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Analysis of Undergraduate Students' Metacognitive Ability in Mathematical Problem-solving using Cloud Classroom Blended Learning

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The COVID-19 pandemic compelled higher education institutions to adopt an alternative approach to learning. For mathematics education, supporting students through blended learning has become increasingly important as it will ensure students' learning is sustained in such a situation. This practical change has illuminated how cloud technology can be employed in mathematics education to improve the instruction process. Using a cloud classroom blended learning-instructional framework for integrating educational cloud tools into mathematics teaching, this study analysed students' metacognitive ability in mathematical problem-solving. A pre-experimental research using a one group pre-test-post-test design was conducted. The sample comprised sixty undergraduate mathematics students enrolled on a Numerical Analysis course. Sample selection was carried out using a simple random sampling technique. Data were analysed using a descriptive analysis, parametric tests, and n-gain. The results revealed that, firstly, the majority of students (90%) achieved a post-test score of metacognitive ability in mathematical problem-solving – this exceeded the 60% threshold. Secondly, students' post-test score of metacognitive ability in mathematical problem-solving (mean score of 82.14, S.D. = 8.29) increased significantly compared to the pre-test score (mean score of 73.54, S.D. = 8.38). Further, the effect size was large. Thirdly, there was an enhancement of metacognitive ability in the mathematical problem-solving of students with a mean n-gain of 0.34, which is in the moderate category. Thus, cloud classroom blended learning significantly improved metacognitive ability in mathematical problem-solving among undergraduate students. Educators can apply the results to assess mathematics learning in order to improve the quality of metacognitive ability in mathematical problem-solving.

Keywords: blended cloud technology, cloud classroom learning, metacognitive ability, mathematical problem-solving, undergraduate students

INTRODUCTION

When the COVID-19 outbreak affected educational management, the adoption of technology-supported approaches for mathematics instruction in higher education became a prerequisite and obliged instructors to rely on technology-related educational practices as the primary source of learning (Alabdulaziz, 2022; Dziubaniuk et al., 2023). Although the employment of digital technology in mathematics classrooms prior to the pandemic was inconsistent in quality, quantity, and efficacy, some scholars viewed digital technology as an educational necessity (Bower, 2017; Organisation for Economic Co-operation and Development: OECD, 2016; Miguel-Revilla, 2020). The pandemic compelled most instructors to switch from face-to-face learning to online platforms. This change in

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practice provided an opportunity to consider how the technologies used in mathematics education can be used to support student learning (Aituganova et al., 2023; Borba et al., 2016). Such a scenario facilitates technology-based learning environments, such as computer-based learning (CBL), web-based learning (WBL) and web-based teaching (WBT) (Sukma & Priatna, 2021). Several types of virtual learning environments are available with similar modes of use and characteristics, including tools for creating and managing content, as well as synchronous and asynchronous modes (Raman et al., 2022). According to Attard and Holmes (2020), the utilization of technology via the provision of various access methods increases the number of opportunities for students to engage in mathematics learning.

The use of cloud technology to support mathematics education has recently become more prevalent (Hariadi et al., 2022; Raman et al., 2022). It is a service derived from public cloud tools to support teaching and learning activities. This compulsory and sudden shift represents an opportunity for a major change to take place among mathematics educators, in terms of adopting an online and blended approach (Banyen et al., 2016; Joubert et al., 2020). Cloud-based tools can be utilised to support students' collaborative learning at low cost. Learning contents can be accessed from either a desktop computer or other mobile devices at any time, making it easier for students to manage their own information (Miguel-Revilla et al., 2020). Improving the quality of instructional organization for students in higher education forms an essential part of modern knowledge acquisition (Heratha & Mittal, 2022; Narayan et al., 2019). Researching information through the network, using such tools and teaching methods, is consistent with the concept of blended learning.

Blended learning is an approach which integrates two models: hybrid learning and face-to-face learning (Wahyuni et al., 2019). It is recommended for improving students' learning outcomes (Hariadi et al., 2016). Because most students tend to think of mathematics as a boring discipline, they sometimes remember methods without understanding the procedure. Several studies have found that the learning process and teaching approach of instructors have changed in a positive way through the development and strengthening of the use of multimedia (Shida et al., 2019). As a result of enforced online learning during the COVID-19 pandemic, it has become important to understand the influence of the utility of blended learning strategies and a cloud learning management system (LMS) on mathematics learning. The cloud platform makes it effortless for students to access their needs regarding visualization and simulation through cloud learning resources (Hariadi et al., 2022). By disrupting the conventional approach of mediating meaningful student-teacher interactions, blended learning allows mathematics instructors to deliver teaching just as they did in mathematics classrooms (Attard & Holmes, 2020; Huang et al., 2021). Moreover, it encourages students to engage in active learning, engendering a more metacognitive approach to solving mathematical problems (Shida et al., 2019). The success of blended learning in higher education depends on the application of cloud technology, where Al-Mamary (2022) found that the perceived ease of use had an impact on students' attitudes toward the LMS.

Mathematics requires the skills of reasoning, problem solving, computation, understanding, and the application of mathematical knowledge to problem solving (National Council of Teachers of Mathematics; NCTM, 2000). The ability to solve mathematical problems is one of the most important skills (Noor, et al., 2020). As Daher and Anabousy (2020) have suggested, problem-solving is the ultimate goal of a course, therefore promoting this ability is the main concern when organizing mathematics teaching and learning activities. This is consistent with Schoenfeld (2001), who stated that developing the problem-solving skills of students should be emphasised in the mathematics learning process. Several studies have been conducted on the use of cognitive strategies for problem-solving in mathematics. Schoenfeld (2001) studied Polya's problem-solving analytical framework, which comprises four phases: understanding the problem, making a plan, carrying out the plan, and looking back. Schoenfield identified several limitations to this framework. For instance, most students tend to think that once they have solved a problem, they need not look back, whereas looking back in order to analyze their thinking is a more important learning process than obtaining the solution (Polya, 1973; Schoenfeld, 2001). Metacognitive ability denotes the ability to plan, select methods to arrive at a solution, including monitoring the procedure used while solving a problem, and evaluate their own ideas and thinking (Ahmad et al., 2018). A criticism that has been raised in this regard is that metacognition is identical to Polya's concept of the mathematical problem-solving process.

Metacognitive awareness, beliefs and problem-solving attitudes are the variables that significantly influenced the problem-solving process (Bas et al., 2016). The metacognitive model, rooted in cognitive psychology, exerts an impact on students' understanding of the problem posed, problem-solving, planning, confidence, and the regulation of personal behaviour in relation to problem-solving, which is a significant component of learning achievement (Lee et al., 2014; Saparbaikyzy et al., 2023). Furthermore, there is a close relationship between metacognition attributes and problem-solving (Bas et al., 2016). According to Al-Ghurbani et al. (2021), cloud technology and related digital systems have become a significant part of the teaching and learning process, having catered to the need of students to improve their learning performance during the pandemic. More importantly, even after the pandemic, the importance of educational cloud technology when conducting mathematics instruction has become increasingly apparent, together with the features of cloud technology (Al-Mamary, 2022). This inspired the authors' viewpoint that metacognition among undergraduate students when solving mathematical problems may be enhanced using cloud classroom blended learning.

Previous studies have revealed how metacognition influences the thinking process during problem-solving, and hence is a critical factor employed by students to operate and maintain behaviours, achieve their academic goals, and also enhance their performance (Bahri et al., 2019; Nguyen, 2023; Shida et al., 2019). To promote higher order mathematical thinking, it is useful to distinguish which problem-solving behaviours are considered cognitive and which are not when developing students' mathematical problem-solving abilities. Metacognitive skills require a metacognitive understanding of the problem-solving process (Jagals & Van Der Walt, 2016). Profound cognitive and metacognitive strategies result in higher levels of problem-solving (Muis et al., 2015). Moreover, metacognitive abilities have sufficient potential to improve the meaningful learning of students in the mathematics classroom (Ahmad et al., 2018). This also explains why it is essential to determine the success or failure of mathematical problem-solving (Shida et al., 2019). Metacognitive ability should therefore be further developed for students alongside other academic capabilities to help them solve mathematical problems appropriately (Aituganova et al., 2023; Bahri et al., 2019; Nguyen, 2023).

Several studies have emphasized various aspects of blended methods and their implementation in the educational process to enhance students' outcomes. There are various ways in which online technologies have been used, including mobile devices to support the teaching process (Aituganova et al., 2023; Hariadi et al., 2022; Semenikhina et al., 2019) and a blended model with cloud-based platforms in other fields (Min & Wu, 2017; Raman et al., 2022; Riyanti & Nurhasana, 2021; Vongsrangsap et al., 2021; Wichadee, 2017; Wahyuni et al., 2019). In mathematics education, blended learning has been founded so that it has an effect on critical thinking skills (Sukma & Priatna, 2021). Regarding metacognitive ability, some studies have implemented teaching strategies, online learning (Bahri et al., 2019; Bahri et al., 2021; Nguyen, 2023; Shida et al., 2019; Winarti et al., 2022). However, few published studies have linked blended learning with cloud technology use incorporated into metacognitive strategies for mathematics higher education. There is a need to determine students' metacognition of their problem-solving in mathematics, which ultimately enhances practical learning performance. This study is consistent with previous literature in terms of using cloud services and a blended model. To address the existing gap, it differs in that it adds technology into teaching practice by utilising the concepts of cloud technology, a blended approach, and mathematics learning to create cloud classroom blended learning, and then exploring its effects on developing the metacognitive ability of undergraduate students. We proposed using cloud classroom blended learning in a mathematics course. The overall objective was to determine whether cloud classroom blended learning affected students' metacognitive ability in mathematical problem-solving. The results may furnish teachers and educators with strategies for improving the performance of students in the wake of COVID-19.

The key research questions in this study were as follows: (1) Are scores of metacognitive ability in the mathematical problem-solving of students higher than the 60% criteria? (2) Are there statistically significant differences between the mean pre-test and post-test scores of students' metacognitive ability in mathematical problem-solving, and how large is this difference? (3) Is cloud classroom blended learning effective in enhancing students' metacognitive ability in mathematical problem-solving?

Literature Review

Metacognitive ability in mathematical problem-solving

This part reviews the framework of metacognitive ability and discusses its importance in solving mathematical problems.

Problem-solving is a key element in mathematics because it is related to the ability to systematize, organize, and use information in any context involving problems, which is essential in modern-day society (Hariadi et al., 2022). Metacognition is defined as an awareness and understanding of one's own thought processes (Crowl, 1997). It is therefore considered a requirement for successful mathematical problem-solving (Jagals & Van Der Walt, 2016). Numerous studies maintain that metacognition can improve students' performance and level of achievement in learning mathematics (Shida et al., 2019; Tanujaya et al., 2017).

Metacognitive ability refers to thinking about the processes involved in higher-order thinking (HOT) for solving mathematical problems effectively (Ahmad et al., 2018; Shida et al., 2019). It has been recognised as crucial to the mathematical problem-solving process and is evidenced by the influence of metacognitive activities on students' problem-solving outcomes. Ahmad et al. (2018) argues that metacognitive abilities contribute to the meaningful development of mathematical learning among students. The framework of metacognitive ability for solving mathematical problems used in this study was suggested by Garofalo and Lester (1985) and comprises four components: orientation, organization, execution, and verification.

Research on metacognitive ability in mathematical problem-solving often involves two components: knowledge of one's personal cognitive processes and observing while engaging in problem-solving activities. Metacognitive knowledge is one of the HOTs included in Bloom's taxonomy, which consists of analysing, evaluating, and creating (Anggraini et al., 2019; Tanujaya et al., 2017). According to Shida et al. (2019), the enhancement of metacognition in problem-solving is affected by e-learning. This is consistent with Bas et al. (2016), who indicated that metacognitive perception, beliefs, and attitudes significantly impact the problem-solving processes.

Contribution of cloud technology to mathematics

The use of technology is a necessity in contemporary mathematics classrooms. Some countries have embedded its use in a mandated curriculum (e.g., the Australian Curriculum Assessment and Reporting Authority (ACARA) 2010). The use of cloud technology in higher education institutions is becoming increasingly popular, a notable example being the application of cloud tools to support teaching and learning activities (Makruf et al., 2022; Tay et al., 2023). Cloud-based tools can be used to support students' collaborative learning at a low cost. Additionally, learning information can be obtained at any time, making it easier for students to manage their own information, which can be accessed from either a desktop computer or mobile devices (Miguel-Revilla et al., 2020). The most important benefits of technology include opportunities for teachers to implement a course to meet the needs of teaching and learning (Roblyer & Hughes, 2019). Cloud devices provide dynamic, graphic, and interactive tools that give students the opportunity to explore mathematical objects from different perspectives with an emphasis on the relationships between them, which is essential for making mathematics more comprehensible, tangible, and manageable (Calder et al., 2018). Accordingly, cloud technology can assist with the learning process and activities associated with mathematics (Al-Mamary, 2022; Bhagat et al., 2016).

Several studies have analysed the use of cloud technology, including the LMS and mobile technology, in mathematics education. For instance, Hilton (2018) conducted a survey on the use of iPads in learning mathematics among primary school students. The results revealed that these help meet the diverse needs of students through the use of apps that enable them to perform tasks at optimal levels. Quantitative research on the use of Moodle-based online learning management was conducted by Makruf et al. (2022), who administered a survey to a sample of undergraduate students from five faculties. The results revealed that the average response in using Moodle for planning in higher education was in the high category, while implementation and evaluation of learning were in the medium category. This indicates that learning implementation and evaluation were important for optimizing the learning process. Similarly, Raman et al. (2022) conducted a survey on behavioural intentions and actual use of Moodle in blended learning, which revealed that usability factors influence Moodle cloud usage among postgraduate students in the context of online learning.

Other studies have proposed approaches for using cloud services, including cloud platforms, in the learning process of mathematics education and assessed its impacts. The factors of cloud technology identified as contributing to mathematics learning were as follows: creating a good learning atmosphere for students; inserting stimulating mathematical contents and practices through cloud technology functionality; using the computer to express mathematical knowledge, and engaging in discussions or social interactions and learning exchanges (Cen & Cai, 2017; Iji et al., 2017; Jin & Ding, 2017; Semenikhina et al., 2019).

Cloud classroom blended learning

In this section, we review and discuss the use of cloud technology in blended learning and describe the cloud classroom blended learning proposed in this study.

In general, blended learning is a strategy that combines face-to-face learning with technology-based learning, such as online learning, computer-based learning (CBL), and other technology-based learning media (Lalima & Dangwal, 2017). A blended learning approach is a learning management approach that combines face-to-face learning and online learning (Attard & Holmes, 2020; Borba et al., 2016). Suanna et al. (2017) referred to blended learning as a combination of two historically separate learning approaches: face-to-face and online learning. The findings of several researchers have revealed that a blended learning approach provides students with better learning outcomes (Wichadee, 2017), including HOTs (Hariadi et al., 2022; Wahyuni et al., 2019).

The blended learning approach has several utilities that may help address some of the key issues in mathematics education (Helsa et al., 2021). First, emerging research has reported improvements in student engagement because of the ability to access lesson content anytime, anywhere (Cronhjort et al., 2018; Huang et al., 2018). This approach gives students more freedom to learn and makes mathematics learning accessible to those who may wish to revise challenging problems (Amirova et al., 2023; Muir & Geiger, 2016). Min and Wu (2017) found that the performance of undergraduate students' was significantly enhanced by using a blended learning strategy incorporated into a cloud learning environment. A study by Raman et al. (2022) revealed that behavioural intentions in a

Moodle blended learning environment were affected by intrinsic motivation (autonomy, competence, and relatedness). Moreover, blended learning incorporated into cloud technology provides students with easier access to learning resources in a variety of ways. It is regarded as strengthening instructor-student relationships. According to Huang et al. (2021), intensive interactions via blended learning environments can play a key role in enhancing problem-solving abilities. The expansion of personal devices has resulted in the opportunity to redefine learning spaces, both inside and outside school, through an array of blended learning approaches (Calder et al., 2018). Cloud technologies provide tools for students to explore and engage with mathematics in creative ways due to the ability to learn anywhere and anytime, as well as the ability to record, annotate and share multimedia (Bhagat et al., 2016). Students can apply cloud technology in mathematics to achieve real and effective course learning outcomes, rather than applying the formulas and procedures learnt by rote to certain scenarios, as would be common in conventional mathematics classrooms (Bray &Tangney, 2017). Lebeaux et al. (2021) found that deploying cloud technology in the form of Moodle for blended learning improved students' satisfaction and attendance.

Cloud tools are generally employed for different educational purposes and learning activities (Han & Trimi, 2022). Cloud education tools include functions which support blended learning (Cen & Cai, 2017; Lakshmi & Dhanalakshmi, 2016). Depending on their utilisation features in particular blended situations, cloud tools can be grouped into three categories: synchronization tools, LMS tools, and social networking tools (Al-Samarraie & Saeed, 2018). One of the key elements in blended learning is an online learning environment where a wide variety of learning resources and activities are provided for students (Min & Wu, 2017). The use of LMS based on cloud education is therefore essential (Al-Mamary, 2020). The employment of cloud-based LMS to enhance the quality of education has been considered by numerous educators (Al-Mamary, 2022; Herath & Mittal, 2022). Google Classroom is a cloud learning management system that exists in the form of Software as a Service (SaaS). This is an open web platform for designing an interactive course which is mobile applications enabled. It was also used by several researchers as part of learning management to improve students' academic performance during the pandemic period (Clark & Post, 2021; Juncha et al., 2021; Vongsrangsap et al., 2021). Notably, Riyanti and Nurhasana (2021) found that students' ability to think logically improved through the use of blended learning via Google Classroom. Additionally, Samsudeen and Mohamed (2019) identified a positive relationship between social influences on behavioral intentions and LMS use by graduate students. In this regard, blended learning with Google Classroom can be mutually beneficial (Tulasi & Suchitra, 2019). We therefore used Google Classroom as an LMS because of its educational support system (provided by our university).

For this study, cloud classroom blended learning comprised four main components: cloud technology for mathematics learning, cloud learning resource, cloud mathematics learning activities, and cloud learning assessment.

The syntax of blended cloud learning consists of two modes of learning activities: classroom activity and online activity. It also combines face-to-face learning and learning using cloud technology.

The architecture of blended cloud technology as an instructional framework in this study is presented in Figure 1.

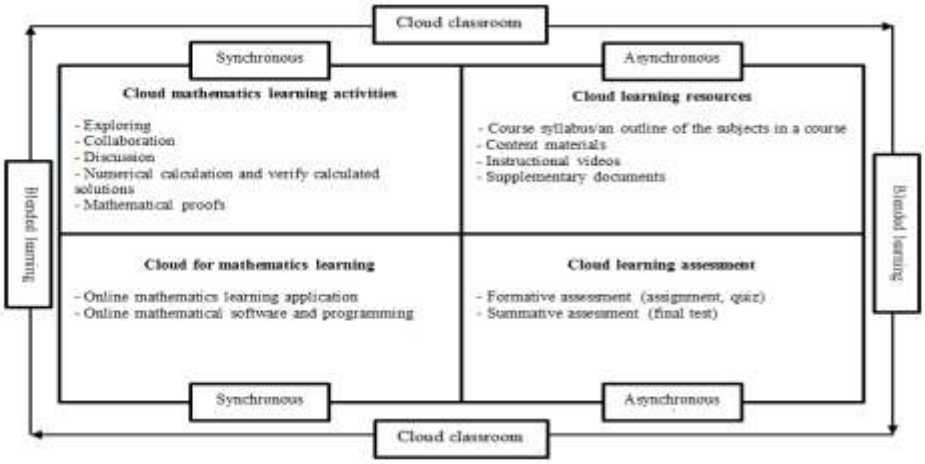

Figure 1
Architecture of cloud classroom blended learning

METHOD

Research Design

This study employed a pre-experimental research to determine whether there is an increase in metacognitive ability in mathematical problem-solving. The research design was one group pre-test-post-test. The pre-test and post-test were performed without a comparison group because classes were scheduled according to the requirements of the course. Thus, a one-group (no control) pre-test-intervention-post-test was applied.

Participants

The participants comprised 60 fourth year undergraduate students from one university in Thailand who enrolled on a Numerical Analysis course. Their average age was 21 years. Participants were recruited using a simple random sampling technique.

Prior to conducting this study, the participants were classified according to their GPA. The results were determined by considering academic performance in Mathematics according to the Bachelor of Education Programme with a major in Mathematics, based on which they were classified as high, intermediate, and low initial mathematical ability groups.

The distribution of participants according to gender and initial mathematical ability is presented in Table 1.

Table 1
The distribution of participants by gender and initial mathematical ability

		Frequency	Percentage
Gender	Male	16	26.67
	Female	44	73.33
Initial mathematical ability	High	12	20.00
	Intermediate	34	56.67
	Low	14	23.33

The distribution of participants by gender was 16 male students (26.67%) and 44 female students (73.33%). In terms of initial mathematical ability, most of the students (56.67%) were intermediate with the remainder being either high (20%) or low (23.33%).

Procedure

The research period for conducting this study was one semester. Cloud classroom blended learning (see Figure 1) was implemented on the Numerical Analysis course for all undergraduate students. As part of the research process, a pre-test was given to participants one week before commencing the study. Cloud-based blended learning was carried out using the Google Classroom platform, where metacognitive attributes were adopted. After the learning was complete, the metacognition of students engaged in mathematical problem-solving was assessed using the post-test.

Research Instruments

The instrument employed for data collection was a test which measured the HOTs involved in metacognitive ability in mathematical problems-solving within the context of the Numerical Analysis course. The content of the post-test was the same as the pre-test, incorporating a set of questions that involved problem-solving based on the lesson during the cloud-based blended learning experience and metacognition as a tool for students to express their thoughts. However, the order of the test items was changed to prevent students from giving the same set of responses. The element used to determine problem-solving cognition was adapted from Garofalo and Lester (1985) and consisted of four parts: Orientation, Organisation, Execution, and Verification. It was improved according to the suggestions of experts before being distributed to the participants. It comprised eight questions that formed part of a subjective test, with each question consisting of four sub-items with a total score of 15 points. The content validity of the instrument was quantitatively assessed by three experts. The difficulty index was in the range of 0.22-0.80, the discriminant index was in the range of 0.22-0.98, and the reliability using McDonald's omega coefficient was 0.87. Regarding the subjective test, participants were asked to describe the cognitive processes involved in mathematical problem-solving based on content materials and according to the curriculum of the Numerical Analysis course.

Data Analysis

The quantitative data comprised scores on both the pre-test and post-test. The results of the analysis comprised descriptive statistics, including frequency, percentage, mean, standard deviation (S.D.), and normalized gain (n-gain). Prerequisites were first performed to verify the significance of the findings through normality and homogeneity testing of the reported metacognitive ability in problem-solving.

The results of normality and homogeneity tests are presented in Table 2 and Table 3, respectively.

Table 2
The normality test of metacognitive ability in mathematical problem-solving

	Class	Test	Kolmogorov-Smirnov		
			Statistic	df	Sig.
Metacognitive ability in mathematical problem-solving	Experiment	Pre-test	0.149	60	0.2
		Post-test	0.063	60	0.2

The Kolmogorov-Smirnov test yielded a significance value for both pre-test and post-test of 0.2 > 0.05. Therefore, the data were normally distributed.

Table 3
The homogeneity test of metacognitive ability in mathematical problem-solving

	Levene statistic	df1	df2	Sig.
Metacognitive ability in mathematical problem-solving	3.017	2	57	0.057

The homogeneity test, which was performed using the Levene statistic, generated a significance value of 0.057 > 0.05. This means that equal variances of the data were assumed. Hence, the data were homogeneous.

The normal distribution and homogeneous variance of the data meant that it met the assumptions required to perform a parametric test. Thus, mean differences in pre-test and post-test scores were compared using the paired samples t-test. Mean differences of male and female students who received cloud classroom blended learning based on students' initial mathematical ability were assessed using a two-way analysis of variance (ANOVA).

The enhancement of metacognitive ability in mathematical problem-solving was determined by n-gain, which was analysed using the average pre-test and post-test scores in accordance with the following formula (Meltzer, 2002):

$$\text{n-gain} = \frac{X_m - X_n}{100 - X_n}$$

where X_m is the post-test score, X_n is the pre-test score, and n-gain is normalized gain. The criteria for interpreting the n-gain level were as follows: n-gain < 0.3 – low; 0.3 ≤ n-gain ≤ 0.7 – medium; and n-gain > 0.7– high.

FINDINGS

Once data collection was complete, the data were analysed to determine the influence of cloud classroom blended learning on metacognitive ability in mathematical problem-solving.

The level of metacognitive ability in mathematical problem-solving

Table 4
Descriptive statistics of metacognitive ability in mathematical problem-solving

		Frequency	Percentage
Post-test	Passed 60% criteria of the full score	54	90
	Did not pass 60% criteria of the full score	6	10

Table 4 presents the metacognitive ability in mathematical problem-solving of the participants after they had used cloud classroom blended learning which adapted metacognitive strategies. The post-test scores revealed that 54 (90%) students passed the criteria of 60%.

The effect of cloud classroom blended learning on the development of students' metacognitive ability in mathematical problem-solving

The results of the paired samples t-test employed to compare the mean pre-test and post-test scores of students is presented in Table 5.

Table 5
Pre-test and post-test comparison of metacognitive ability in mathematical problem-solving

Score of metacognitive ability in mathematical problem-solving					
Test	n	Mean	S.D.	t	p
Pre-test	60	73.54	8.38	13.63	0.00*
Post-test	60	82.14	8.29		

Note: *p < .05

Table 5 presents the analysis of the pre-test and post-test scores for metacognitive ability in mathematical problem solving. The mean score for the pre-test was 73.54 (S.D. = 8.38), while the mean score for the post-test was 81.14 (S.D. = 8.29). The paired samples t-test performed to determine the mean difference yielded a t-value of 13.63 (p < 0.00). There was a statistically significant difference between the mean pre-test and post-test scores of students after they received cloud classroom blended learning. The analysis thus revealed students obtained a higher post-test score compared to pre-test.

To ascertain the extent to which the intervention worked, the effect size was calculated, which yielded a Cohen's d (Furr, 2008) of 1.02 – a large effect.

In addition, because the data were normally distributed and homogeneous, a two-way ANOVA was then performed to examine whether there were differences in the mean post-test scores of student when classified by gender and initial mathematical ability, and the interaction effects of these on metacognitive ability in problem-solving.

Table 6
Post-test of metacognitive ability in problem-solving according to gender and initial mathematical ability

Source	Type III sum of squares	df	Mean square	F	Sig.
Correct model	706.555[a]	5	141.311	2.279	0.06
Intercept	229885.80	1	229885.80	3706.70	0.00
Gender	10.056	1	10.056	0.16	0.68
Initial mathematical ability	495.71	2	247.856	3.99	0.02
Gender and initial mathematical ability	65.847	2	32.92	0.53	0.59
Error	3349.021	54	62.019		
Total	408825.07	60			

Table 6 presents the results of a variability analysis to determine whether there was a significant difference in students' post-test scores of metacognitive ability in problem-solving according to gender and initial mathematical ability. The results revealed that the metacognitive ability of students who received cloud classroom blended learning differed according to their initial mathematical abilities. A Scheffe test was then performed, as displayed in Table 7.

Table 7
Comparison of differences in metacognitive ability in problem-solving categorized by initial mathematical ability

(I) Initial mathematical ability	(J) Initial mathematical ability	Mean difference (I-J)	Std.error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
High	Intermediate	7.02*	2.64	0.03	0.37	13.68
	Low	8.70*	3.09	0.02	0.90	16.5058
Intermediate	High	-7.02*	2.64	0.03	-13.68	-0.373
	Low	1.67	2.50	0.79	-4.61	7.97
Low	High	-8.70*	3.09	0.02	-16.50	-0.90
	Intermediate	-1.67	2.50	0.79	-7.97	4.61

Note: Based on observed means. The error term is Mean Square (Error) = 62.019. * The mean difference is significant at the 0.05 level.

Table 7 reveals a mean difference between high initial mathematical ability students and intermediate/ low initial mathematical ability students ($p < 0.05$). This indicates that there were significant differences in the metacognitive ability in mathematical problem-solving of high initial mathematical ability students compared to those with intermediate and low initial mathematical ability. This means that students in the high group had significantly better post-test scores than those in the intermediate and low groups.

The enhancement of students' metacognitive ability in mathematical problem-solving was assessed by calculating the normalized gain, as displayed in Table 8.

Table 8
The normalized gain score of metacognitive ability in mathematical problem-solving based on students' initial mathematical ability

Class	Initial mathematical ability group	n	Mean	S.D.	Interpretation
Experimental	High	12	0.40	0.25	Medium
	Intermediate	34	0.32	0.17	Medium
	Low	14	0.28	0.21	Low
	Overall	60	0.34	0.20	Medium

The potential of cloud classroom blended learning was analysed using the descriptive statistics of n-gain presented in Table 8. The mean n-gain of metacognitive ability in mathematical problem-solving of undergraduate students who received cloud classroom blended learning was 0.34, which was in the medium category. For high-ability students, the mean n-gain of metacognitive ability in mathematical problem-solving was 0.40. The mean n-gain of metacognitive ability in mathematical problem-solving of students with intermediate-ability was 0.32, which was also in the medium category. For low-ability students, the mean n-gain in mathematical problem-solving was 0.28, which was in the low category. Thus, the mean n-gain of metacognitive ability in mathematical problem-solving of high-ability students was higher than intermediate-ability and low-ability students. This reflects the effectiveness of cloud classroom blended learning in developing students' metacognitive ability in mathematical problem-solving.

DISCUSSION

In this study, cloud classroom blended learning using the approach of metacognition for undergraduate students was implemented, following which its effect on the enhancement of undergraduate students' metacognitive ability in solving mathematics problems was assessed. After the cloud classroom blended learning approach was implemented, more than 80% of students had a pass score criterion. Analysis of the pre-test and post-test scores revealed that the overall metacognition in mathematical problem-solving of the students had significantly improved. The average score obtained on the pre-test was 61.28%, while the average score on the post-test was 68.45% – an increase of 7.17%. Based on the results, students who received cloud classroom blended learning obtained a better post-test score in metacognitive ability in problem-solving, theoretically caused by the learning approach with metacognitive strategies. Students have plan or structuring to solve the problem, verification of the solution that performed the implementation of metacognitive learning activities. This mean they will formulate their own hypotheses and solutions via the learning activities that occur during classes, as students are required to take responsibility for their learning which necessitates the use of metacognitive skills. In cloud classroom blended learning, students are required to study in both synchronous and asynchronous mode. Students work on activities, so they are faced with striving to make problems clear and well-structured through processes using cloud learning resources. The findings also revealed that students in the high group had significantly better post-test scores than those in the medium and low groups. However, no difference in post-test scores was found between the medium and low groups. This describes how such learning partially distinguishes students' mathematical thinking ability, especially when used to solve mathematical problems.

Regarding cloud learning resources, students accessed the instructional videos uploaded by the instructor prior to the class sessions, and spent time in class participating in learning activities and discussions of problem-solving. This reflects that fact that individual and task perception, especially via planning and monitoring, are imperative for mathematics problems (Jagals & Van Der Walt, 2016). As Jansen et al. (2018) revealed, students regularly engage in metacognitive activities when they work on task orientation, and will also contribute to their understanding by examining their performance. Furthermore, the formative assessment, including an assignment and quiz, gradually increased their levels of motivation as well as an awareness and understanding of their own thought processes. The results were in accordance with previous studies (Huang et al., 2021; Min & Wu, 2017; Shida et al., 2019). They were also consistent with previous studies that employed blended learning and incorporated cloud technology knowledge and teaching knowledge as a framework for teaching and learning, resulting in an improvement of students' metacognitive abilities (Bahri, et al., 2021; Winarti et al., 2022).

With respect to learning environments, these appear to exert a positive influence on metacognitive ability. This finding is consistent with Shida et al. (2019) who found that the e-learning environment improves metacognitive skills in problem-solving. Similarity, students perceive that online learning environment has an effect on their metacognitive skills (Jansen et al., 2018). The findings also correspond with those of Bahri et al. (2019) who reported that students' metacognitive skills could be enhanced by the integration of problem-based learning and a Reading, Questioning, and Answering strategy.

The finding implies that cloud classroom blended learning can enhance the metacognitive ability of students. This was supported by the average n-gain, which denotes an overall improvement in the moderate category. This may be because cloud classroom blended learning is the leading educational technology. The integration of technology strategies into learning theory to facilitate conditions leads to extended learning. In class, students were provided with opportunities to analyse data and understand problems, devise a plan to determine solutions and discriminate, along with the correctness and completeness of the answers, and assess decisions and outcomes arising from the planned implementation. Prior to class, students explored their knowledge and thought processes to find solutions to problems from the given materials. The problems that students experienced through their surrounding environment required interpretation and the expression of their own thinking. Understanding these problems had a direct impact by enhancing their cognitive ability to solve mathematical problems (Muis et al., 2015; Riyanti & Nurhasana, 2021). This is consistent with the findings of Clark and Post (2021), who found that synchronous participation in the class contributes to improving students' learning performance in a blended learning environment. Moreover, the use of cloud technology in such an approach can support communication between students and their instructor in blended learning, even in the online learning process (Wagiran et al., 2022). A cloud LMS provides flexible learning and also allows students to explore mathematical operations more effectively (Al-Mamary, 2022). This explains why cloud classroom blended learning significantly enhances the metacognition of students' mathematical problem-solving, resulting in higher levels of achievement. It is a method of teaching and learning management using technology that is consistent with learning in the digital world. Hence, it is recommended that instructors or educators adopt this approach for teaching.

However, there are also some limitations of this study that need to be addressed. First, it did not aim to investigate the advantages or disadvantages of cloud classroom blended learning compared to conventional learning. There may be other factors that would have affected the results. Second, this study was limited in that there was no control group data available for comparison to verify the results, which would have served to validate the findings.

CONCLUSION

In this study, cloud classroom blended learning was proposed and its effects on improving undergraduate students' metacognitive ability in mathematical problem-solving were analysed. After the cloud classroom blended learning was implemented, most students reported higher metacognitive ability in mathematical problem-solving than the criteria 60% of full score. Specifically, they obtained a post-test score in metacognitive ability in mathematical problem-solving that was higher than their pre-test score. In fact, the pre-test and post-test scores were significantly different, with a large effect size. This implies the approach adopted strongly affected metacognition in mathematical problem-solving. In addition, students' metacognitive ability in mathematical problem-solving was enhanced, with an average n-gain in the medium category. Based on the findings, it can be concluded that students who received cloud classroom blended learning exhibited increased metacognitive ability in mathematical problem-solving.

The results of this study will encourage instructors in higher education to adopt cloud technology as an LMS and support undergraduate students' learning to prepare them for digital transformation in the twenty-first century. Interested educators should consider how to plan for integrating educational technology in order to meet the needs of teaching and learning contexts. In the future, if an epidemic or similar situation arises, cloud classroom blended learning may be implemented to enhance metacognitive ability in problem-solving.

One suggestion for further research would be to determine other variables involved in students' learning processes that affect the cognition of mathematical problem-solving, such as technological, pedagogical, and mathematical knowledge of the use of mathematical technology and technological literacy in mathematics education. In addition, cloud-based communication tools may be integrated to improve mathematical learning activities; for instance, by using collaborative and cognitive strategies for higher education students.

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