The Influence of an Interactive Learning Model Based on the PDEODE Strategy with Cloud Technology on Students' Self-Regulation in Mathematics Learning

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***Abstract*—Self-regulation is playing a key role in cognitive learning and coping activities. This study implemented an interactive learning model based on the Predict-Discuss-Explain-Observe-Discuss-Explain (PDEODE) strategy using cloud technology as an instructional approach to examine its impact on undergraduate students' self-regulation in mathematics learning. The sample comprised 60 undergraduate students who participated in a set theory course. A randomized control group pre-test–post-test design was utilized. The 30 students in the experimental group engaged in an interactive learning model based on the PDEODE strategy with cloud technology and the 30 in the control group followed the conventional method. The research instruments were the instruction plan and a scale assessing self-regulation in learning mathematics. The data were analyzed with a descriptive analysis, normalized gain (n-gain), and the t-test. The findings confirmed that the mean self-regulation score in the experiment group exceeded the criterion of 60% and was statistically significant at the 0.05 level. The experiment group achieved a higher improvement level in self-regulation compared to the control group. In addition, there were statistically significant differences between the two groups in the mean post-test scores of self-regulation in favor of the experimental group at the 0.05 level. The results indicate that the method proposed has a positive effect and could be adopted as an approach to reflect on self-regulation in learning for undergraduate students in the context of mathematics courses. The PDEODE strategy, particularly when supported by cloud technology, promotes students' participation through more collaborative activities, unlike learning practices that rely on memorization.**

***Keywords*—interactive learning, cloud technology, Predict-Discuss-Explain-Observe-Discuss-Explain (PDEODE) strategy, self-regulated learning, undergraduate students**

I. Introduction

Mathematics is one of the priorities of many educational institutions owing to its role in meeting the comprehensive requirements of educational community development [1]. Educators have focused on the important role mathematics plays in helping students develop their ability to solve mathematical problems, which is considered a significant part of their learning performance [2]. Several studies have focused on the significance of mathematical proficiency in solving problems as one of the key outcomes of learning mathematics and have suggested various instructional strategies to advance it among students [3].

Self-regulated learning is the ability of students to control themselves to learn or work successfully according to set goals [4]. It has been suggested that self-regulated learning is positively reflected in students' problem-solving ability, which is an important mathematical competency [5]. This corresponds with the findings of Altun and Erden [6], who noted that self-regulated learning significantly affects mathematics performance. Students who demonstrate greater self-regulated learning have a higher possibility of better academic achievement and are more successful in learning mathematics. Thus, enhancing self-regulated learning in mathematics is essential to prepare students for the future.

The student-centered educational philosophy aims to blend instructional approaches with cooperative learning to enable students to shift from passive learning to interactive knowledge building, stimulating motivation and a passion for learning, and enhance students' self-regulated efficiency [7]. In some areas, mathematical knowledge is gained from discovery and thinking [8]. These processes have been discussed extensively because they have an impact on the issues involved in teaching mathematics. A variety of learning activities should be used to assist students to gain knowledge of mathematics. Instructors should conduct teaching and learning so that students can apply mathematical knowledge beyond the information they have learned by helping all students to participate in mathematics learning, to collaborate in the enhancement of their learning performance [9]. Generally, in a normal classroom, cooperation in activities is usually undertaken by students who have an outstanding mathematical ability, such as answering questions, commenting, or presenting. Some traditional approaches may affect students' mathematical performance and cause anxiety [10]. This is consistent with the work of Justicia-Galiano *et al*. [11], who found that learning anxiety affects mathematical computation and performance. In our experience, learning that encourages independent study through the use of computer technology and electronic media assists students to work on their own, including controlling their own learning. Constructive mathematical issues help students study difficult concepts in terms of the ways they can apply them, making learning less boring. Such approaches encourage students to actively participate in learning by interacting appropriately with instructors and peers to achieve further goals [12]. The aforementioned interaction between various individuals can be increased in an interactive learning model in a cooperative setting. In cooperative learning, students are divided into small groups to create a collaborative learning environment and assist each other, reflecting the fundamentals of coexistence in society. This also helps students learn how to construct knowledge on their own.

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One of the teaching approaches based on the constructivist approach is the Predict-Discuss-Explain-Observe-Discuss-Explain (PDEODE) strategy [13]. In a learning environment involving this strategy, students' discussions as well as their various perspectives and collaboration are encouraged [1, 14]. Hence, it supports an interactive classroom environment through class discussion, and adapting pedagogy methods to social context conditions has become the basis for enhancing students' learning ability in mathematics teaching in higher education institutions. Previous studies show that cognitive abilities such as conceptual understanding, problem-solving, achievement, or even motivation can be developed through the PDEODE strategy [1, 3, 13, 14].

In terms of the educational context, technological change, and competencies required by the job market, students need to be proficient in mathematics [15]. The scope of education has evolved from the utilization of technology and digital devices [16, 17]. In the Information Age, technological devices are used to improve and modernize education in many countries [10]. The adoption of cloud technology is increasing due to its impact on teaching and learning by connecting with conventional educational technology [18, 19]. Cloud technology, including cloud-based applications, offers possibilities to improve interactive learning. Many aspects of the implementation of constructivist features and cooperative learning have been enhanced with cloud-based technologies [20]. For instance, Google apps allow users to share and edit documents at the same time, while also keeping a digital record of group members' collaboration.

As educational cloud technology advanced, using such platforms became important to encourage students in developing their learning [17, 18, 21, 22]. In our experience, lecture-based teaching may prevent teachers and students from interacting and communicating as they should. One of the benefits of cooperative learning is that it reinforces a true understanding of the content of a particular topic [23, 24]. Thereby, students can comprehend the material to develop their self-regulated ability. This provides the opportunity for students to be actively involved in learning mathematics in the classroom and enhance their mathematical development. Students' ability to self-regulate their learning also makes mathematics more meaningful and creates a beneficial environment [5]. A learning approach that integrates the framework of cooperative learning and the concept of constructivist theory incorporated in the PDEODE strategy, as well as the use of cloud technology tools, may be reflected in the learning outcome. Thus, this study was carried out to analyze its effectiveness in enhancing self-regulation among students in tertiary education. This may suggest to instructors or educators how they could benefit as well as enabling them to apply the results to achieve their particular goals for mathematics education.

As mentioned previously, the objective of this study was to investigate the self-regulation scores achieved by undergraduate students after they have participated in an interactive learning model in a cooperative setting based on the PDEODE strategy using cloud technology compared to the criterion of 60%. In addition, this work also aimed to study the increase in the self-regulated learning of undergraduate students following the above-mentioned intervention, and to compare the self-regulation in mathematics learning between the groups that followed this method and a conventional one.

The main research question formulated in this study is whether interactive learning in a cooperative setting based on the PDEODE strategy using cloud technology affects self-regulation in learning. How this approach, compared to a conventional method, influences the ability to self-regulate is also considered.

II. Literature Review

A. *An Interactive Learning Model in a Cooperative Setting*

An interactive learning model is considered a teaching approach with an emphasis on knowledge construction concerning the problem-solving abilities of students [24, 25]. It can be any teaching strategy involving students in the learning process and making them accountable for understanding and implementing the material [9, 26], in which classroom interaction and the learning experience methods are determined from the course learning context [27]. There are two key principles involved in interactive learning [23], including the development of understanding and the mental thinking process, and it is likely to have a profound effect on activating knowledge in solving problems. The interactive learning approach provides an interplay between the thinking of instructors and students [24]. Instructors assign tasks that encourage students to think mathematically to establish the concept being taught and apply mathematical rules as strategies for planning to solve problems [25, 28]. Social interaction among students and instructors is important in interactive learning activities, and is also significant for building knowledge and enhancing academic skills [29].

Cooperative learning serves as a form of group study for students to practice collaborative skills in working together to achieve the same learning goals. The advantages of cooperative learning for students are that: (a) students can aid each other through learning activities; (b) they serve as intelligent student tutoring groups; and (c) normal interactions between students and groups can improve their understanding of group members' lesson content as well as improving their communication in order to achieve the desired goal [30]. There are studies on the implementation of this strategy to enhance students' learning in various aspects, such as achievement or thinking skills. Ling *et al*. [31] found that cooperative learning assists students to attain better achievement in mathematics than non-cooperative learning strategies. Similarly, Nugroho *et al*. [29] noted that there was an interaction between interactive learning in a cooperative setting and students' interpersonal intelligence on mathematics achievement. In addition, students learning with the cooperative model develop better mathematical critical thinking abilities than those using the conventional approach [23]. In addition, educational literature has indicated positive effects on other aspects, such as motivation [28] and learning satisfaction [7].

The interactive learning model in a cooperative setting adopted in this study consists of five phases as follows: Introduction, Activity or solution to a problem, Presentation and Discussion, Cover, and Assessment [23].

B. The PDEODE Strategy for Mathematics Education

The PDEODE strategy is considered a form of interactive learning based on constructivist theory [3, 13]. The key concept of the strategy is to stimulate thinking with mathematical questions or problems for students to predict, discuss, exchange ideas, analyze, compare, observe, collect data, and interpret to achieve a conceptual clarification of phenomena and mathematical solutions [32].

Such strategies involve group discussions, predictions, interpretations, and finding solutions which tend to rely on the awareness and observation of students' own thoughts [33]. These indicate the important role of the instructors in providing guidance and encouraging students to participate in small group collaboration and discussion [34, 35]. Using this strategy for students has the advantage of providing an interactive learning environment that supports students in collaborating with their colleagues in groups as they solve problems or discuss predictions, thereby linking prior knowledge with new information [3, 13]. Costo [36] suggested the six steps of the PDEODE strategy, consisting of predict, discuss, explain, observe, discuss, and explain, which can be employed to structure learning activities.

The use of this strategy has been studied in the development of school students in various aspects such as problem-solving ability, conceptual understanding [3], learning achievement and motivation [1, 34]. The results indicated that the experimental group using the PDEODE strategy had higher academic outcomes than the control group. Similarly, Al-Kassi and Al-Qahtani, [14] found that the PDEODE strategy positively affects the enhancement of first-grade students' metacognition skills. Some studies have employed this strategy in science teaching. For example, Al-Shahrani [37] noted that there were differences between experimental and control groups in terms of achievement and creative thinking, with the experimental group who were taught with the PDEODE strategy demonstrating a better performance. Implementing the PDEODE strategy for mathematics education is not restricted to improving students' cognitive performance, but also enhances their confidence as well as divergent thinking [35].

C. Cloud Technology in Teaching Mathematics

As information and communication technologies are viewed as a learning tool in the classroom and as a way for students to attain familiarity with innovative technologies, stakeholders and educational institutions are interested in the employment of these devices as a means for teaching and learning [38]. To empower mathematics learning with key competencies needed in the 21st century, cloud technology-based education is required [39]. Cloud technology has enabled the development of systems as well as cloud-based applications that support and assist students, and, importantly, the cognition and technological skills of higher education students represent aspects of the development of the teaching profession in the future [40].

As the main attributes of an interactive learning model include student-oriented learning, using more than one medium of expression or communication [41], cloud technology, particularly cloud-based tools, is an interesting approach to cooperative learning that serves as the theoretical foundation for mathematics instruction. There are a number of aspects involved in utilizing cloud tools in teaching and learning. In terms of cooperative learning, this can include applying cloud technology-based intellectual tools in blended learning with practical skills, for learning resources, and exchanging ideas among students to enhance creative skills [42]. According to Wang and Wu [7], cloud tools were utilized as a form of online cooperative learning and this significantly positively correlates with the problem-solving abilities of college students. The study of Aberbach *et al.* [43] revealed the effectiveness of the proposed recommendation system in the context of an e-learning environment in providing advice on learning topics in response to students' preferences.

D. Self-Regulated Learning

Self-regulation is regarded as the personal ability to regulate the cognitive process, perception, and supervising of thinking, including the individual's strategies for handling emotions and behaviors associated with environmental change [44]. According to Zimmerman [45], the theoretical foundation of self-regulated learning includes cognition, metacognition, and motivation. It consists of three aspects as follows: planning—the determination of objectives and stages of learning or performance as a guideline for performing tasks effectively, for example, the need for students to analyze in order to find solutions to mathematical problems; supervision—an examination and review of the appropriateness and validity of the selected methods and procedures used in learning or performing tasks; and assessment—an examination of the results obtained from learning or performance, which will ensure that the results are accurate and consistent with the objectives set [46]. In learning, there is a need for self-control, which is key to completing academic work [40]. Self-regulation in the educational process including mathematics learning is a fundamental pillar required in academic performance because it comprises stimulating skills for learning, the combination of qualities that form an individual's distinctive character, which affects the recommended approach [43], and future academic success [47]. The higher their self-regulation ability, the greater the possibility that individuals will be good at coping with problems [45, 48].

Self-regulated learning in mathematics refers to the ability of individuals to acquire knowledge and skills for solving mathematical problems through self-control [49, 50]. This is supported by Joyce *et al*. [51], who stated that it was related to learning mathematics using technology through the Internet, especially cloud technology as a learning medium to acquire such knowledge and skills. Enhancement of the ability to self-regulate is part of the socio-cultural theory-based learning that has impacted the mathematics curriculum in recent years [52]. Social cognitive researchers have highlighted three determinants of self-regulation in mathematics learning [45, 53]: personal, behavioral, and environmental influence. Self-regulated students can take responsibility for their own learning progress and plan for choosing the appropriate learning strategies to achieve a task, which could be enabled or practiced via certain instructional strategies [54]. Thus, it is important to support, improve, and maintain self-regulated skills which can be empowered through the use of appropriate instructional approaches and learning environments in the digital age [55, 56]. The cooperative learning strategy is one of those considered suitable for enabling students to advance into self-regulation, as these learning strategies emphasize the learning process, including group discussion, social interaction, and assessment [30]. These encourage students to be self-organized, plan, and assess their learning and their own thinking to solve problems [57, 58]. In the authors' views, to achieve complete mathematical knowledge or skills, it is necessary to rely on an important assumption that students will have a tendency to acquire knowledge or develop other capabilities. If students can control their emotions and behavior in the learning environment well, they will be more likely to generate new meanings or to develop experiences for successful mathematics studies based on them. As stated previously, ability of self-regulation is indubitably reflected in success in learning, solving mathematical problems. The framework of the PDEODE strategy has a foundation in constructivism theory. As such it can be practiced and instructed using a model of interactive learning based on the PDEODE strategy.

Based on the related studies mentioned, few works have incorporated cooperative learning models with other mathematics teaching techniques or cloud technology in the educational process of undergraduate students. We have therefore eliminated this gap by adopting the PDEODE strategy in a cooperative setting with the use of cloud technology to study undergraduates' self-regulated learning in the context of a mathematics course.

III. Method

A. The Research Design

This study was designed as quantitative research. A quasi-experimental research approach with a randomized control-group pre-test–post-test design was employed [59], in which one group was randomly given the intervention (experimental group) and another received no intervention (control group). The experimental group was taught with the interactive learning model in a cooperative setting based on the PDEODE strategy using cloud technology, and the control group with the conventional method. The level of self-regulated learning was investigated after the intervention in order to determine the effects.

B. Sample

The sample for this study was selected using a simple random sampling method and consisted of 60 undergraduate students in a mathematics department enrolled in the set theory course at a university in Thailand. The sample comprised 17 male (28.33%) and 43 female (71.67%) students between the ages of 20 and 21. The experimental class and the control class each included 30 students.

C. Research Procedure and Implementation

The study was carried out for one semester in the context of a mathematics course with the following stages.

Stage 1: the participants were given a pre-test survey to assess their self-regulation ability.

Stage 2: learning and instruction for the set theory course were conducted with the interactive learning model in a cooperative setting based on the PDEODE strategy using cloud technology (see Table 1) for students in the experimental group and with a conventional method for the control group.

Table 1. The syntax of the PDEODE strategy utilized for an interactive learning model in a cooperative setting using cloud-based technology

Learning phase	Learning strategies and activities	Cloud technology used
Introduction	a) The instructor provides the materials for learning b) The instructor displays the problem or situation to be explored to the students **Prediction stage** c) The instructor gives the students the chance to guess the solution to the displayed situation	Content creation tools (Google Docs), cloud storage (Google Drive)
Activity or solution to problem	a) Catch students' attention by reminding them about lesson materials they will study **Discussion stage** b) Group work—organize students into groups and have each group discuss their own experiences, predictions, and ideas to acquire the predictions that everyone in the group agrees on. These modes are supported via file sharing in the cloud c) Students consider the lesson content carefully and carry out activities and assignments regarding the lesson	Cloud collaboration tools, content creation tools, communication tools
Presentation and discussion	a) The results of the group work are shown in presentations developed by the students **Explanation stage** b) Each group of students gives reasonable arguments for the solution they agreed on, and the group exchanges their own solution with the other students. This step provides a logical argument for their predictions c) During the group presentations, the instructor promotes the use of questions to stimulate mathematical thinking that links the representations of relevant mathematical symbols	Presentation tools, communication tools, Google Sheets, data gathering tools (Google Drive)
Cover	a) Interactions between instructor and students via opinions; the students find more online learning resources and share them with peers in the group; investigation of their opinions and solutions' validity **Observation stage** b) The instructor fosters a good learning environment for exchanging ideas through group discussions to present and discuss suggestions **Discussion stage** c) Class discussions; discussion of reasoning for the group's consensual and non-consensual results from observations and predictions and to correct any inconsistencies	Data gathering tools, cloud-based mathematical applications, cloud collaboration tools
Assessment	a) Collaborative reflection **Explanation stage** b) The instructor allows for other groups to give suggestions in response c) Students evaluate their peers' work and activities	Data gathering tools, cloud reflection tools (online notebook, Google apps), content creation tools (Google Docs, Google Slides, Google Meet)

Stage 3: after completing the course, all participants in both groups were given the self-regulated learning questionnaire which included the same set of items as the pre-test one.

Stage 4: the self-regulation scores were analyzed to investigate the effectiveness of the proposed instruction approach.

The syntax of the PDEODE strategy for interactive learning in a cooperative setting using cloud technology that we utilized as a framework in this study is outlined in Table 1. The learning activities employed included group work, student presentations, class discussions, collaborative reflection, and peer and self-evaluation.

D. Research Instrument

The instrument for data collection in this study involved a scale for assessing self-regulation in learning mathematics, which was adapted from literatures [44, 48], because its strategies represented behavior consistent with mathematics learning and individual, behavioral, and environmental self-regulation. It evaluated the characteristics of self-regulation in mathematics learning in 10 areas as follows: 1) self-evaluation; 2) self-organization and transforming transformation; 3) goal-setting and planning; 4) seeking information; 5) keeping records and monitoring; 6) environmental structuring; 7) giving self-consequences; 8) rehearsing and memorizing; 9) seeking social assistance; and 10) reviewing records. It considered self-regulation in three aspects: 1) individual self-regulation; 2) behavioral self-regulation; and 3) environmental self-regulation. There were three items for each area, totaling 30 items. It employed a four-point rating scale from 1 (none/seldom) to 4 (every time/most of the time) for students to choose the answers that corresponded to the level of their practices, and a total score of 120. High scores indicated higher self-self-regulation in mathematics than low scores. All items of the questionnaire were investigated and appraised regarding their content validity and construct validity by three experts in mathematics education before it was distributed to the participants. The Cronbach's Alpha reliability coefficient for the questionnaire was 0.73, which was considered to be in the appropriate range.

E. Data Analysis

The data used for analysis in this study were the self-regulation scores obtained from students' responses to the self-regulation scale. The scores represented their ability to self-regulate in learning mathematics. The prerequisite tests with regard to the students' self-regulation included one to evaluate the normal distribution of samples using the Kolmogorov-Smirnov test, as well as Levene's test to assess the homogeneity of the sample variance. The self-regulation scores were analyzed by descriptive statistics such as the mean and standard deviation. A one-sample t-test was utilized to examine the self-regulation scores compared to the 60% criterion, and the independent sample t-test was deployed to investigate whether there was a difference in the means of the self-regulation scores for the post-experimental and control groups. To determine the increase in students' self-regulation in learning, the normalized gain (n-gain) was calculated with the following formula [60]:

$$\text{n-gain} = [(X_m - X_n)/(100 - X_n)],$$

where n-gain is the normalized gain, X_m is the post-test score, and X_n is the pre-test score. The criteria for interpreting the n-gain level were as follows [59]: n-gain ≥ 0.7—high, 0.3 ≤ n-gain < 0.7—medium, and n-gain < 0.3—low.

The level of significance alpha considered in the Kolmogorov-Smirnov normality test was α = 0.05. The following hypotheses were used in the test, H_0: data were normally distributed, and H_a : data were not normally distributed. If the significant value was below 0.05, H_0 was rejected, i.e., H_a was accepted, and if the significant value was above 0.05, H_0 was accepted.

The level of significance (α = 0.05) was determined in Levene's test. If the significant value was below 0.05, H_0: data were homogeneous and rejected. If the significant value was above 0.05, H_0 was assumed.

The prerequisite test analysis including the normality and homogeneity tests for the post-test self-regulation scores for both groups are presented in Tables 2 and 3, respectively.

Table 2. Analysis of the Kolmogorov-Smirnov normality test for the self-regulation score

Group	Statistic	df	Sig.
Experiment	0.089	30	0.200
Control	0.101	30	0.200

Table 3. The analysis of homogeneity test for self-regulation score

	Levene statistic	df1	df2	Sig.
Self-regulation score	0.069	1	58	0.794

Table 2 shows the normality test based on the Kolmogorov-Smirnov analysis. For the experiment and control group post-test scores, the significance value was 0.200, which is greater than 0.05. This implies that both the scores for the experiment and control groups were normally distributed.

Table 3 shows the results for the homogeneity tests of the self-regulation scores. The significant score for the experimental group was 0.794, which is higher than 0.05. This means that the data were homogeneous.

According to these tests, the data were normally distributed with equal variances. These could be analyzed further with a one-sample t-test to compare with the 60% threshold, and an independent sample t-test to determine the difference that occurred in the mean scores for self-regulated learning in the experiment and control groups with a 5% significance level.

IV. Results

In this study, we intended to examine undergraduate students' self-regulated learning following an intervention involving the proposed approach.

A. The Self-Regulated Learning of Undergraduate Students

The results for the self-regulated learning of undergraduate students against the criterion of 60% of the full score are presented in Table 4.

Table 4. The analysis of students' self-regulated learning compared to the required level

	N	Test value	Mean	SD	95% CI	t	df	Sig.
Experiment	30	72	85.53	5.54	[12.09,14.96]	18.89	29	0.000*

*Significance level of 0.05.

Table 4 presents the descriptive statistics depicting students' self-regulated learning. The full self-regulation score was 120, so the expected value was 72. This shows that after the implementation of the intervention, the students had mean scores for self-regulation ability equal to 85.53. Based on the one-sample t-test, this was higher than the 60% threshold with statistical significance at the 0.05 level.

B. The Self-Regulated Learning of Undergraduate Students in the Experimental and Control Groups

In this section, the comparison between the experimental and control groups in terms of their self-regulated learning is examined. The study of the enhancement of students' self-regulated learning analyzed by *n*-gain is presented in Table 5.

Table 5. The normalized gain score for self-regulated learning according to learning approach

Group	N	Score		Range	Mean	SD	Category
		Min	Max				
Exp.	30	0.42	1.22	0.80	0.53	0.16	Medium
Cont.	30	0.01	0.90	0.89	0.31	0.20	Medium

According to Table 5, the mean n-gain for the self-regulated learning of the experimental group was 0.53, while for the control group it was 0.31. Although both groups increased their self-regulation skills in the medium category, the experimental group result was numerically higher than that for the control group. Hence, this proposed approach was verified as more effective for enhancing performance with regard to students' self-regulated learning than the conventional method.

To examine the significance of the finding above, the independent sample t-test was applied to investigate the difference between the post-test self-regulation scores of the experimental and control groups. The results are depicted in Table 6.

Table 6. The comparison of post-test self-regulation scores based on the learning approach

Group	N	Mean	SD	95% CI	t	df	Sig.	Effect size
Exp.	30	85.53	5.54	[3.41,9.38]	11.72	58	0.000*	1.12
Cont.	30	79.13	5.81					

*Significance level of 0.05.

As shown in Table 6, the mean post-test score for the experimental group was 85.53, while for the control group it was 79.13. The mean difference between the post-test scores of both groups was 6.40. The independent sample t-test revealed that the t value was 11.72. The significance value was 0.000, which is less than 0.05. This means there was a statistically significant difference (α = 0.05) between the experimental and control group in the post-test scores assessing self-regulation. In regard to the effect size, the Cohen's d was 1.12, which is at a high level. According to the findings, the approach involving an interactive learning model in a cooperative setting based on the PDEODE strategy using cloud technology has a statistically significant positive influence on self-regulated learning at the 0.05 level.

V. Discussion

This study employed cloud technology in a cooperative learning environment using the PDEODE strategy. After the implementation of this approach, the mean self-regulation score was 85.53, which exceeded the specified criterion of 60% of the full score. The authors attribute this finding to the following reasons. In the strategies utilized, students have the opportunity to practice thinking and are encouraged to reflect on their mathematical learning. The instructor encouraged the conversation to elicit the students' answers, sometimes discussing them simultaneously, and to share ideas via cloud applications. While one student presents, the rest of their peers will ask questions for explanations or revisions, which represents attempts to obtain more information from other sources when assigned a task during the cover phase. This approach makes students motivated to succeed in learning mathematics. This finding is supported by previous studies [1, 6, 14, 28, 58]. In the assessment phase, students review their own work and that of their peers, indicating that they begin to assess the quality and progress of their efforts. This demonstrates self-regulated learning in terms of self-evaluation, i.e., students checking their understanding after work and discussions with peers in the group. This follows [56], who suggest that self-regulated learning depends on a type of personal influence, as well as the learning context, especially the components of the work performed and the circumstances. Additionally, the proposed teaching approach contributes to the interaction between three aspects, the personal, environmental, and behavioral components, which is believed to result in self-regulation processes in accordance with the social cognitive learning theory [1, 34].

The students who learned by the interactive learning model based on the PDEODE strategy with cloud technology demonstrated their increased self-regulation level with a mean n-gain of 0.53, which was numerically higher than that demonstrated by the control group at 0.31. This may be because of the self-regulation ability that students improved through the learning activity process. The support of cloud technology in practical learning activities makes it possible to explore the consensus of online resources in team discussions. During rational argumentative situations, students convince each other to participate in ongoing discussions. These signify that cloud mathematical tools, as independent learning resources, are practical devices that can enhance students' ability to regulate themselves to gain knowledge and skills and advance their learning [18, 48]. This finding conforms to the study of Wang and Wu [7], which shows that the use of cloud technology in a cooperative setting improves the self-regulated ability for problem-solving. It also corresponds with the viewpoint of Fung *et al.* [51] that students take control of their personal usage of cloud tools to acquire knowledge and problem-solving skills as well as the learning environment through interactive learning and small group discussion. In these processes, students learn to organize and plan to solve problems [53, 57]. Another finding revealed that the mean score for self-regulated learning from the post-test completed by the experimental group was 85.53, better in comparison to students taught with the conventional method at a 0.05 significance level. This outcome is in line with the work of Al-Kassi and Al-Qahtani [14], who indicate that the PDEODE strategy has a positive effect on the development of students' metacognitive self-regulation. On the basis of these findings, we recommend incorporating cloud technology into an interactive learning environment to promote greater self-regulation in mathematics learning.

However, this study was limited to a sample of third-year students in a government university in Thailand. Regarding the time limit, this approach was used for one semester in a set theory course. As the data used for analysis were self-regulation scores provided by the participants, this may have introduced errors because they completed the questionnaires by themselves. This work was also limited in that it only examined one psychological variable. Other cognitive variables, like academic coping strategies or thinking skills, may also be affected by this instructional approach.

VI. CONCLUSION

In this study, the integration of cloud technology into an interactive learning model in a cooperative setting using the PDEODE strategy was proposed. This work achieved the research objectives, which were guided by the following key questions: whether students' self-regulation in learning after implementation would achieve the set criterion of 60%, and what the advantage of using an interactive learning model based on the PDEODE strategy with cloud technology in mathematics instruction is on improving self-regulation in mathematics learning among undergraduate students. The findings show that the students' mean self-regulation score was 85.53, statistically significant and exceeding the 60% threshold at the 0.05 level. The increasing self-regulation level of the experimental group was in the medium category, with a mean n-gain of 0.53, higher than the control group, which had a mean n-gain of 0.31. The mean post-test score of the experimental group for self-regulation was 85.53, statistically significantly higher than the control group's mean score of 79.13 at the 0.05 level. This indicated that the interactive learning model based on the PDEODE strategy with cloud technology significantly outperformed the conventional approach.

According to the findings of this analysis, the utilization of the PDEODE strategy in combination with interactive learning supported by cloud technology for teaching mathematics has been demonstrated to be effective in improving self-regulation in mathematics learning. It may be considered one of the strategies employing educational technology which empowers self-regulated learning. Thus, the authors recommend the following: various educational cloud technologies should be incorporated into the PDEODE strategy for teaching mathematics and supported by an interactive learning environment. A study applying the aforementioned approaches to develop learning competencies, such as conceptual understanding, procedural understanding, and increasing students' problem-solving skills, should be carried out. The instructional process, including the instructor, is an important factor and should involve the design and provision of an appropriate learning environment to develop self-regulation in learning. Further works could consider other theories regarding cooperative learning.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

BC carried out the literature review, conducted the research, collected and analyzed the data, wrote the paper; AA conceived and designed concept of the study, drafted the literature review, evaluated designing analysis presentation, reviewed and corrected manuscript. All authors have read and approved the final version.

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