The Impact of a Cloud-Based Blended PBLRQA Strategy on the Mathematical Conceptual Thinking Ability of Undergraduate Students

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***Abstract*—Mathematical conceptual thinking is defined as possessing the cognitive proficiency to systematically interpret, classify, and integrate mathematical information. It plays an important role in facilitating the application of concepts to solve mathematical problems. In this study, a cloud-based blended Problem-based Learning, Questioning, Reading, and Answering (PBLRQA) strategy was proposed to investigate students' mathematical conceptual thinking. A quasi-experimental method with a pre-test-post-test control group design was employed. A total of 60 mathematics undergraduate students were recruited for this study. They were divided into two groups of 30 students; an experimental group that used a cloud-based blended PBLRQA strategy and a control group that used a conventional approach. The research instrument was a mathematical conceptual thinking test. Data were analyzed using descriptive statistics, n-gain, and a t-test. The findings revealed that the n-gain score, or an increase in the level of mathematical conceptual thinking, was higher in the experimental group than in the control group. In addition, the mean score of mathematical conceptual thinking in the post-test completed by the experimental group was significantly higher than that of the control group. Thus, under the contextual constraints of an undergraduate mathematics course, the cloud-based blended PBLRQA strategy was more effective in improving the mathematical conceptual thinking of students than the conventional learning approach. Interested educators can deploy such an analysis in their practices to assess the contribution made by the quality of mathematical conceptual thinking ability.**

***Keywords*—Problem-based Learning, Questioning, Reading, and Answering (PBLRQA) strategy, cloud technology, mathematical conceptual thinking, undergraduate students**

I. Introduction

Mathematics is often used as a tool to express content knowledge and ideas through formal thinking [1, 2]. An important form of mathematics literacy is the mathematical process of thinking, which is what students use in attempting to solve problems and is considered indicative of mathematical competence [3]. Specifically, mathematical thinking refers to the process whereby students' express facts, use mathematical concepts and principles to solve problems, or engage in reasoning and advanced mathematical thinking. It also plays a crucial role in learning and daily living [4–7]. A significant issue for discussion in mathematics education is the need to support mathematical thinking and understanding [4].

Mathematical conceptual thinking forms the basis of other kinds of thinking. Those with a mathematical conceptual ability will find it easier to understand their lessons [8]. Mathematics activities should therefore be designed to encourage students to learn to think using mathematical concepts and to solve mathematical problems in various situations [9]. Moreover, these skills are relevant to the learning standard of mathematics curriculums and educational contexts in Thailand. For this study, mathematical conceptual thinking is defined as the process of translating a given mathematical problem through knowledge schematization and visualization to find rules, principles and relationships for mathematical identification. It is measured by the ability to identify, classify, and analyze the principles and rationale of the mathematical methods employed. Conventional learning approaches, generally comprising lectures and explanations by instructors, rely on rote memorization rather than conceptual understanding. However, this may not fully reflect the way in which students' practice mathematical conceptual thinking in a proper learning environment [10]. Mathematics activities emphasize that students should practice their thinking processes while learning to identify problems, thereby familiarizing them with the possibilities and limitations of mathematical methods [3]. This is in line with [11], who stated that mathematics teaching methods should help students think independently by allowing them to master and explore technologies through an accessed platform. This applies not only to school students but also university students [12]. To facilitate this process, various approaches based on learning theory have been implemented.

Problem-Based Learning (PBL) is a teaching model based on constructivist methods that has been widely applied to support the development of higher-order thinking skills, character, and interest in education [13, 14]. It is a learning approach that uses problems as a tool to help students learn. It emphasizes the need for students to be responsible for learning, planning, implementing and modifying content in a meaningful way to gain understanding, along with the ability to apply knowledge and learning processes in other contexts [15]. This is consistent with [16] who implied it is the students' responsibility to understand the specific concepts and relations of lesson contents. Studies have revealed that the application of PBL as a pedagogical tool contributes to enhancing academic outcomes and the development of twenty-first century skills [17]. Adopting the PBL approach has multiple benefits for students, but also some limitations. For example, students have often not read the lesson material beforehand, resulting in low comprehension [18]. Similarly, [19] found that students have

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very little interest in reading the lesson material in preparation for the next class. According to the constructivist paradigm, students are not empty vessels; instead, they should be viewed through the lens of empirical theory as possessing their own initial knowledge, which they then use as a foundation to extend their knowledge [20]. However, students' initial knowledge during class is inadequate. Using questions that allow students to practice thinking in mathematical problem situations is a useful strategy for developing their cognitive ability [21].

To address the aforementioned weaknesses of PBL, supplementing it with a Questioning, Reading, and Answering (RQA) technique will enable students to practice using mathematical concepts to solve problems. The combination of PBL and RQA is known as the PBLRQA learning strategy. According to [22], asking questions that enable students to derive solutions from examples is extremely important. It has also been suggested that organizing mathematics activities using only one educational theory or strategy may not reflect learning outcomes as it has certain limitations [23, 24].

To keep pace with changes in a global society, including technological advances in teaching and learning, incorporating technology into activities during an instructional approach presents a substantial challenge for mathematics educators [25]. Nowadays, there are tools available for calculating and presenting mathematical work based, in particular, on cloud technology [26, 27]. The advantages of cloud technology have been expanded in education through increased interactivity among instructors and students [28, 29]. With the development of cloud technology, users do not need to setup a system, or to install additional functions [30]. They rely on the cloud's features to work through the internet [31]. The beneficial features of cloud technology compared to other technologies are accessibility, collaboration, real-time feedback, resource sharing, and flexible computer resources tailored to the needs of users [29, 32, 33]. It has been found that learning by constructing knowledge through a cloud environment is another approach to learning that effectively enhances students' performance and learning outcomes [32–34]. For instance, incorporating cloud tools into properly designed learning activities may provide students with more interactive and enhanced mathematical learning than traditional methods [32, 35]. A notable study found that using effective and appropriate technology to support learning activities aimed at expanding mathematical conceptual thinking leads to better mathematics learning outcomes for students [2, 4, 36, 37].

Given the significance of the stated problems regarding the use of traditional methods, previous studies have solely deployed either PBL, the RQA strategy, or PBL with RQA without support from technology or other educational platforms on mathematics undergraduate courses. No previous studies have been conducted on the application of PBL, RQA, and PBLRQA to study conceptual thinking ability. This study corresponds with previous literature regarding the execution of the PBLRQA strategy. To close existing gaps and provide a novel solution, it uses cloud technology as a tool to facilitate learning activities based on the PBLRQA strategy in order to explore the mathematical conceptual thinking ability of undergraduate students. In the proposed framework, (R) reading techniques include exploration to gather information on the problem, supplemented by (Q) questioning techniques to enable students to think analytically and examine the problem logically, based on which they then proceed to find the answer or solution to the problem (A). These are inserted into the main steps of PBL (raising problems, understanding problem, collecting data, selecting and presenting solutions, analysis, and evaluation), and all stages are assisted by cloud technology. The key research questions were: Does the proposed approach improve students' mathematical conceptual thinking ability? Is the use of the proposed approach more effective in developing mathematical conceptual thinking ability than the conventional approach?

II. Literature Review

A. An Overview

Problem-solving is a key skill in teaching mathematics; therefore, to create an active environment, it is necessary to develop students' perspectives, both strategically and conceptually, in the subject. A mathematics learning process will proceed well if instructors provide opportunities for students to practice thinking processes while learning lesson materials [3]. Undergraduate students today are classified as Generation Z—digital natives who grew up using technology in their daily lives [38]. To respond to social conditions and learning behaviors in line with the changing times, educational cloud technologies have been extended to higher education institutions [26, 28]. Hence, a student-centered learning approach for the development of critical competencies, particularly mathematical conceptual thinking, should be considered.

B. PBLRQA Learning Strategy

Based on constructivist learning theory, PBL encourages students to process ready-made information and consolidate knowledge about the social world and environments [14, 39, 40]. The mathematical situations students encounter should be clear, unambiguous, and contain obstacles that motivate students to try to solve the problem, which itself should be amendable [17]. The PBL teaching method adopted in this study consisted of five main syntaxes [41]: (1) Propose problem situations, (2) Management for students to learn and understand the problems, (3) Assistance with individual and group exploration, (4) Presentation of the chosen solution, and (5) Analysis and evaluation of problem-solving processes.

The PBL approach has been employed to improve students' academic outcomes, including various aspects of thinking skills [39]. For instance, [13] found that compared to traditional strategies, students taught using PBL exhibited a greater increase in their mental capacities, including complete ideas and a possible course of action. A study by [42] promoted mathematical experiences in the fractional thinking of elementary students using problem-based instruction. The qualitative analysis revealed that this can develop students' mathematical thinking levels and can be adapted for students with different cognitive abilities. In a study by [17], high school students in the experimental class who received the PBL model via e-learning environments during the COVID-19 period exhibited higher post-test scores and greater improvement in creative thinking ability than students in a control class.

In studies examining the effect of the PBLRQA strategy on student learning outcomes in both cognitive and affective areas, the strategy was found to increase learning motivation, the metacognitive skills of students with high and low levels of academic achievement [43], cognitive learning, learning retention, and personality characteristics among students in basic biology lectures [8, 19]. Researchers focusing on employing the PBLRQA strategy to attain particular learning aims, such as [44], have integrated it with Moodle-based e-learning to increase self-regulated learning among students. From the review of literature and the criticism of authors, some aspects of the practical application of the PBLRQA strategy in the classroom are clearly challenging, need extensive effort on the part of the instructor as a facilitator, and to ensure problems are appropriate, questions should not to be so difficult for students that they are discouraged from attempting them. Students should be prepared and able to adapt to certain learning situations, such as not being able to obtain exact solutions right away as they need to apply themselves.

C. Cloud Technology in Mathematics Education

As suggested by the evaluation in the Program for International Student Assessment (PISA) [45], the use of aids and tools, including technology, is one of the eight mathematical competencies required to promote learning during mathematical activities. Therefore, the use of a certain platform will make teaching and learning in the classroom stimulating, engaging, and more convenient for both students and instructors [46, 47].

Cloud technology is a form of computing that enables users to access shared resources over a network on demand quickly and conveniently from anywhere and at any time, all without the user having to manage the resources themselves [48, 49]. It is a technology that helps increase the efficiency of simultaneously accessing and using educational resources at various levels [50]. Cloud technology can be used over the internet to store and share information, and also to collaborate [51]. The application of a cloud technology service for learning mathematics consists of three main models [52]: Infrastructure as a Service (IaaS) - a resource-based service where computer resources are created as a group (resource pool) on a server, which is a large backup device that has the ability to send and receive data on the internet. Service providers can determine the direction of resource usage at any time to meet users' needs (dynamic resource provisioning); Platform as a services (PaaS) - an operating system built into the fabric of a virtual machine that functions as a framework for application development and to simplify cloud application development; and Software as a service (SaaS) - the highest level of the service provider consisting of applications used on the cloud system, such as Microsoft 365, Google Workspace, and Zoom Cloud Meetings.

The appropriate utilization of cloud technology to increase access to mathematics resources for all students and at all levels of education should be considered when organizing the teaching and learning process [53, 54]. The most commonly used form of cloud for teaching is SaaS [5, 49]. In one study, Weinhandl *et al*. [55] suggested that the cloud facilitates the exploration of mathematical concepts faster and more accurately. Thus, it has been implemented to support the learning process, an example being [56], who proposed cooperative PBL using Google Apps. They found that students using the cooperative PBL method through Google Apps had higher levels of academic achievement than those who studied using lectures and exercises in class.

Cloud technology for mathematics education provides educational tools such as online classrooms, along with teaching and learning management services related to Q&A communication and exploration, which is one element of the constructivist approach. Studies have also found that cloud-based educational tools stimulate students' logical thinking in the domain of higher education mathematics [46, 57]. Authors [58, 59] classified cloud technology tools for learning management into five kinds: Collaboration tools, Data gathering tools, Content creation tools, Presentation tools, and Communication tools. In addition, [60] suggested different kinds of cloud technology tools for learning management based on [58, 59], and these can be employed for both informal and formal learning. In terms of tools to support mathematics learning, [61] stated that these comprised dynamic graphing tools, dynamic geometry tools, algorithmic programming languages, spreadsheets, data loggers (motion detector and GPS), and Computer Algebra Systems (CAS). Moreover, CAS such as Mathematica, Maple, MuPAD, MathCAD, Derive and Maxima can facilitate a hands-on approach to learning, resulting in students becoming active participants in the process of discovering and gathering personal knowledge, thereby enhancing their theoretical and geometric understanding. In another example, Massive Open Online Courses (MOOCs) allow multiple students to engage concurrently, enabling them to access the curriculum at any time and from any location [62]. However, further studies on the employment of digital platforms for mathematics learning are required [63].

With regard to cloud deployment in mathematics education as a means to improve student learning, previous educators have utilized ICT-based pedagogy approaches, Open and Distance Learning (ODL) applications, virtual education platforms, and distributed Open Educational Resources (OER) [26, 64]. Notably, using cloud technology through digital devices affects students' reading stories [65]. Some studies have improved students' mathematical knowledge using web-based interactive visualizations of dynamic objects [66, 67]. Previous studies have also found that using cloud technology improves the conceptual thinking abilities of students [59]. For these aspects, the link between the applications of certain technological tools in mathematics contexts reflects the challenges and expansion of classroom practice in mathematics education. However, few studies have incorporated cloud technology integrated with the PBL into a RQA approach for the mathematics education of undergraduate students. Therefore, in the present study, a cloud-based blended PBLRQA strategy was implemented on a mathematics course.

D. Mathematical Conceptual Thinking

Mathematical concepts are ideas derived from experiences or phenomena, such as concepts about quantities, numbers, being equal, being exactly equal, and so on. Mathematical thinking refers to an individual's cognitive process of perceiving, encountering, and reasoning using concepts and principles to comprehend how to solve problems, and then acquiring mathematical knowledge [68, 69]. Thinking ability is one of the five significant competencies required by students in the twenty-first century [44, 70] and corresponds to learning thinking skills and the nature of mathematics, which involves the use of thought [70]. The authors of [71] suggested that some thinking skills could be practiced through conceptual learning. Conceptual thinking in mathematics involves considering mathematics problems through knowledge structures and visualization [72]. Promoting and stimulating students' conceptual thinking in mathematics will lead to mathematical understanding [73]. Similarly, [74] suggested that developing mathematical thinking through mathematical conceptualization is a tool for developing the brain in terms of skills and thought processes. Students have to collect data obtained from observations, consider relations in order to identify connections between mathematical concepts, and generate conclusions [75]. Therefore, when teaching mathematics in the classroom, students should have the ability to use mathematical concepts as this is an essential component of mathematical performance. The conceptual learning-cognitive dimension on a mathematics course can be developed through techniques such as pattern observation, interpreting data to impose general principles, and analyzing the similarities, differences, and relationships between mathematical features that correspond to learning concepts [11].

Mathematical conceptual thinking requires the definition of concepts and relevant structures in a particular content area [76]. It concerns students' ability to remember and organize definitions and theorems in problem-solving conditions. Students with strong mathematical conceptual thinking will be able to apply and interpret conceptual mathematics representations and integrate definitions, principles, facts, and symbols in a mathematical environment [73]. The determinants of mathematical conceptual thinking have been proposed by a number of researchers. In [77], the abilities of conceptual thinkers were summarized as follows: ability to analyze composition, ability to arrange concepts, and ability to logically summarize principles. As suggested by [78], mathematical conceptual thinking involves the ability to distinguish, analyze, collect, and summarize data. In addition, [79] described the abilities of mathematical conceptual thinking as analyzing, identifying, and linking observational data, and then deriving conclusions from the data obtained.

The use of mathematical concepts involves the ability to utilize knowledge and to possess an understanding of facts and the symbolic meaning of principles and relationships in mathematics in various scenarios [80]. The indicators for mathematical conceptual thinking abilities in this study were adopted from [76] and consist of the following components: identification, classification, analysis of the relevant mathematical definitions, and the principles and rationale of mathematical methods.

As evidenced in the literature, PBL as well as RQA strategies have been used alone but have been limited to school students, with some researchers applying it to college students but not mathematics students. In addition, most students nowadays, particularly undergraduates, use the internet and social media as part of their daily lives. An analysis of mathematical conceptual thinking as reflected and represented in the PBLRQA strategy is presented in Table 1.

Table 1. Analysis of the relevance of the PBLRQA strategy and mathematical conceptual thinking ability in this study

	Approach and strategy	**Mathematical conceptual thinking ability obtained**
PBL	A learning model that provides problems as a tool to motivate students to learn. The role of the instructor in the PBL strategy: - facilitator and guide in the learning process. - propose interesting problems consistent with basic knowledge, abilities, and lesson material to encourage students to express their ideas. The role of students in the PBL strategy: - practitioners. -find out how to solve problems based on previous information/ experience. -learning in small groups.	- Ability to identify and analyze relationships and concepts. - Ability to analyze mathematical theory or principles.
RQA	The instructor contributes reading material for students. Students are encouraged to read materials and derive relevant concepts from content.	- Ability to identify definitions, and then classify the related definitions and relations. - Ability to analyze the mathematical theory or principles. - Ability to examine the solutions that have been derived to sensibly solve the problem.

Providing students with PBL integrated into a RQA technique supplemented by cloud technology will, in addition to helping them learn independently, enable them to practice thinking about mathematical concepts by exploring various tools and educational services based on cloud. To fill the gaps in research, we proposed cloud-based learning based on the PBLRQA for mathematics undergraduate students, and determined its effectiveness in enhancing the mathematical conceptual thinking ability of undergraduate students.

III. Materials and Methods

Mathematical thinking and concepts are important domains that should be promoted for success in learning mathematics. To achieve this goal, the role of students and instructors essentially differs from that in traditional methods in that it adopts a student-centered mode, emphasizing learning activities that allow students to communicate with their peers through stimulus-response learning, discrimination learning, concept learning, and problem learning. To further strengthen these learning theories, an environment with media, tools, and challenging problems that support students in constructing knowledge and concepts by themselves should be provided.

Research by [8, 43] revealed that students who used the

PBLRQA strategy exhibited higher development of metacognitive skills than students who used traditional methods. Moreover, the interaction between learning strategies and academic achievement enhanced students' metacognitive skills—an ability related to and necessary for thinking. Additionally, it was found that PBL combined with cooperative learning on cloud computing using Google Apps resulted in better learning outcomes among students on an introductory programming course than students who used lectures-based learning and exercises in class without technology. Thus, this study was conducted to develop students' mathematical conceptual thinking through PBLRQA strategies combined with educational tools based on cloud technology.

A. Research Design

This study employed a quantitative research method using a pre-test post-test control-group design to examine whether learning using such an instructional model influences mathematical conceptual thinking ability. The experimental group used the PBLRQA strategy supported by cloud technology, and the control group used a traditional approach.

B. Sample

The sample consisted of 60 third year university students majoring in mathematics who participated in a Number Theory course. The two classes of participants were selected using simple random sampling with the experimental group comprising 30 students and the control group comprising 30 students. The average age of participants was 21 years.

C. Research Procedure and Implementation

The development of the PBLRQA strategy supported by cloud technology involved the following procedures: (1) The study of the innovative learning strategy used (i.e., the PBLRQA strategy; (2) The analysis of cloud learning tools; (3) Designing the teaching approach by incorporating cloud-based learning with the PBLRQA strategy. Because the SaaS model is more practical and convenient than other cloud services model, users can create and edit online without installing the program on any devices, and our university supports this model for both instructors and students. Thus, the SaaS model including the cloud learning management system was employed as a tool for learning activities in accordance with the PBLRQA strategy; (4) Development of material lessons; (5) Putting the validated learning approach into practice with mathematics undergraduate students.

The intervention was implemented on a Number Theory course for third year undergraduate students as this course comprises content that involves rather abstract concepts. It requires the ability to use relevant mathematical concepts which may influence students' problem-solving and conceptual thinking skills and can be integrated into the PBLRQA strategy.

The developed course materials provided in the cloud were assigned to students to read in preparation for the next class. To facilitate this, reading strategies were used whereby students read or studied materials related to conceptual knowledge before class in the form of learning resources and media obtained from cloud-based platforms.

The proposed syntax views for implementing the PBLRQA strategy supported by cloud technology are presented in Table 2.

Table 2. Syntax views on implementing the PBLRQA strategy supported by cloud technology

	Learning strategy and activity	**Features related to the use of the cloud**
PBL	(a) Raising problems or situations related to the topic. (b) Management for students to learn and understand the problem: - Students consider and perceive the intended problem (words, a language, or conditions). (c) Assistance with individual and group exploration: - Collecting data and feasibility of solution (PBL stage).	The stage for giving topics or devising problems in the form of a question through cloud content creation and the use of an online whiteboard platform.
R-Reading	- Reading about the problem situation: - Students study, research, collect relevant knowledge, and select possible and effective solutions to problems (R-Reading stage).	Class discussion platform: - classwork features (assignments, question, material). Stream (learning resources) on Google Classroom, the online whiteboard platform.
PBL	(d) Students present solutions and explain their reasons (PBL stage.)	
Q-Questioning	- Asking questions about the feasibility of the solution. - Analyzing and examining the theorems and definitions required. (Q-Questioning stage).	Class discussion platform: - classwork features (assignments, question, material) on Google Classroom.
PBL	(e) Students analyze and evaluate the reasonableness of the problem-solving process and the answers obtained (PBL stage).	Class discussion platform: - classwork features (assignments, question, material). Stream (learning resources) on Google Classroom.
A-Answering	- Proceeding with the selected solution. - Discussion and argumentation with peers. - Creating a summary of readings and discussions (A-Answering stage).	

In the initial stage of the study, both groups of students were given a pre-test to evaluate their mathematical conceptual thinking ability. The instructional approach using a cloud-based blended PBLRQA strategy was implemented for the experimental group and conventional learning for the control group. For the control group, the conventional approach comprised lectures and explanations by the instructor. The students listened, reviewed, and took notes based on information and assignments provided by the instructor. After the course was completed, both groups of students completed a post-test of mathematical conceptual thinking using the same materials and questions as the pre-test.

D. Research Instrument

The data collection instrument was a mathematical conceptual thinking test. The test was self-constructed by the authors on the Number Theory course. It comprised 9 subjective items regarding mathematical concepts and their applications with a full score of 100 (this work accounted for 40 percent of their final grades). The indicators used to gauge mathematical conceptual thinking abilities consisted of three components: (1) ability to identify and classify definitions and relations, (2) ability to analyze the mathematical theory or principles, and (3) ability to examine sensible solutions derived to resolve the problem.

The content validity of the test was verified by three mathematics education experts who considered the consistency of the operational definitions and indicators of mathematical conceptual thinking ability deployed. They also provided comments on improving the use of language to ensure all items were clear and unambiguous. Improvements to the test were made based on their suggestions before being distributed to the participants. The difficulty of the test items ranged from 0.20 to 0.79, which was considered suitable. The discriminant value ranged between 0.25 and 0.98, which was deemed appropriate, and the reliability of the test, determined by McDonald's omega coefficient, was 0.88.

E. Data Analysis

Data comprised participants' pre-test and post-test scores on the mathematical conceptual thinking test. The statistics used for data analysis were descriptive statistics such as mean ($\bar{x}$) and standard deviation (S.D.). The increase in mathematical conceptual thinking score was determined by average normalized gain (n-gain) using the following formula [81]: n-gain$=\frac{X_m-X_n}{100-X_n}$, where X_m is the post-test score and X_n is the pre-test score. The interpretation of n-gain level was based on the following criteria: n-gain ≥ 0.7- high, 0.3 ≤ *n*-gain < 0.7- medium, and n-gain < 0.3-low. An independent t-test was then conducted to determine whether there were differences in mathematical conceptual thinking ability between students in the experimental and control groups. The effect size of the difference (Cohen's d) was then measured to provide an important indicator of how much conceptual thinking ability students will acquire if the findings of this study are applied.

To determine the significance of the findings, the data were first subjected to a normality and homogeneity test, as shown in Table 3 and Table 4, respectively.

Table 3. Normality test of mathematical conceptual thinking ability

Test	Group	Shapiro-Wilk		
		Statistic	df	Sig.
Pre-test	Experiment	0.934	30	0.063
	Control	0.944	30	0.114
Post-test	Experiment	0.963	30	0.376
	Control	0.937	30	0.075

Table 4. Homogeneity test of mathematical conceptual thinking ability

Test	Levene statistic	df1	df2	Sig.
Pre-test	1.241	1	58	0.270
Post-test	0.732	1	58	0.396

Regarding the normality test, the mathematical conceptual thinking ability values for the pre-test undertaken by the experiment and control group were 0.063 and 0.114, respectively, which were greater than 0.05. Similarly, the significance values for the post-test completed by the experiment and control group were 0.376 and 0.075, respectively, which were also greater than 0.05. Hence, it was concluded that the data were normally distributed.

Table 4 presents the results of the test of variance in mathematical conceptual thinking scores for the two groups. The Levene's test yielded values of 1.241 and 0.732 for the pre-test and post-test, respectively. The respective significance values were 0.270 and 0.396, which were greater than 0.05. Thus, equal variances of the data were assumed.

Because the normality test and homogeneity test of mathematical conceptual thinking scores met the assumptions of normal distribution and homogeneity of variance, a t-test could be conducted [82, 83].

F. Ethics Considerations

This study also followed ethical requirements regarding the need for anonymity. Participants' names were not provided and no individual identifying information about the participants was included in the data analysis report. The data collected from the participants did not present any risk of physical harm as they were obtained from a mathematical conceptual thinking test based on a topic from a course in the students' existing curriculum.

IV. RESULTS

The data were then analyzed to determine the impact of a cloud-based blended PBLRQA strategy on the mathematical conceptual thinking ability of students.

A. The Improvement in Students' Mathematical Conceptual Thinking

To determine the improvement in students' mathematical conceptual thinking, n-gain was analyzed. The pre-test scores post-test scores, and n-gain of undergraduate students in the experimental and control groups are displayed in Table 5.

Table 5. Results of the mathematical conceptual thinking test and average normalized gain of experimental and control groups

Group	Pre-test		Post-test		n-gain
	Mean	S.D.	Mean	S.D.	
Experiment	40.26	10.58	77.50	8.14	0.62
Control	30.82	10.76	69.74	8.92	0.55

Table 5 presents a descriptive analysis of the mathematical conceptual thinking pre-test and post-test scores of the experiment and control groups. The average n-gain in the mathematical conceptual thinking ability of students using a cloud-based blended PBLRQA strategy was 0.62, which was in the medium category, while for students using conventional teaching methods it was 0.55, also in the medium category. The significance of the higher n-gain in educational terms indicates that, overall, the experimental group students developed a greater degree of mathematical conceptual thinking than the control group. This suggested that the proposed intervention improved students' mathematical conceptual thinking.

B. The Effectiveness of the Cloud-Based Blended PBLRQA Strategy

To examine whether the proposed approach was more effective in enhancing mathematical conceptual thinking than the conventional approach, the validity of the research hypothesis was tested. This states that there would be statistically significant differences (< 0.05) between the mean scores of the two groups on a mathematical conceptual thinking in favour of the experimental group. Thus, the post-test scores were compared, as presented in Table 6.

Table 6. Comparison of mathematical conceptual thinking ability for the post-test completed by the experimental and control groups

Group	N	Mean	S.D.	t	df	Sig.	Effect size
Exp.	30	77.50	8.14	3.516	58	0.001*	0.90
Cont.	30	69.74	8.92				

Note: *$p < 0.05$

As shown, the p-value was 0.001 (which was less than 0.05), confirming that there were statistically significant differences between the mean scores on the post-tests in favour of the experimental group. Thus, the research hypothesis could be accepted as the proposed approach was more effective in enhancing mathematical conceptual thinking ability. The effect size based on Cohen's d was 0.90, indicating a large effect [84]. This implies the proposed approach had a significant and highly positive effect on students' mathematical conceptual thinking, as the mean score of mathematical conceptual thinking ability of the experimental group was in the 89th percentile of the control group for undergraduate students on this mathematics course. This is because the conventional teaching method mainly focuses on instructor lectures and explaining the content through materials and textbooks. Therefore, unlike the proposed approach, students do not practice using their ideas and are less trained in reasoning and articulating their solutions.

V. Discussion

This study analyzed the effect of using a cloud-based blended PBLRQA strategy on undergraduate students' mathematical conceptual thinking ability. With respect to the results for the first question, the mathematical conceptual thinking ability of students using the proposed approach improved, as demonstrated by a higher average n-gain score than the control group. Although both groups were in the medium improvement category, the experiment group exhibited a numerical improvement greater than that of the control group. These findings can be explained as follows. The cloud-based blended PBLRQA strategy improved mathematical conceptual thinking ability because implementing this learning approach practiced, encouraged, and developed students' understanding, identification, analysis, and application of concepts to mathematics problems. Because students read and explored the content of the materials before and during class, which included the use of a questioning and answering strategy, they were able to analyze the relationships between concepts involved in the problem and identify reasonable solutions. In the PBLRQA syntax, the aim was to assist students in developing their inquiry and problem-solving abilities as well as thinking skills. The experimental group outperformed the control group in terms of mathematical thinking because the approach provided them with opportunities to explore content through practice, seek knowledge, and apply problem solving methods from prior experiences. This helped them to integrate their knowledge and devise solutions which they could use to connect and express their thinking. These led to a higher ability to interpret, classify, and analyze mathematical concepts in the post intervention. This result is supported by previous studies indicating that the PBLRQA approach is beneficial in improving cognitive skills, metacognitive skills, and problem-solving [8, 18, 19].

With respect to the second research question, the results indicated that the proposed approach was more effective in increasing mathematical conceptual thinking than the conventional approach. This may be because, in the conventional approach, students acquired knowledge from the instructor's lectures, they did not seek knowledge by themselves and did not reflect on problems with their peers. Furthermore, they did not practice developing their own ideas and were less familiar with analyzing, interpreting, and expressing their solutions. In addition, no cloud technological tools were used to support their activities. Research by [19] also found that PBLRQA strategy can develop students' cognitive learning. The results of this study are supported by the attributes of PBL, which is a vital practice that provides students with a welcoming learning environment in which to acquire the skills to overcome problematic scenarios, as well as a student-centered and constructivist learning environment. The PBL approach has been demonstrated to enhance self-learning skills, academic outcomes, problem-solving skills, and critical thinking skills [17, 85]. These imply that the process of raising problems in the form of questions in the PBLRQA strategy is important in strengthening students' conceptual thinking abilities. This corresponds to the results of [44], which revealed that PBLRQA learning develops students' thinking skills and their capacity for self-regulated learning. Additionally, mathematical conceptual thinking will be reflected when students engage in detailed discussions, achieved by considering problems with peers in small groups.

During the process of reading and using questions in the RQA stage, students' understanding and consideration of concepts, including the relationships between various principles and theories, were practiced. The author of [86] argued that there are two phases of questioning: acceptance and challenge. This means that when reading or answering information about the current problem situation, the process of using conceptual thinking is performed. While students are searching for information to answer questions relating to what they know, what they want, and what concepts they can use to address which situation, it is appropriate for them to apply mathematical methods. This reveals their ability to use mathematical concepts, which is the phase involving the use of thinking [9]. In the proposed approach, interaction through the use of questions related to problems and the solutions of instructor and peers, generated through peer discussion, created intellectual conflict and aroused curiosity—critical mechanisms for stimulating students to think in terms of identifying, defining, reflecting, and ultimately engaging in the intellectual restructuring of conceptual thinking. Qualitative insights from the authors' perspective as instructors, based on observations during the experiment, were that the experimental group were more enthusiastic about learning as they performed the activities by themselves and the atmosphere in the classroom was better. Nevertheless, there were some resource constraints in the implementation, such as unstable internet connections or even students forgetting their mobile devices.

The findings suggest the instructor's role was to create an appropriate learning environment by encouraging students to use conceptual thinking to extend analytical thinking, problem-solving skills, and engage in further thinking. To support this, a conductive learning environment should be provided that enables students to communicate with each other about mathematical problems through the use of challenging questions and quizzes, along with the use of technology to enhance the learning experience and the process of knowledge construction in the classroom. The main rationale underpinning this learning method is that students should be the constructors of their own knowledge through problem-solving, and each student's acquisition of mathematical knowledge and concepts may differ after exposure to the stimulus; in this case, cloud technology tools that support collaboration, access to lessons prepared by the instructor, and other learning resources through the use of a browser without having to install any programs. In addition, the components of cloud collaborative tools allow for flexible teaching and learning and the ability to share learning resources such as Google classroom, as well as other learning resources. This entails providing functions that are consistent with mathematical activities, such as numerical computation, graph plotting, and so on (through cloud content creation, and an online whiteboard platform), which will result in a better understanding of mathematical concepts. Alongside this, the support of cloud technology gives students a greater understanding of the content they learn and is consistent with existing studies [32, 33, 36, 37, 56]. Compared to previous research, the novel framework for this study was the blending of cloud technology tools that are relevant and supportive of learning activities into an approach using PBLRQA. For these reasons, mathematical conceptual thinking and the application of mathematical concepts are enhanced by the PBL using questions to encourage discussion, exploration, and understanding, including with the support of cloud technology. Based on the findings, it can be concluded that the use of PBLRQA strategies with cloud tools in teaching mathematics has been demonstrated to be practically valuable in enhancing conceptual thinking ability. However, it is important to note that this study was limited to a targeted group of third-year students undertaking a Number Theory course for a duration of one semester.

VI. Conclusion

A PBL approach incorporating a RQA strategy deployed in the form of cloud-based blended learning was proposed in this study. The main aim was to assess the effect of the proposed approach on mathematical conceptual thinking ability. The results revealed that the approach improved students' mathematical conceptual thinking ability, as evidenced by the superior n-gain scores of the experimental group. The results also revealed differences in mathematical conceptual thinking abilities between students in the two groups as the experimental group significantly outperformed the control group on the post-test of mathematical conceptual thinking ability. Higher education reform should therefore emphasize the effectiveness of using a student-centered mode instead of a teacher-centered mode. This should become the educational paradigm of this era, enhancing students' skills for future career development. The promotion of the use of aids and tools, whether digital technology, educational innovations to support intellectual development and experiences in mathematics education, reflect academic expansion.

The implications for practice from this study are that the development of teaching mathematics for undergraduates should consider theories, principles and models as a conceptual framework together with learning media, including learning resources that are consistent with the characteristics and contexts of the students. The research findings may be applied or extended to other mathematics educational theories such as constructivist learning in prospective practical education. Interested educators may adapt the proposed approach to other problem-solving-oriented subjects that need to develop conceptual thinking by considering the key stages and tools and adapting them to suit the context of the subject and ages of the students. The authors recommend conducting further research on how this approach can be used with other modern technologies, using a larger sample size to verify its applicability in the development of students' performance, such as conceptual understanding and problem-solving skills in other mathematical topics or at other educational levels.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

AA conceived and designed the concept of the study, drafted the literature review, conducted the research, wrote the manuscript; BC carried out the literature review, verified data accuracy, analyzed the data, reviewed and edited the manuscript. All authors read and approved the final version.

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