions:

1. How does hybrid mathematics learning evaluation influence students' metacognitive creative problem-solving?
2. To what extent does gender moderate the relationship between hybrid mathematics learning evaluation and metacognitive creative problem-solving?

METHOD

This study employed a quantitative cross-sectional research design to examine the structural relationships among hybrid mathematics learning evaluation and metacognitive creative problem-solving, with gender tested as a moderating variable. A cross-sectional design was considered appropriate because the data were collected at a single point in time to analyze the relationships among variables without manipulating experimental conditions (Siregar et al., 2025). The study used a correlational approach and structural equation modeling (SEM) to test direct, mediating, and moderating effects within a unified analytical framework (Nirmala et al., 2025; Nurjannah et al., 2025). The flowchart of the research design in Figure 1.

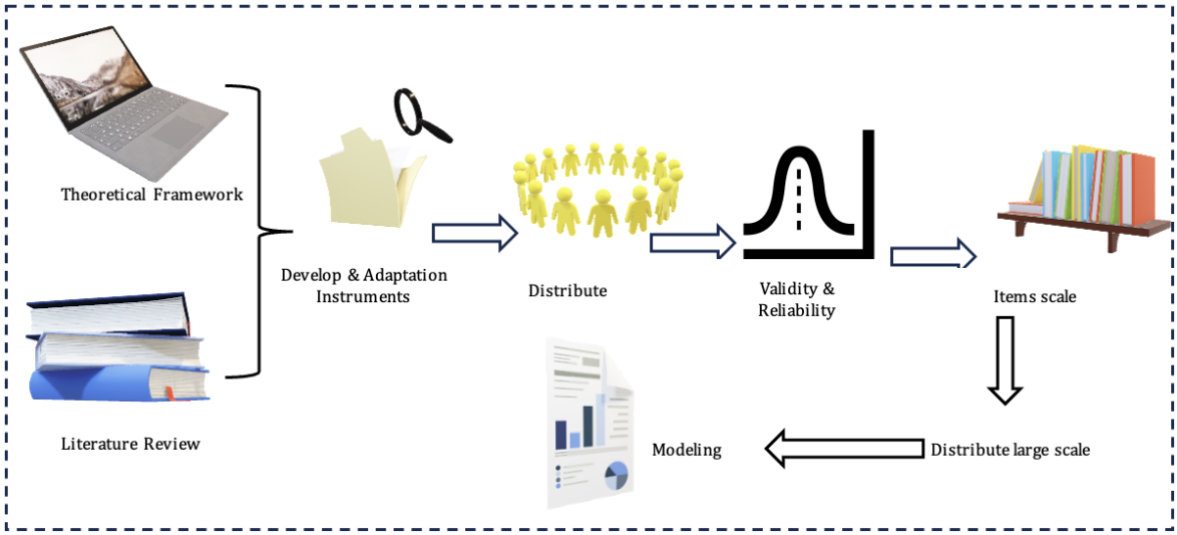

Figure 1. Research Design

Participants

The study included 147 undergraduate students majoring in mathematics. Among the participants, 42.9% (n = 63) were female, while 57.1% (n = 84) were male. Participants had an average age of 19.10 years (SD = 1.45, SE = 0.20). Participants were selected using simple random sampling from the undergraduate mathematics student population, and data were collected using a structured questionnaire administered in online formats during class sessions. The study received ethical clearance from the Institutional Review Board (IRB) at the university, and all participants gave their informed consent before taking part.

Instruments

Hybrid Mathematics learning object evaluation. Adopted the Learning Object Evaluation (LOS) scale (Kay & Knaack, 2009), consisting of five items. An example items are "Working with the learning object helped me learn", "The feedback from the learning object helped me learn, the graphics and animations from the learning object helped me learn", "The learning object helped teach me a new concept", and "Overall, the learning object helped me learn." The original scale demonstrated strong internal consistency (α = 0.89) and has been widely used to assess students' learning support and instructional effectiveness of digital learning objects. In the present study, the scale's validity and reliability were re-examined.

Metacognition in Creative Problem-Solving. Adopted from the MCPS scale (Urban & Urban, 2023), comprising 4 items. Example*: "*When writing an essay or working on a project, I ask myself if what I am doing is leading to the fulfillment of my goal." "When preparing for an assignment, I try to identify potential problems or things I don't understand well." The original instrument reported satisfactory reliability (α = 0.83). The adapted version used in this study was subjected to validity and reliability testing. Participants responded to all instruments using a 7-point Likert scale, where 1 indicated strong disagreement, and 7 indicated strong agreement.

Data Analysis

For data analysis in the present study, different statistical software packages have been used, and their names are SPSS 29, SmartPLS 4, and R software. The data analysis of the present study is done in different stages.

At first, preliminary data analysis is done using SPSS 29 software. The preliminary data analysis involves calculating different types of statistics and correlations between different variables. The validity and reliability of the measuring tools have to be assessed before performing Structural Equation Modeling (SEM). The questionnaires' internal consistency and construct validity were evaluated using Confirmatory Factor Analysis (CFA). Measurement model characteristics, such as indicator reliability, composite reliability, and convergent validity, were investigated using SmartPLS version 4. The chi-square statistic (χ^2), degrees of freedom (df), p-value, Root Mean Square Error of Approximation (RMSEA), Goodness-of-Fit Index (GFI), and Standardized Root Mean Square Residual (SRMR) were among the goodness-of-fit indices used to assess model fit. The chi-square statistic was presented and analyzed analytically, but additional indices were highlighted due to their great sensitivity to sample size. In particular, Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) values greater than 0.90 were considered indicative of acceptable model fit.

Following validation of the measurement model, SEM analysis was conducted to test the hypothesized direct, mediating, and moderating relationships (Pujayanto et al., 2025; Siyahtaş & Ceviz, 2025). Multi-group analysis (MGA) using SmartPLS version 4 was performed to examine gender differences in structural paths and report the model fit, such as SRMR, d_ULS, d_G, Chi-square, and NFI. Additionally, R software was utilized to generate graphical visualizations of the structural relationships among variables, illustrating students' performance patterns within the measurement scale.

RESULTS AND DISCUSSION

Reliability and Validity of the Instruments

To assess the construct validity, confirmatory factor analysis was performed, and the results were satisfactory based on the model fit values of chi-square = 1.435, df = 15, $p < 0.001$, CFI = 0.958, TLI = 0.986, GFI = 0.966, RMSEA = 0.054, and SRMR = 0.041. The results are presented in Table 1. The factor loadings of the indicators were satisfactory, with values ranging from 0.523 to 0.814 for hybrid mathematics learning evaluation and from 0.746 to 0.833 for metacognition in creative problem-solving, indicating that the indicators effectively measured the constructs of interest. The reliability of the measures was further established by the Cronbach alpha values of 0.88 and 0.77 for hybrid evaluation and metacognition, respectively. The composite reliability values of 0.87 and 0.77, which are higher than the minimum of 0.70, also established the reliability of the measures. Convergent validity of the measures was established through Average Variance Extracted (AVE), which gave values of 0.62 and 0.47 for metacognition in creative problem-solving and hybrid mathematics learning evaluation, respectively. The value of 0.47, although not satisfactory, is still acceptable based on established methodological guidelines.

Table 1. Reliability and Convergent Validity

Laten Variables		Outer loads	Cronbach's alpha	Composite Reliability	AVE
Hybrid Mathematics learning evaluation	HM1	0.523	0.88	0.77	0.47
	HM2	0.814			
	HM3	0.689			

Laten Variables		Outer loads	Cronbach's alpha	Composite Reliability	AVE
	HM4	0.686			
Metacognition in creative problem-solving	MC1	0.746	0.77	0.87	0.62
	MC2	0.833			
	MC3	0.784			
	MC4	0.795			

Discriminant Validity

Discriminant validity was examined in this study, as proposed by Hair et al. (2021). The measurement of discriminant validity was conducted by applying the Fornell-Lacker criterion, as proposed by Henseler et al. (2015). The results are presented in Table 2, and the values range from 0.428 to 0.790. Since all values are less than 0.90, as proposed by Hair et al. (2010) and Henseler et al. (2015), the constructs have satisfactory discriminant validity.

Table 2. Discriminant Validity using Fornell-Larcker Criteria

	MC	HM
Metacognition in creative problem-solving	0.790	
Hibryd Mathematics learning evaluation	0.428	0.686

Note: MC = Metacognition in creative problem-solving; HM = Hybrid Mathematics learning evaluation

Descriptive Statistics

The descriptive statistics and correlation coefficients of the variables analyzed in the study are shown in Table 3. As shown in the table, the mean scores of the two variables were both above the midpoint of the scale, indicating that the responses of the participants were generally positive. Specifically, the mean score of the hybrid mathematics learning evaluation was 5.42 (SD = 0.97), whereas the mean score of the metacognition in the context of creative problem-solving was slightly lower at 5.17 (SD = 1.15). This is also shown in Figure 2 with regard to the responses of the participants divided into two groups: male and female. As shown in the table, the skewness and kurtosis of the two variables were both within the normal range, ranging from −1.21 to −0.76 and from 0.93 to 3.35, respectively. As shown in the correlation matrix, there was a significant positive correlation between the hybrid mathematics learning evaluation and metacognition in the context of creative problem-solving ($r = .370$, $p < .01$). This indicates that the more positive the responses of the students were toward the hybrid mathematics learning evaluation, the more positive their metacognitive creative problem-solving would be.

Table 3. Statistical Description of the Data.

Variables	M	SD	Skewness	Kurtosis	1	2
Hybrid Mathematics learning evaluation	5.42	.97	-1.21	3.35	-	
Metacognition creative problem-solving	5.17	1.15	-.76	.93	.370**	-

Note: ** $p <$ 0.01

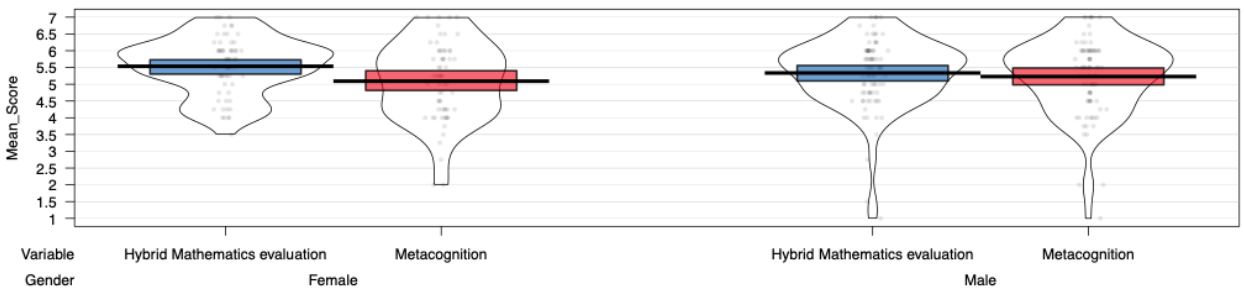

Figure 2. Violin Plot of The Variables among Genders.

Figure 2 displays the violin plot for the evaluation of learning in hybrid mathematics and metacognition in creative problem-solving for both gender groups. The violin plot shows the density and distribution of the results for both male and female respondents. The violin plot shows that the results for the evaluation of learning in a hybrid form of mathematics are symmetrical for both genders, but female respondents have a higher median and a lower density, showing that there was less variation in the results for female respondents. The results for male respondents are less consistent, showing a wider range of results for metacognition. The density of the results for both sets of respondents shows that most of the results are centered around the range of scale points 5 and 6, showing that most respondents had a positive perception of both learning evaluation and metacognition. Although there are no significant differences between the results for both groups, there are subtle differences that provide a preliminary indication that there are grounds for performing a multi-group analysis.

Structure Model: Effects of Hybrid Mathematics Learning Evaluation on Metacognitive Creative Problem-Solving

The structural model was assessed through standard PLS-SEM procedures, considering model fit indices, total effects, predictive relevance, and effect sizes. Overall, the model showed an acceptable fit, with SRMR = 0.085, d_ULS = 0.258, d_G = 0.109, Chi-square = 99.385, and NFI = 0.804, demonstrating that the proposed model provided an adequate representation of the observed data.

The analysis of total effects indicated a positive association between hybrid mathematics learning evaluation and metacognition in creative problem-solving across the full sample (β = 0.373; see Figure 3). This result implies that higher evaluations of hybrid mathematics learning are linked to greater levels of metacognitive creative problem-solving. Path analysis indicated that the effect of hybrid mathematics learning evaluation on metacognition was slightly higher for male students (β = 0.475) than for female students (β = 0.269); however, multi-group analysis (see Table 4) showed that this difference was not statistically significant (p = 0.285), indicating that the relationship between hybrid mathematics learning evaluation and metacognitive creative problem-solving is invariant across genders.

The predictive capability of the model was evaluated using R^2 and f^2 values. Across the full sample, hybrid mathematics learning evaluation accounted for 13.9% of the variance in metacognition in creative problem-solving (R^2 = 0.139; adjusted R^2 = 0.133), with an effect size of f^2 = 0.162, reflecting a small to medium effect. Gender-specific analyses revealed that for female students, R^2 = 0.072 (adjusted R^2 = 0.057) and f^2 = 0.078, indicating a small effect, whereas for male students, R^2 = 0.226 (adjusted R^2 = 0.216) and f^2 = 0.292 corresponded to a medium effect. Therefore, the results indicate that hybrid mathematics learning evaluation positively influences students' metacognitive creative problem-solving, highlighting that well-designed hybrid evaluation systems can support metacognitive engagement across diverse student groups, independent of gender.

Multi-Group Analysis Across Gender

In the final stage of the analysis, a multi-group comparison was performed to examine whether gender affected the structural relationships among hybrid mathematics learning evaluation and metacognitive creative problem-solving. The findings indicated that there are no significant differences between female and male students. In other words, it is noted that the path from hybrid mathematics learning evaluation to metacognitive creative problem-solving is not statistically significant (difference = -0.206, p = 0.285; see Table 4). These findings further support the idea that gender does not moderate the effect of hybrid mathematics learning evaluation on metacognitive creative problem-solving, which in turn supports the invariance of the proposed structural model for male and female students.

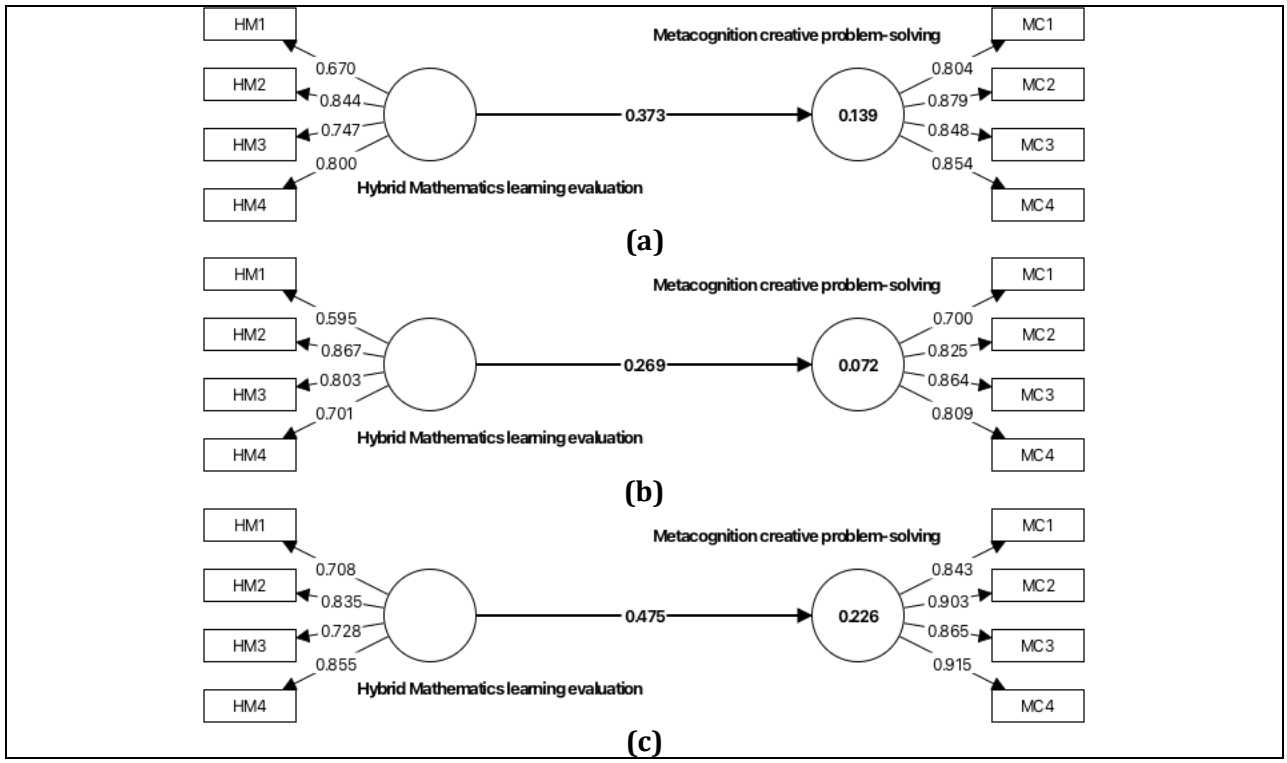

Figure 3. Standardized Path Model in the (a) Complete Variable, (b) Female, and (c) Male

Table 4. Multi-Group Analysis

Relationship	Difference (Female - Male)	*p* value
Hybrid Mathematics learning evaluation -> Metacognition creative problem-solving	-0.206	0.285

The purpose of the current study was to investigate the association between hybrid mathematics learning evaluation and metacognitive creative problem-solving, with special emphasis on possible gender differences. The structural model provided an acceptable fit, which means that the proposed framework is an appropriate representation of students' learning experience in the hybrid mathematics setting. From a deeper perspective, the study revealed that hybrid learning can affect metacognitive creative problem-solving through the framework of evaluative mechanisms in both face-to-face and online settings. Hybrid learning was realized through a combination of in-class collaborative work on problem-solving and an asynchronous online component of reflective work. During the in-class meetings, students were asked to solve non-routine math problems, justifying their reasoning process, and compare their solution strategies with those of their peers. For the online component, students had to submit their written reflections on their solution process, mistakes, and alternative strategies. It is worth noting that the criteria for the evaluation of their work were the quality of their reasoning, strategic planning, and reflective explanations, rather than the quality of their final solution.

Overall, across the entire sample, it was found that there was a significant and positive relationship between the evaluation of hybrid mathematics learning and metacognitive creative problem-solving. This indicates that if students are exposed to evaluation strategies that are perceived as reflective and process-oriented, it is likely that students will be inclined to develop planning, monitoring, and regulation in terms of their problem-solving strategies (Al-Rousan et al., 2025; Shen et al., 2025; Suherman et al., 2021). The underlying mechanism for this relationship is indicated by three different and significant processes. The first is that the prompts for evaluation allowed for anticipatory planning prior to students undertaking tasks. The second is that feedback and comments through the rubric and technology allowed for monitoring during task performance. The third is that reflection strategies allowed for evaluative regulation after task performance. In terms of the hybrid model, in which students are exposed to both virtual and face-to-face learning,

it is indicated that repeated cycles of reflection increase cognitive engagement beyond face-to-face time and result in deeper processing of mathematical reasoning (Hermita et al., 2024; Singh et al., 2021). The moderate correlation and significant structural paths provide empirical evidence that evaluation meaningfully contributes to students' metacognitive creative problem-solving, supporting self-regulated learning perspectives that emphasize feedback as a trigger for metacognitive control.

Gender-disaggregated analyses showed that the strength of the relationship was also gender-disaggregated. The effect of the hybrid mathematics learning evaluation on metacognitive creative problem-solving was more descriptive for male students, with higher values in the path coefficients and explained variance. Although the results are not significantly different, gender-disaggregated results are provided to describe and diagnose the results and to put them in context to better understand the students' engagement and possible considerations for the design of the instruction and future research on metacognitive skills in hybrid mathematics learning evaluation contexts (Boekaerts, 1999; Guo, 2024; Zimmerman, 2000). The results showed that the relationship was positive and significant, although it was less descriptive for female students. Female students are known to be more methodical and systematic in solving mathematical problems. They are known to be internally structured and consistent in regulating and solving mathematical problems (Lemieux et al., 2019; Lin et al., 2012). The descriptive gender-specific results provide context for understanding patterns of engagement without implying differential effectiveness.

On the other hand, the multiple-group analysis failed to find any significant moderation in the structural relationship by gender. This finding suggests that the essential cognitive process through which hybrid evaluation facilitates metacognitive regulation is equivalent for both male and female students. From a theoretical point of view, planning, monitoring, and evaluative regulation are general processes of self-regulated learning that can be triggered by structured feedback, regardless of gender (Boekaerts, 1999; Guo, 2024; Zimmerman, 2000). Thus, the absence of significant moderation supports the structural invariance of the evaluation–metacognition pathway across gender groups.

In addition to understanding the mechanisms of hybrid learning, it is also essential to place the findings in the context of the existing body of literature. The significant correlation between hybrid mathematics learning evaluation and metacognitive creative problem-solving is in line with previous research that confirmed the significance of formative and process evaluations in developing metacognitive skills (Barak & Dori, 2009; Reeves & Laffey, 1999; Smit et al., 2024). Previous research confirmed that using structured feedback in a blended environment can facilitate reflective thinking (Galvis, 2018; Prasse et al., 2024). However, most of the previous research was conducted on general academic performance or specific metacognitive skills. This study extends the general body of research by examining the specific area of metacognitive creative problem-solving in mathematics, using the framework of hybrid evaluation. By incorporating all three components in a structural model (Cheng, 2011; Suherman et al., 2025; Suherman & Vidákovich, 2024), this research extends the general body of literature to offer a comprehensive understanding of the role of evaluation in developing higher-order cognitive skills.

Additionally, whereas previous studies have examined gender differences in mathematics performance and metacognitive strategy use (Hardy III & Gibson, 2017; He & Wong, 2021; Lemieux et al., 2019), few studies have examined whether gender moderates the structural relationship between evaluation and metacognitive regulation in a hybrid environment. The fact that gender did not significantly moderate the structural pathway to metacognitive regulation contributes to the literature by showing that the evaluation metacognition pathway is structurally invariant for both male and female students. This contradicts the idea that a hybrid or technology-based evaluation practice favors one gender over the other (Mintu-Wimsatt, 2001). But instead supports the idea that a well-designed evaluation practice can be a powerful metacognitive regulator.

The originality of this research lies in its threefold practical, methodological, and theoretical contribution. From a practical perspective, it supports the idea of cognitively transformative effects of hybrid learning by demonstrating its dependency upon the presence of an emphasis in evaluation. From a methodological perspective, it extends the range of mediation and multi-group structural modeling in the context of a hybrid mathematics environment. From a theoretical perspective, it extends self-regulated learning and expectancy-value theories by demonstrating the

role of hybrid evaluation in activating metacognitive regulation in creative mathematical problem-solving.

By placing hybrid mathematics evaluation within a cognitive-motivational framework, examining its structural invariance in relation to gender, this research adds new dimensions to the body of research on hybrid learning in higher education settings, with implications for mathematics education in particular, in terms of creating supportive environments for the development of metacognitive skills in students of diverse backgrounds, as well as for education research in general, in understanding the role of hybrid mathematics evaluation in enabling students to engage in creative problem-solving, beyond the use of technological formats in education.

LIMITATIONS

Nevertheless, the current study has a number of important drawbacks. First and foremost, the cross-sectional design of the current study makes it challenging to determine causal correlations between metacognitive creative problem-solving and learning appraisal of hybrid mathematics. It is also true that the structural model's results showed important connections between the study's constructs; however, further research could examine how the hybrid mathematics learning evaluation affects students' metacognitive abilities over time and at various phases of the learning process. Second, the present study is based on self-reported data to assess the learning evaluation of hybrid mathematics and metacognitive creative problem-solving, which might be influenced by different types of response biases, including social desirability and self-awareness differences. Future studies could use more valid measures of the constructs of the present study by using different types of data, such as learning analytics and performance-based problem-solving tasks, and teacher evaluations.

CONCLUSION

This study clearly illustrates the value of hybrid mathematics learning evaluation in the meaningful promotion of students' metacognitive creative problem-solving. In answer to RQ1, the results clearly indicate that the more positive evaluations in hybrid mathematics learning are positively correlated with the promotion of metacognitive creative problem-solving. The structural model clearly illustrates that the total effect is meaningful across the entire sample. In answer to RQ2, the results clearly indicate that gender does not significantly moderate the relationship. This illustrates that hybrid evaluation is beneficial to both males and females. In terms of the implications of this study, it clearly illustrates the value of hybrid mathematics learning evaluation in the promotion of metacognitive creative problem-solving. In this regard, it is suggested that educators and educational developers utilize evaluation as a tool to promote metacognitive creative problem-solving in mathematics learning. In this regard, this study contributes to the body of research in mathematics education by clearly illustrating the value of hybrid evaluation in the promotion of metacognitive creative problem-solving.

AUTHOR CONTRIBUTIONS

For his part, Mu was involved in funding acquisition, conceptualization, visualization, and writing. Specifically, he was involved in review and editing. Ma, on the other hand, was involved in writing, formal analysis, methodology, and editing/visualization.

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