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The Influence of TPACK, ICT, HOTS, and 4C on Students' Mathematical Concept Understanding

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Abstract: This research was conducted to determine whether there is an influence of TPACK, ICT, HOTS, and 4C on students' understanding of mathematical concepts. This study used a quasi-experimental design involving two sample classes: an experimental class and a control class. The research instruments included observation sheets to assess the implementation of teaching activities by the teacher and student engagement during the learning process, as well as a test sheet to measure students' understanding of mathematical concepts. The data analysis techniques used were descriptive analysis to describe teacher and student activities during the learning process and to determine the categories of students' understanding of mathematical concepts, as well as inferential analysis to test the research hypothesis. The results of this study indicated that: (1) the percentage of teacher activity implementation using TPACK, ICT, HOTS, and 4C had an average of 87.5%; (2) the percentage of student activity in improving mathematical concept understanding with the application of TPACK, ICT, HOTS, and 4C had an average of 82%; and (3) based on the hypothesis test, it can be indicated that there is a significant difference in the average mathematical concept understanding of students. Therefore, it can be concluded that TPACK, ICT, HOTS, and 4C have an influence on students' understanding of mathematical concepts.

Keywords: hots; ict; mathematical concept understanding; tpack.

INTRODUCTION

Mathematics is a compulsory subject that equips students with the ability to think logically, critically, and creatively (Rachmantika & Wardono, 2019). Although often perceived as difficult, these skills are crucial in the modern era. A challenge for teachers, as stated by (Widayati, 2022), is to make mathematics learning more enjoyable so that students are not afraid and become more interested in learning. The current approach to mathematics instruction remains teacher-centered, which tends to be monotonous, leading to passive and disengaged students. As a result, students struggle to understand mathematics because they are not directly involved in the application of the material to everyday life.

One of the goals of mathematics education, according to (Depdiknas, 2006), is to understand concepts. Developing students' understanding of mathematical concepts is an important challenge in mathematics learning, as it is a primary objective and part of the graduate competence standards. Conceptual understanding is key in mathematics education (Radiusman, 2020). A lack of conceptual understanding can affect students' ability to progress to more advanced levels, as it serves as the foundation for more complex concepts.

According to the KKBI (Depdiknas, 2008), "understand" refers to a correct understanding or view of something, while "understanding" is the process of mastering or comprehending something. Understanding is the ability to grasp the meaning of a concept and express it in one's own way, even if the words used differ from those in a book, as long as the meaning remains the same (Novitasari, 2016). Therefore, understanding is the process of comprehending something and being able to express it based on one's own thoughts. According to the KKBI, a "konsep" is a design, idea, or understanding of something. A concept is an idea that helps a person categorize objects as examples or non-examples (Fajar, et al., 2018). This indicates that a concept is a tool for identifying objects based on their characteristics (Novitasari, 2016).

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Mathematical concept understanding is the ability of students to deeply comprehend basic mathematical concepts and procedures (algorithms), and to apply them flexibly, accurately, efficiently, and appropriately in various situations (National Council of Teachers of Mathematics, 2000). The indicators of conceptual understanding, according to (Lestari & Yudhanegara, 2015), are as follows: (1) restating learned concepts; (2) classifying objects based on their concepts; (3) applying concepts algorithmically; (4) providing examples or counterexamples of a concept; (5) presenting concepts in various representations; and (6) relating various mathematical concepts either internally or externally.

Several issues with mathematical concept understanding include low conceptual understanding among students at SMP Widya Bhakti Ruteng, as indicated by students' inability to solve problems that focus on mathematical concept understanding after being given a test (Adrianus, et al., 2019). Similarly, students at SMP Negeri 12 Kendari in class VIII also exhibit low mathematical concept understanding, as evidenced by their difficulty in understanding problem statements and their inability to distinguish between the given information and the problem's requirements (Anzar, et al., 2019).

At SMP Negeri 5 Kendari, class VIII also experiences similar symptoms of low mathematical concept understanding, where students are unable to fully grasp mathematical concepts. This is indicated by the results of observations conducted through the test answers given by the teacher to the researcher, which show that students struggle to choose procedures or alternative answers, as well as to draw conclusions from the problems. Additionally, students' low interest in mathematics is due to the lack of innovation in teaching methods. In line with the teacher interviews, it was also revealed that the learning outcomes in class VIII at SMP Negeri 5 Kendari need improvement. The lack of mathematical concept understanding among class VIII students at SMP Negeri 5 Kendari is caused by several interconnected factors, including the students, teachers, teaching models, and the learning environment. The student-related factors include: (1) lack of interest in mathematics, resulting in students only listening to what the teacher presents; (2) memorizing formulas without understanding the concepts; (3) dependency on the teacher and lack of initiative to seek information; (4) difficulty in understanding problems; and (5) lack of concentration during lessons. Teacher-related factors include the inadequate implementation of the STAD cooperative learning model in a comprehensive manner, without involving all innovative components such as collaboration, ICT, 21st-century skills (4C), and literacy. As a result, students feel bored, and their understanding of mathematical concepts remains low, which impacts their learning outcomes. To improve students' mathematical concept understanding, it is crucial to design learning that encourages students to build their own knowledge and supports conceptual understanding.

To improve students' mathematical concept understanding, innovative learning needs to be applied. Innovative learning refers to learning activities that incorporate the latest learning elements of the 21st century and are integrated into the components and stages of the learning process to achieve the learning objectives. Innovative learning with TPACK (Technological, Pedagogical, Content Knowledge) is a framework that integrates three key aspects, which, when applied in education, can enhance students' conceptual understanding. These three components are as follows: (1) Content Knowledge (CK): Teachers with deep understanding of the content can provide clearer and more comprehensive explanations of the concepts being taught (Shulman, 1986); (2) Pedagogical Knowledge (PK): Using appropriate pedagogical strategies, such as problem-based learning, discussions, or collaborative learning, can help students better understand concepts (Grossman, 1990); and (3) Technological Knowledge (TK): Using supporting technology, such as educational software or visual aids, can make concepts more interactive and easier to understand (Mishra & Koehler, 2006).

Innovative learning components that can improve students' mathematical concept understanding, according to the indicators, include the following: (1) Collaboration between students and teachers: In the learning process, class discussions allow students to share ideas, ask questions, and receive feedback from the teacher and peers, which helps students understand concepts from various perspectives (Vygotsky, 1978); (2) HOTS-oriented: One aspect of HOTS, analysis, helps students break down information into smaller parts to understand the structure and relationships between parts. This is a crucial step in deeply understanding concepts, as it allows students to explore details and organize information in a structured manner (Bloom, 1959); (3) Integrating Information and Communication Technology (ICT): The use of ICT in learning provides access to articles, videos, and other digital materials, enabling students to explore and deepen concepts from various perspectives (Koehler & Mishra, 2009); (4) 21st Century Skills (4C)-oriented: Critical thinking, communication, collaboration, and creativity can enhance concept understanding by allowing students to analyze, express, collaborate, and create innovative solutions (C21, 2015); (5) Developing literacy skills: Developing literacy skills, including reading, writing, digital, and media literacy, can improve concept understanding by enabling students to access, analyze, and convey information effectively from various sources (Leu et al., 2013); (6) Character Education Knowledge (PKK): Character education that emphasizes positive values can help students better understand mathematical concepts and develop character in problem-solving.

Innovative learning is closely related to concept understanding. Teachers need to continue innovating in their teaching practices according to students' characteristics and available support. This innovation is implemented in four stages: planning, implementation, monitoring, and evaluation. The implementation of innovative learning can enhance students' understanding of concepts through relevant techniques and approaches. A study by (Gunawan et al., 2020) developed a TPACK-based mathematics learning tool at SMPN 17 Tanjung Jabung Timur to improve the critical thinking skills of class VIII students. Using a research and development (R&D) approach, the tool was designed to integrate content knowledge, pedagogy, and technology. After being trialed, the results showed a significant improvement in students' critical thinking skills. The use of technology in learning also received positive feedback, as it facilitated students' understanding of the material. Overall, the TPACK-based learning tool was proven to be effective and can be applied to improve the quality of mathematics education in other schools.

This study fills the gap in the literature by developing and applying innovative learning based on TPACK elements and incorporating ICT, HOTS, and 4C components to enhance students' mathematical concept understanding. This innovative learning approach provides concrete solutions to the problems identified in previous studies, which revealed low student understanding of concepts and minimal engagement in mathematics learning. It is hoped that through the implementation of innovative learning integrated with technology and 21st-century skills, students' mathematical concept understanding will improve, ultimately enhancing their overall learning outcomes.

METHODS

This study is a quasi-experimental research. The population consists of all 8th-grade students of SMP Negeri 5 Kendari. The sample for this study was selected randomly by class, with class $VIII_K$ as the experimental group and class $VIII_H$ as the control group, using the posttest-only control group design. The instruments used in this study are as follows: (1) Observation Sheet: The observation sheet includes the implementation of the lesson by the teacher, such as whether the teacher successfully applies the planned learning steps, as well as the use of technology and innovative strategies. Additionally, student engagement is observed, including their participation in discussions, collaboration, and the application of mathematical concepts during the learning activities. This observation aims to assess how effectively the learning process is carried out and how actively students engage in understanding the material; (2) Mathematical Concept Understanding Test: This test is used to measure students' understanding of mathematical concepts.

In this study, data analysis used two techniques: descriptive analysis and inferential analysis. Descriptive analysis is used to describe the activities of the teacher and students during the learning process and to categorize the level of students' understanding of mathematical concepts. On the other hand, inferential analysis is used to test the hypothesis using the t-test (Independent-Samples T test in SPSS 25.0 software) with the following decision criteria: (1) The percentage of teacher activity implementation in the experimental class is higher than in the control class; (2) The percentage of student activity in improving conceptual understanding in the experimental class is higher compared to the control class; (3) Based on the hypothesis test, it can be indicated that there is a significant difference in the average mathematical concept understanding between the experimental class and the control class. Before conducting the hypothesis test, prerequisite tests such as normality and homogeneity tests are carried out to ensure the data meets the requirements before further testing.

RESULTS AND DISCUSSION

The results of the observation regarding the implementation of teaching by the teacher in both the experimental and control classes from the first to the fourth meeting can be seen in Figure 1.

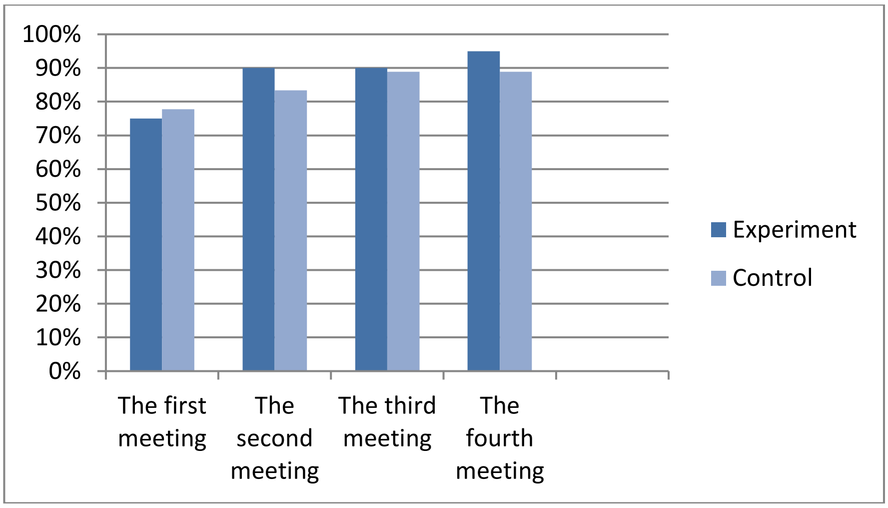

Figure 1. Diagram of Teacher Activity Distribution in the Experimental and Control Classes

The results of the observations regarding the teacher's activity in the experimental and control classes during the mathematics learning process on the circle topic show improvement from meeting to meeting. In the experimental class, during the first meeting, the success rate reached 75% as the teacher was still adjusting to the new method, had limited guidance in group activities, and did not use time effectively. By the second meeting, the success rate improved to 90%, although there were still shortcomings in appreciating student presentations and summarizing the material. In the third meeting, the success rate remained at 90%, but new challenges arose, such as a lack of guidance for student preparations. In the fourth meeting, the success rate increased to 95% after the teacher reflected and adjusted the time management, though there were still slight shortcomings in preparing students for the lesson. The average implementation of the learning activity design was 87.5%, with 12.5% of the activities not being carried out. The overlap from all the meetings indicates that some aspects of the learning activities were not fully applied, particularly in the teacher’s guidance before the lesson began. Pre-lesson guidance is crucial for creating an optimal environment for understanding the concepts taught. However, the activities that were not carried out had a minimal impact on the concept understanding, as the percentage of unimplemented activities was only 2.5%.

In the control class, the teacher's activity observations showed that during the first meeting, the achievement of all aspects of learning reached only 77.77%, categorized as "good." This was due to the absence of a question-and-answer session during the apperception phase and the lack of guidance in drawing conclusions at the end of the lesson, which made students less active. In the second meeting, success improved to 83.33%, categorized as "very good," although there were still some shortcomings, such as the lack of prompting questions and insufficient guidance in drawing conclusions. In the third and fourth meetings, the success rate increased to 88.88%, but the same issues persisted, including the absence of prompting questions and a lack of direction with the presented problems. Overall, the observations indicated that the teacher needed time to adapt to the innovative teaching method used, as reflected in the increasing percentage of indicator achievement in each meeting. The average implementation of the learning activity design was 84.72%, with 15.28% of the activities not being carried out. The overlap from all the meetings suggests that there were activities that were not fully applied, such as the teacher’s lack of guidance in drawing conclusions at the end of the lesson. Proper guidance in summarizing is essential to ensure students truly understand the material and can connect it with prior knowledge. However, similar to the experimental class, the unimplemented activities did not have a significant impact on concept understanding, as the percentage of unimplemented activities was only 2.77%.

The results of the observations on student activities during the learning process, related to the activities aimed at improving students' understanding of mathematical concepts in the experimental and control classes from the beginning to the fourth meeting, can be seen in Figure 2.

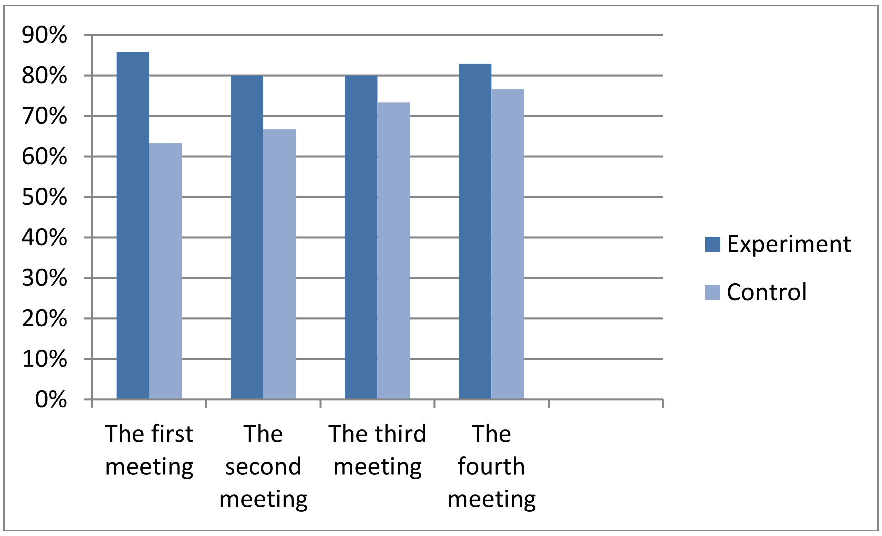

Figure 2. Diagram of Student Activity Distribution Related to Activities for Improving Mathematical Concept Understanding in the Experimental and Control Classes

The results of the observation of student activity in mathematics learning aimed at improving students' understanding of mathematical concepts in the experimental class are as follows. In the first meeting, the success rate reached 86%, with 14% of activities not fully implemented. These shortcomings included students not answering the triggering questions, not observing the instructional video shown, not answering the teacher's questions, and not asking about the issues presented in the Student Worksheet (LKPD). In the second meeting, the success rate was 80%, with 20% of activities not carried out. This was due to students not answering the teacher's triggering questions, not responding to questions about the problems given, and not summarizing the material at the end of the lesson. In the third meeting, the success rate was 80%, attributed to several learning activities not being properly implemented. Students again did not answer the teacher's triggering questions, did not respond to questions related to the problems presented, did not observe the problems and videos shown, and failed to summarize the material at the end of the lesson. In the fourth meeting, the success rate reached 82.85%, with some activities not carried out. These included students not answering the teacher's triggering questions, not responding to questions about the problems presented, and not summarizing the material provided. The average success rate achieved was 82%, with 18% of the activities not implemented. These include students not answering triggering questions, not observing the problems and videos shown, not answering the teacher's questions, and not summarizing the material at the end of the lesson. The failure to carry out these activities can affect students' understanding of mathematical concepts, which can be indicated by the following indicators: restating the concepts learned, classifying objects based on their concepts, applying concepts algorithmically, providing examples or counterexamples of a concept, presenting the concept in various representations, and linking different mathematical concepts internally or externally.

Meanwhile, the results of the observation of student activity in mathematics learning aimed at improving students' understanding of mathematical concepts in the control class are as follows. In the first meeting, the success rate reached 63.33%, with 36.67% of activities not fully implemented. In the second meeting, the success rate increased to 66.66%, with 33.34% of the activities not carried out. In the third meeting, the success rate rose to 73.33%, with 26.67% of the activities not implemented. In the fourth meeting, the success rate reached 76.66%, with 23.34% of the activities not carried out. The incomplete implementation of activities in the first, second, third, and fourth meetings can be indicated by the following issues: students not answering the triggering questions from the teacher, students not observing the problems presented by the teacher, students not engaging in discussions while working on the Student Worksheet (LKPD), students not asking questions to the teacher related to the LKPD, students not presenting their group work results, and students not summarizing the material given at the end of the lesson. With an average success rate of 70%, there were 30% of the learning activities that were not carried out. These include students not answering triggering questions, not observing the problems from the teacher, not engaging in discussions while completing the LKPD, not asking questions to the teacher regarding the LKPD, not presenting their group work results, and not summarizing the material provided. The incomplete implementation of these activities can negatively affect students' understanding of mathematical concepts, as indicated by the following indicators: restating the concepts learned, classifying objects based on their concepts, applying concepts algorithmically, providing examples or counterexamples of a concept, presenting concepts in various representations, and linking different mathematical concepts internally or externally.

The distribution of posttest scores on mathematical concept understanding for students taught in the experimental and control classes can be seen in Table 1.

Table 1. Distribution of Posttest Data on Students' Mathematical Concept Understanding

No	Value	Category	Experimental Class Frequency	Experimental Class Percentage (%)	Control Class Frequency	Control Class Percentage (%)
1	86 – 100	Very Good	0	0	0	0
2	71 – 85	Good	17	47,22	4	10,53
3	56 – 70	Satisfactory	6	16,67	10	26,31
4	41– 55	Low	13	36,11	18	47,37
5	0,00 – 40	Very Low	0	0	6	15,79
	Total		36	100	38	100

Based on Table 1, the distribution of students' understanding of mathematical concepts can be visualized in the diagram below.

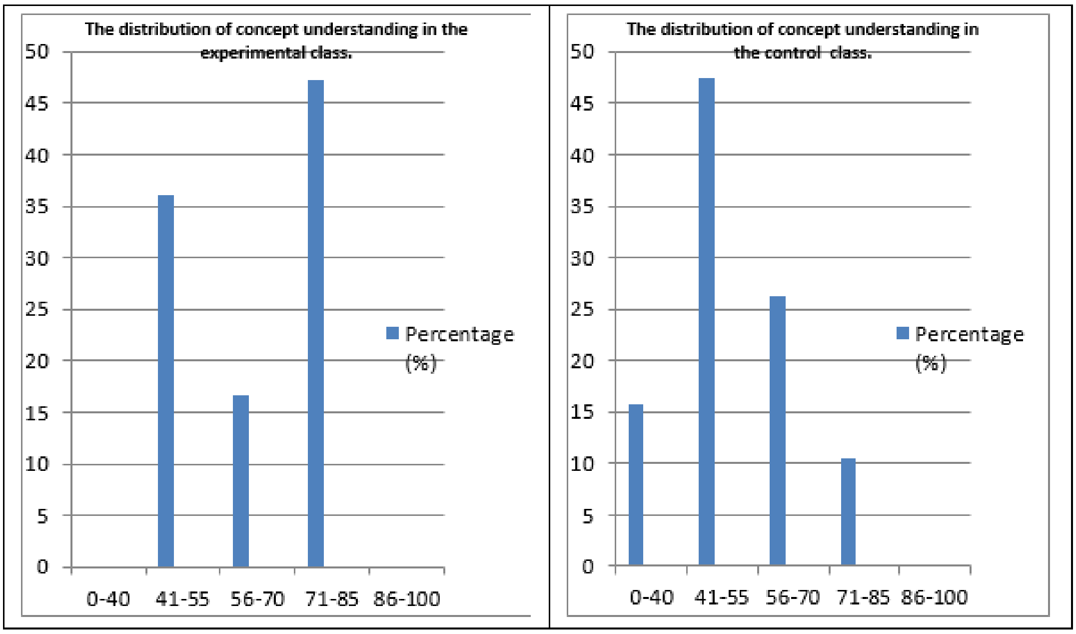

Figure 3. Distribution Diagram of Students' Mathematical Concept Understanding in the Experimental and Control Classes per Indicator

Based on the distribution of posttest scores, the results of mathematical concept understanding in the experimental and control classes show a significant difference. In the experimental class, 17 students (47.22%) were in the good category, 6 students (16.67%) in the sufficient category, and 13 students (36.11%) in the low category. Meanwhile, in the control class, 4 students (10.53%) were in the good category, 10 students (26.53%) in the sufficient category, 18 students (47.37%) in the low category, and 6 students (15.79%) in the very low category.

In innovative learning, it can be indicated that there is a positive impact on increasing the number of students who achieve good scores and reducing the number of students with very low scores. However, there are still some students in the "sufficient" and "low" categories, which suggests the need for further evaluation of the implementation of TPACK, ICT, HOTS, and 4C. Meanwhile, in the class that did not apply TPACK, ICT, HOTS, and 4C, it was indicated that more participants were in the "low" and "very low" categories. This suggests that not implementing TPACK, ICT, HOTS, and 4C may be less effective in motivating students to achieve better results.

The difference is caused by the use of different teaching tools between the two classes. The experimental class prioritizes the TPACK (Technological Pedagogical Content Knowledge) approach, which enhances students' understanding of mathematical concepts. Additionally, the experimental class applies innovative learning that includes collaboration between teachers and students, HOTS (Higher Order Thinking Skills) orientation, integration of Information and Communication Technology (ICT), and the development of 21st-century skills (4C). Meanwhile, the control class lacks the integration of TPACK, ICT, HOTS, and 4C, which impacts the students' understanding.

The distribution of students' mathematical concept understanding per indicator for the experimental and control classes can be seen in Table 2.

Table 2. Level of Students' Mathematical Concept Understanding per Indicator in the Experimental Class and Control Class

No.	Indicator	Percentage of Experimental Class (%)	Category	Percentage of Control Class (%)	Category
1	Rephrasing the concepts that have been learned (M1)	78,47	High	75,65	High
2	Classifying objects based on their concepts (M2)	82,63	High	73,02	High
3	Applying concepts through algorithms (M3)	55,55	Sufficient	29,6	Low
4	Providing examples or counterexamples of a concept (M4)	72,22	High	55,92	Sufficient
5	Presenting concepts in various representations (M5)	74,3	High	65,13	Sufficient
6	Relating different mathematical concepts internally or externally (M6)	37,5	Low	30,26	Low

Based on Table 2, a diagram showing the distribution of students' mathematical concept understanding per indicator can be seen in the image below.

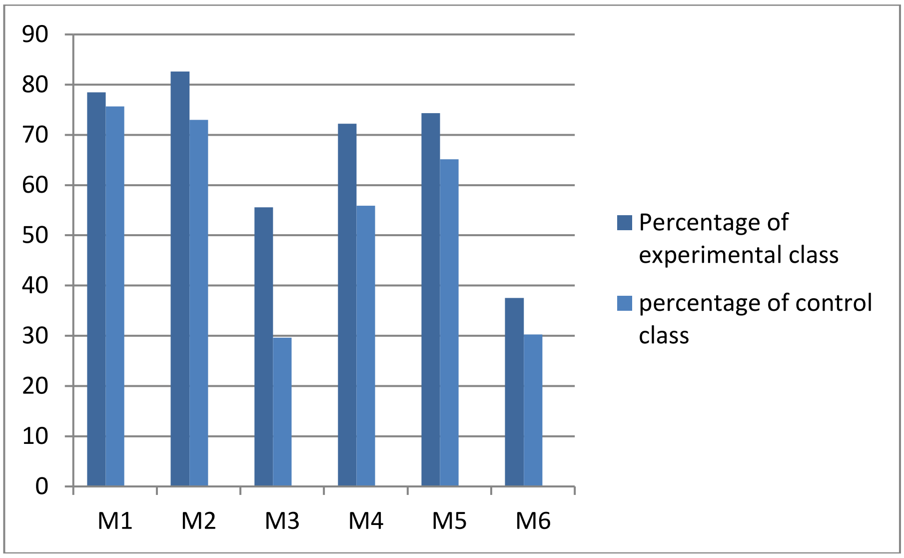

Figure 4. Distribution of Students' Mathematical Concept Understanding per Indicator

Based on the descriptive analysis of the posttest, from all the indicators above, the one that contributed the most to the mathematical concept understanding in the experimental class was the indicator of restating the learned concept, classifying objects based on their concepts, applying concepts through algorithms, providing examples or counterexamples of a concept, and presenting concepts in various representations. Meanwhile, in the control class, the indicators that contributed the most were restating the learned concept, classifying objects based on their concepts, providing examples or counterexamples of a concept, and presenting concepts in various representations. This indicates that, with an average of mathematical concept understanding, the experimental class performed better, with an average mathematical concept understanding of 66.06, compared to the control class, which had an average of 53.05. Data from the posttest of both the experimental and control classes were used in this analysis. Table 3 shows the results of the data normality calculation.

Table 3. Normality of Data on Mathematical Conceptual Understanding in the Experimental and Control Classes

Class	Sig	Description
Posttest experimental class	0.085	Normal
Posttest control class	0.067	Normal

Based on the normality test, the significance value for the experimental class is 0.067 (greater than α = 0.05), which means H_0 is accepted, and the posttest data on students' mathematical conceptual understanding in the experimental class is normally distributed. Similarly, for the control class, the significance value is 0.085 (greater than α = 0.05), which also indicates that the posttest data in the control class is normally distributed.

Then, the homogeneity test was conducted to determine whether the variance of the posttest data is homogeneous. The results of the homogeneity test for students' mathematical conceptual understanding in the experimental and control classes are presented in Table 4.

Table 4. Homogeneity of Mathematical Concept Understanding in the Experimental and Control Classes

Class	Sig	Description
Experimental Control	0.284	Homogen

Based on the homogeneity test, a significance value of 0.284 was obtained (greater than 0.05), which means H_0 is accepted. This indicates that the distribution of the posttest data in both the experimental and control classes has homogeneous variance. Since both groups' data are normally distributed and homogeneous, a hypothesis test was conducted using a t-test with the help of SPSS. The hypothesis testing was carried out to determine whether there is a difference between the experimental class and the control class. Table 5 below shows the calculation of the hypothesis test analysis.

Table 5. Hypothesis Test of Students' Mathematical Concept Understanding in the Experimental and Control Classes

Class	Sig. (2-tailed)	Description
Experimental Control	0.000	Reject H_0

Based on the results of the teacher's activity implementation in the experimental class, it is better compared to the teacher's activity implementation in the control class. Furthermore, the student activity in enhancing mathematical concept understanding in the experimental class is better than in the control class. Meanwhile, the students' mathematical concept understanding in the experimental class is also better than in the control class. This is indicated by the higher average success rate in the experimental class compared to the control class. The improvement in mathematical concept understanding in the experimental class is attributed to the influence of TPACK, ICT, HOTS, and 4C. With the t-test results, the sig. (2-tailed) value was found to be $< \alpha = 0.05$, thus H_0 is rejected and H_1 is accepted. The rejection of H_0 indicates that there is a significant difference in the average mathematical concept understanding scores between students taught using TPACK, ICT, HOTS, and 4C and those not using TPACK, ICT, HOTS, and 4C. Therefore, it can be concluded that innovative learning has a significant effect on students' mathematical concept understanding.

CONCLUSION

Based on the results of this study, several conclusions can be drawn as follows: (1) The percentage of teacher activity implementation in the experimental class is higher, with an average of 87.5%, compared to the control class with an average of 84.72%; (2) The percentage of student activity implementation in enhancing concept understanding in the experimental class is higher, with an average of 82%, compared to the control class with an average of 70%; (3) Based on the hypothesis test conducted, it can be indicated that there is a difference in the average mathematical concept understanding between the experimental class and the control class. Therefore, it can be concluded that innovative learning has an effect on students' mathematical concept understanding.

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