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Integration of Technology, Traduction, and Content in Mathematic Learning to Forther Higher Order Thinking Skills

Mas'ud B, Marwati Abd. Malik

Mathematics Education Department, Muhammadiyah University of Parepare
Email: umpar.masud@gmail.com

Abstract

This study examines the integration of technology, pedagogy, and content (TPACK) in mathematical learning to enhance the Higher Order Thinking Skills (HOTS) of students, including analysis, evaluation, and creation, in the era of the Fourth Industrial Revolution. (4IR). Using a quasi-experimental design, the study involved 60 students from 2nd Parepare State High School, Indonesia. The experimental group received mathematical learning with TPACK, while the control group used traditional methods. The results of statistical analysis showed a significant improvement in post-test and HOTS scores in the experimental group compared to the control group. Qualitative data also shows a positive perception of students towards technology-based learning, which improves engagement and understanding of abstract concepts. This research confirms that TPACK integration significantly improves HOTS students in mathematics learning, showing the importance of teacher preparedness and professional development for successful implementation. These findings made important contributions to mathematical education in the 4IR era.

Keywords: TPACK Integration; Higher Order Thinking Skills (HOTS); Quasi-Experimental Design; Fourth Industrial Revolution (4IR).

In the context of the 4.0 industrial revolution, integrating technology into mathematical education is essential to fostering higher thinking skills (HOTS) such as analysis, evaluation, and creativity. The Technology Content Pedagogy Knowledge Framework (TPACK) is an instrument in this integration, as it combines content knowledge, pedagogical knowledge, and technology knowledge, enabling educators to design effective and relevant learning strategies. For example, the use of innovative technologies such as VR applications, interactive video lectures, and collaborative projects has been shown to transform traditional teaching practices, transforming students from passive students into interactive and creative participants, thereby improving their learning performance and outcomes (Gou et al., 2023). Integrating these technological and pedagogical advances can significantly improve the teaching and learning of mathematics, making it more attractive and effective in developing HOTS students.

The successful implementation of TPACK in education hinges not only on the availability of technology but also on the readiness and competence of teachers to design meaningful learning experiences, manage pedagogical interactions, and deliver content tailored to students' needs. In the context of whole-school physical activity programs, the Creating Active Schools (CAS) initiative demonstrated that successful implementation is underpinned by factors such as acceptability, intervention complexity, and school culture, which are also relevant to TPACK implementation (Morris et al., 2023). Moreover, authentic assessment practices in teacher education, such as self- and peer-assessment, have been shown to foster reflection and critical thinking, which are crucial for teachers to adapt and thrive in technology-mediated learning environments (Ketonen et al., 2023). Additionally, outdoor learning experiences mediated by technology have proven effective in enhancing student teachers' understanding of complex concepts like biodiversity, suggesting that experiential learning can be a valuable component of TPACK training (Morris et al., 2023).

The integration of technology, pedagogy, and content knowledge (TPACK) is crucial for enhancing HOTS in mathematics education, especially within the framework of the Fourth Industrial Revolution (4.0) (Satang, 2024). Research indicates that while technology can stimulate students' higher-order thinking, many teachers do not utilize it effectively for this purpose, highlighting the need for understanding teacher attitudes and professional development tailored to different teacher profiles (Wijnen et al., 2022). The transformative approach to TPACK, which views it as a unique knowledge domain, has shown promising results in understanding technology-integrated instruction, particularly in science education, and can be extended to mathematics (Kadıoğlu-Akbulut et al., 2023). Historical trends in pedagogical content knowledge (PCK) frameworks, evolving into TPACK, have demonstrated their effectiveness in teaching mathematics, but empirical studies are needed to further explore their impact in the classroom (Habiyaremye et al., 2022).

The integration of technology, pedagogy, and content significantly influences students' improvement of HOTS in math learning, as evidenced by various studies conducted (Kiltz et al., 2023). Furthermore, preservice teachers who experienced emergency remote education reported higher levels of technological pedagogical content knowledge (TPACK), which is crucial for effectively integrating technology into teaching practices to improve student outcomes, including HOTS in math learning (Brianza et al., 2023). However, the transition to remote and blended learning also posed challenges, such as delayed peer relationship development and disrupted communication, which could impact the effectiveness of technology integration if not properly managed (Kennedy & Gill, 2023). The improvement rate of HOTS is likely higher in students who receive math learning with this integrated approach compared to those who receive conventional learning, as the former benefits from enhanced engagement, accessibility, and tailored instructional strategies.

The integration of technology, pedagogy, and content to enhance HOTS in mathematical learning is a multifaceted challenge that requires comprehensive and empirical research. Previous studies have often focused on isolated aspects, such as technology or pedagogy alone, leading to less effective outcomes in improving HOTS. For example, the study by Naidoo and Reddy highlights the importance of technology-based teaching methods in the Fourth Industrial Revolution (4IR) era, the focuses on the experiences and views of participants rather than a robust empirical integration of technology, pedagogy, and content (Naidoo & Reddy, 2023). Furthermore, Perry et al.'s systematic review of factors predicting mathematics performance in PISA identifies numerous individual, household, and school-related factors but lacks a detailed explanation of how these can be integrated to enhance HOTS (Perry et al., 2023). On the other hand, Goel's study on the temporal dynamics of number and letter processing using MEG data provides insights into early visual processing but does not address the pedagogical or technological integration needed for improving HOTS in mathematics (Goel, 2023).

The study by Banerjee et al. demonstrates the effectiveness of Collaborative Online International Learning (COIL) in fostering global citizenship education, which indirectly supports the development of HOTS by encouraging critical and comparative thinking among students from different cultural backgrounds (Banerjee et al., 2023). Scheiner's research further contributes by focusing on the critical skill of noticing students' strengths in mathematical thinking, which is essential for teachers to foster an environment that promotes HOTS (Scheiner, 2023). Moreover, Mulligan et al.'s interdisciplinary approach to teaching data modelling and statistical reasoning from an early age provides a solid foundation for developing HOTS, as students engage in problem posing, data generation, and inferential reasoning through inquiry-based investigations(McCluskey et al., 2023). Finally, Al-Rahmi et al. emphasize the role of digital media in enhancing academic performance and satisfaction in HEIs, suggesting that the integration of digital media platforms can significantly improve students' active learning and knowledge exchange, which are crucial for developing HOTS (Al-Rahmi et al., 2023).

The research on the TPACK framework in mathematics learning is pivotal as it addresses critical constraints such as technology availability and teacher readiness, which are essential for enhancing students' HOTS. The study by Kadıoğlu-Akbulut et al. findings suggest that desktop software, emerging ICTs, and hardware significantly contribute to different dimensions of TPACK, such as designing, implementing, and planning, thus providing a nuanced understanding of technology-integrated instruction (Kadıoğlu-Akbulut et al., 2023). Moreover, Bjelobaba et al. propose a Collaborative Learning and Student Work Evaluation (CLSW) model using blockchain technology to enhance teaching and learning environments, ensuring data security and promoting student-centered learning, which aligns with the goals of TPACK (Bjelobaba et al., 2023).

Literature review

Holistic Education in Mathematical Learning

Holistic education in the context of mathematical learning emphasizes not only the development of academic skills but also the nurturing of character traits such as critical thinking, creativity, and social empathy, which are essential for facing real-world challenges. The humanistic role of teachers, characterized by integrity, dignity, and freedom, has been shown to significantly impact students' mathematics achievement. Factors such as fair treatment, enthusiasm, and moral support from teachers are crucial predictors of success in mathematics learning (Joshi et al., 2022). Furthermore, interdisciplinary approaches that combine mathematics with science, as seen in the Interdisciplinary Mathematics and Science Learning project, have been effective in developing students' data modelling and statistical reasoning from an early age. This approach encourages problem posing, data generation, and inferential reasoning, fostering a deeper understanding of mathematical concepts (Mulligan et al., 2023).

Higher Order Thinking Skills (HOTS) in Mathematical Learning

Higher Order Thinking Skills (HOTS) are essential in mathematics education as they enable students to engage deeply with mathematical concepts, fostering critical analysis, evaluation, and creativity. Recent studies underscore the importance of HOTS in enhancing students' analytical and problem-solving abilities. For instance, a study on a virtual makerspace learning design, which aligns with Self-Determination Theory, demonstrated significant improvements in students' spatial reasoning, creativity, and anxiety reduction, particularly benefiting those with initially low spatial reasoning scores (Fowler et al., 2023). This suggests that environments promoting autonomy and competence can effectively nurture HOTS. Additionally, the development of numerical simulations in cardiovascular research highlights the role of advanced computational techniques in solving complex problems, which parallels the analytical and evaluative skills emphasized in HOTS (Pepe et al., 2023). Furthermore, research on the temporal dynamics of number and letter processing using magnetoencephalography (MEG) reveals that early visual processing is distinctly shaped by experiences with numbers and letters, indicating that HOTS can be fostered through targeted cognitive training (Goel, 2023).

Integration of Technology in Mathematical Learning

The integration of technology into mathematical learning significantly improves high-order thinking skills (HOTS) by providing students with tools such as mathematics software, modeling applications, and interactive simulations, which facilitate a deeper and more interactive understanding of complex mathematic concepts. The PICRAT model, as discussed by Wang, provides a structured framework for integrating innovative technology into teaching, transforming students from passive students into interactive and creative students, leading to improved learning outcomes and improved student performance in mathematics (Wang, 2023). The interdisciplinary approach to data modeling and statistical considerations in early education, as illustrated by Mulligan et al., suggests that involving students in problem formulation, data generation, and interpretation through technology can develop their statistical thinking and argument skills from an early age, more supporting the development of critical and analytical thinking skills in mathematics (Mulligan et al., 2023).

Effective Pedagogy in Mathematical Learning

Research shows that active, collaborative, and project-based learning methods contribute significantly to the development of these skills. For example, an interdisciplinary approach that combines mathematics and science through survey-based research has shown that students can engage in data modelling and statistical considerations from an early age, thereby promoting critical thinking and problem-solving skills (Mulligan et al., 2023). Factors such as fair treatment, enthusiasm, and moral support from teachers are significant predictors of success in learning mathematics (Khadka et al., 2023). Positive factors include student values and family socio-economic status, while negative factors include absenteeism, bad behavior, and teacher deficiencies (Perry et al., 2023). In addition, the development of unconnected computational thinking resources, such as the CT Obstacle Course, has been effective in introducing problem-solving skills to students without formal computer science training, thereby supporting learning at various skills levels and promoting teamwork and communication (Lehtimäki et al., 2023).

Content Integration in Math Learning

The integration of relevant and contextual content in mathematics learning is crucial to fostering high-level thinking skills as well as increasing student engagement and motivation. For example, the role of a humanistic teacher, characterized by integrity, dignity, and freedom in an online classroom, has proven to have a positive impact on students' mathematical learning achievements. Factors such as fair treatment, enthusiasm, and moral support from teachers are significant predictors of student success, emphasizing the importance of a supportive and attractive learning environment (Khadka et al., 2023). Finally, a teacher education program that aims to shift the focus of prospective teachers from deficit-based thinking to strength-based thought in mathematics education reveals that critical reflection on student mathematical thinking can produce more effective teaching strategies that emphasize students' strengths and potential (Scheiner, 2023).

Materials and methods

Research Design

This study used a quasi-experimental design, utilizing non-equivalent control groups. This design is selected to compare two groups of students: one group receiving mathematical learning with integration of technology, pedagogy, and content (an experimental group) and one group accepting conventional learning (Control Group).

Research Subject

The subject of the research was a student of the State Secondary School of 2nd Parepare Indonesia who was selected purposively by sampling. The sample consists of two classes of approximately 30 students each. The first class (experimental group) will receive mathematical learning with the integration of technology, pedagogy, and content, while the second class (control group) would receive conventional mathematics learning.

Research Variable

The research was carried out in three departments of the southern region of Peru: Apurímac, The study has two variables: the independent variable and the dependent variable. Independent variables: Integration of technology, pedagogy, and content in mathematical learning. Dependent variable: High-level thinking skills (HOTS) of students measured through the HOTS test before and after intervention

Research Instruments

The tools used in this study include: (1) HOTS Tests: These tests are designed to measure students' high-level thinking skills, which include analytical, evaluative, and creative abilities. The tests will be given before and after the treatment for measuring the improvement in HOTS skills, (2) questionnaires: questionnaires are used to gather demographic data and additional information about students' perceptions of the learning they receive, (3) Class Observations: The observations are performed to see directly how the integration of technology, pedagogy, and content is applied to learning and how students respond to such learning methods.

Research Procedures

The study was conducted using the following procedures: first, a Pre-Test: Before the intervention, all students from both groups will be given a HOTS test to measure their initial abilities. Second, after the Pre-test, learning will be carried out against the experimental group and the control group. Experimental groups, students in this group will receive mathematical learning with technology integration (e.g., the use of mathematics software and interactive simulation), pedagogy (eg., project-based and collaborative learning), and content (eg, contextual and real-life-relevant problems), Control groups: Students in these groups will receive Mathematics learning with conventional methods (For example, lectures and routine exercises). During the learning period, class observations will be carried out to observe the application of learning methods and student interactions. Third, after the intervention, all students will be given the same HOTS test to measure the improvement in their high-level thinking skills. Fourthly, a questionnaire will be given to students to collect data about their perception of the methods of learning received.

Data Analysis

The data collected from the Pre-Test and Post-Tests will be examined using both descriptive and inferential statistics. Coupled-tests are utilized to compare the scores of pre-tests and post-tests within each group. Uncoupled tests are employed to assess disparities in post-test scores between experimental and control groups. Qualitative analysis, data from the questionnaire will be qualitatively analyzed to give a deeper insight into the process and student perception of the learning received.

Hypothesis 1: "Application of Technology, Pedagogy, and Content Integration to Higher Order Thinking Skills (HOTS) students in mathematical learning". To answer the first hypothesis, the statistical hypotheses are formulated as follows:

$$H_0: \mu_1 = \mu_2 \ against \ H_1: \mu_1 \neq \mu_2$$

Acceptance criteria Hypothesis: If p-value < 0.05: H_0 rejected or H_1 accepted. If p –value 0.05 : H_0 accepted or H_1 rejected.

Hypothesis 2: "There is a significant difference in the level of improvement in high-level thinking skills between students receiving mathematical learning with the integration of technology, pedagogy, and content with students who receive conventional learning." To answer the second hypothesis, the statistical hypotheses are formulated as follows:

$$H_0: \mu_{gK} = \mu_{gE} \ against \ H_1: \mu_{gK} \neq \mu_{gE}$$

Acceptance criteria Hypothesis: If p-value < 0.05: H_0 rejected or H_1 accepted. If p –value 0.05 : H_0 accepted or H_1 rejected.

Hypothesis 3: “Application of Technology Integration, Pedagogy, and Content Effective Improvement of Higher Order Thinking Skills (HOTS) students in mathematics learning”. To answer the hypothesis 3 the following statistical hypotheses are formulated based on the above 3 criteria.

$$H_0: \mu_{gK} = \mu_{gE} \ against \ H_1: \mu_{gK} \neq \mu_{gE}$$

Acceptance criteria Hypothesis: If p-value < 0.05: H_0 rejected or H_1 accepted. If p –value 0.05 : H_0 accepted or H_1 rejected.

Results

Descriptive Statistical Analysis Results

Results of descriptive statistical analysis of pre-test and post-test data for control groups and experimental groups are presented in Table 1.

Table 1. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Experiment Group Pre-Test Value	30	30	55	44.83	6.226
Experiment Group Post-Test Value	30	70	100	85.33	6.940
Control Group Pre-Test Value	30	30	65	44.50	7.807
Post-Test Value of Control Group	30	45	85	63.83	9.348
Ngain Control Group	30	.00	.70	.3348	.19901
Ngain Experiment Group	30	.45	1.00	.7281	.13523
Valid N (listwise)	30				

Results of Inferential Statistical Analysis

The results of inferential statistical analysis for testing the normality of pre-test and post-test data in both control and experimental groups are displayed in Table 2.

Table 2. Tests of Normality

Group		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pretest	Control Group	.208	30	.002	.937	30	.077
	Experiment Group	.163	30	.040	.934	30	.063
Postest	Control Group	.141	30	.133	.967	30	.469
	Experiment Group	.149	30	.086	.958	30	.271
Ngain	Control Group	.097	30	.200*	.957	30	.266
	Experiment Group	.097	30	.200*	.982	30	.886

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 1, describes the results of normality tests using the Kolmogorov-Smirnov and Shapiro-Wilk tests, post-test data and Ngain data, for both groups showing normal distribution (p > 0.05). For pre-tests, control group data and experiment data are not normally distributed according to the Kolmogorov–S Mirnov tests (p < 0.05), but are normally distributed by the Shapiros-Wilks test (p> 0.05). In conclusion, the post-test and Ngains data meet the normality assumptions, while the pre-Test data require further interpretation or the possibility of using non-parametric tests.

Below is a summary of Levene Test results for Error Variance Equality, presented in Table 3.

Table 3. Levene's test of equality of error variances

		Levene Statistic	df1	df2	Sig.
Pretest	Based on Mean	.367	1	58	**.547**
	Based on Median	.299	1	58	**.586**
	Based on Median and with adjusted df	.299	1	51.887	**.587**
	Based on trimmed mean	.467	1	58	**.497**
Postest	Based on Mean	1.998	1	58	**.163**
	Based on Median	1.850	1	58	**.179**
	Based on Median and with adjusted df	1.850	1	52.963	**.180**
	Based on trimmed mean	1.992	1	58	**.164**
Ngain	Based on Mean	3.471	1	58	**.068**
	Based on Median	3.434	1	58	**.069**
	Based on Median and with adjusted df	3.434	1	50.712	**.070**
	Based on trimmed mean	3.471	1	58	**.068**

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Group

Table 3 explains the Levene's Test of Equality of Error Variances test results, the error variance for pre-test, post-test and Ngain values between groups is the same. All test results show that there is no significant difference in the variance of error between the groups. Thus, the assumption of homosexuality is met, which means that the variation of error of the dependent variable is consistent and equivalent for both groups.

Results of inferential statistical analysis of intergroup influence tests, presented in Table 4.

Table 4. Tests of Between-Subjects Effects

Dependent Variable: Postest

Source	Type II Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	6946.344[a]	2	3473.172	50.525	.000	.639
Intercept	8150.745	1	8150.745	118.572	.000	.675
Group	6943.944	1	6943.944	101.016	.000	.639
Pretest	12.594	1	12.594	.183	.670	.003
Error	3918.239	57	68.741			
Total	344625.000	60				
Corrected Total	10864.583	59				

a. R Squared = .639 (Adjusted R Squared = .627)

Table 4, describes that the model corrected significantly explains variations in the student's post-test values. Group factors show significant influence on the post-test values, with a significant contribution to data variability. On the contrary, the pre-test value does not have a significant impact on the after-test valuation, suggesting that the students' initial abilities have no significant impact after the treatment. Overall, this model explaines most variability in the data, which indicates that the given treatment has a significant and significant effect on student learning outcomes.

The results of inferential statistical analysis of independent sample tests are presented in Table 5.

Table 5. Independent Samples Test

Levene's Test for Equality of Variances		t-test for Equality of Means						
							95% Confidence Interval of the Difference	
F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
3.471	.068	-8.954	58	.000	-.39333	.04393	-.48126	-.30540
		-8.954	51.073	.000	-.39333	.04393	-.48152	-.30514

Table 5, shows that the variance between groups can be considered equal. The t test showed significant differences between the experimental and control groups in the value of Ngain. These results showed that the improvement in learning outcomes in experimental groups was significantly greater than in the control groups. This significant average difference reinforced the conclusion that learning methods applied to experimental group were more effective in improving the student learning outcome.

Results of inferential statistical analysis of a single sample test, presented in Table 6.

Table 6. One-Sample Test

	Test Value = 0.3					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Ngain of Experimental Group	17.342	29	.000	.42814	.3776	.4786

Based on the results of the One-Sample Test for the value of the experimental group, as outlined in Table 6, it was found that the average value of experimental groups differs significantly from the set comparative value, namely 0.3. The test results showed that the improvement in the learning outcome of the group is significantly higher than that of the comparative. The 95% confidence interval for the average difference also does not include a value of 0.3, which reinforces the conclusion that the learning method applied to the group effectively improves student learning outcomes above comparative values.

Qualitative Analysis Results

The qualitative analysis resulted in the percentage of respondents responding to each statement. Based on the calculations, the following are the average respondent percentages for each category of 10 statements given: highly agreed 34.0%, agreed 47.0%, disagreed 12.33%, highly disagreeed 6.7%. This explains that the majority of the respondents showed a positive perception of mathematical learning integrated with technology, pedagogy, and content. The high percents in the categories "very agreed (34%)" and "agreed (47%)" indicated that students felt significant benefits from the use of technology in mathematics learning.

The integration of technology into mathematical learning has shown significant benefits, in facilitating understanding of abstract concepts and increasing student interest and motivation. Participants in this study, including graduate students and mathematics school teachers, emphasized the value of technology in making abstract math concepts more understandable and interesting to students (Naidoo & Reddy, 2023). This is in line with the need for further training for teachers to optimize the use of technology in mathematics education (Edstrand & Sjöberg, 2023). The benefits of digital tools in teaching and learning, as experienced by university teachers, include practical and administrative benefits, time and place independence, and pedagogical benefits such as improving learning and developing teaching methods (Kallunki et al., 2023).

Discussion

The study presents a comprehensive model for integrating technology, pedagogy, and content in mathematics education, aimed at increasing student engagement and fostering critical and creative thinking skills, which are essential to preparing students for future challenges. In addition, the Remote Classroom Modelling (RCM) model proposed by Rizk, Taylor, and Taylor emphasized the importance of participatory involvement and expert support in developing technological, pedagogical, and teacher content knowledge, which is essential for the successful implementation of such integrated learning models (Rizk et al., 2022). Adopting the PICRAT model by Wang in a linguistic course shows how systematic integration of various technologies can transform traditional practices and transform students into interactive and creative students, thereby improving learning outcomes (Bao & Hosseini, 2023).

The future research directions suggested for expanding the sample to various learning contexts and geographic regions to enhance the generalizability of findings are well-founded. This approach aligns with the need for a broader understanding of how TPACK can be effectively integrated across different educational settings and subjects. The study by Çakiroğlu and Aydın highlights the importance of developing TPACK during emergency remote teaching (ERT), suggesting that instructors rated their non-technological knowledge higher than their technological knowledge, indicating a gap that needs addressing through diverse educational contexts and subjects (Çakiroğlu & Aydın, 2023). The comprehensive approach of integrating technology, pedagogy, and content in mathematical learning, as mentioned, can benefit from the robust methodologies used in social media engagement studies, which provide a taxonomy of quantitative and behavior-based metrics that could be adapted for TPACK research(Tarifa-Rodríguez et al., 2023). Furthermore, the review by van Wijngaarden et al. on educational programs for integrated care in medical education underscores the importance of experiencing complexity and adaptive expertise, which can be paralleled in TPACK research to understand the multifaceted nature of integrating technology in education(Wijngaarden et al., 2023). While the study on quasifission mechanisms in superheavy nuclei by Mcglynn and Simenel may seem unrelated, the rigorous methodological approach and detailed analysis of complex systems can inspire similar thoroughness in TPACK research, ensuring that diverse qualitative and quantitative methods are employed to gain deeper insights into the process and impact of TPACK integration (Mcglynn & Simenel, 2023).

The Integration of TPACK in mathematical education has shown significant improvements in student's High Order Thinking Skills (HOTS), such as analysis, evaluation, and creativity, compared to conventional learning methods (Çakiroğlu & Aydın, 2023). The humanistic role of teachers, including their enthusiasm, moral support, and understanding of students' limitations, has proven to significantly predict student achievements in mathematics, suggesting that a supportive and comprehensive teaching approach is essential for student success. In addition, interventions designed to support English as Additional Language (EAL) students in acquiring pre-algebraic knowledge and skills also show that students who receive instruction with visual and linguistic support, and who leverage their native language knowledge, outperform their peers in both mathematics and academic dictionaries (August et al., 2023).

Conclusions

The integration of technology, pedagogy, and content in mathematics learning shows a significant influence on student HOTS improvement. This marked the results of descriptive and inferential statistical analysis showing a significant improvement in the post-test values and the value of the experimental group in comparison with the control group.

There is a significant difference in the rate of HOTS improvement between students who receive mathematical learning with the integration of technology, pedagogy, and content compared to students receiving conventional learning. It marked the t-test results for the Ngain values showing significant differences between the experimental group and the control group, with experimental groups showing greater improvements.

The integration of technology, pedagogy, and content has proven to be effective in improving HOTS students in mathematics learning. It is characterized by results of inferential statistical tests, including t tests and variance analysis, showing that the TPACK method contributes greatly to student variability and improvement of learning outcomes. Qualitative analysis also shows positive perceptions of students towards technology-based learning, with the majority of students feeling that technology helps them understand abstract concepts, improves learning motivation, and facilitates practical application of mathematical concepts.

Conflicts of Interest

The authors have no conflicts of interest. Study sponsors did not affect the study design, data analysis, manuscript writing, or publication decision.

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