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Knowledge retention of students learning mathematics with culture and technology: A study of junior high school students

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Abstract

The transition from Pedagogical Content Knowledge (PCK) to Technological-Pedagogical-Content Knowledge (TPACK) underscores the need for a more meaningful integration of technology into mathematics teaching. Yet, this paradigm shift has not been accompanied by substantial gains in students' conceptual understanding and mathematical problem-solving skills, which are the central focus of the present study. The purpose of this study is 1) to describe the differences in the increase in students' mathematical ability (conceptual understanding and problem solving) in culture and technology-based learning and conventional learning, and 2) to describe the effects of both types of learning on student knowledge retention. This study is a quasi-experimental study comparing culture- and technology-based learning and conventional learning. The instrument used in this study is a mathematical ability test (pretest and posttest). Data analysis uses a difference-of-means test (N-Gain), t-test, two-way ANOVA, and MANOVA. The results show that the average increase in the culture and technology-based learning group is higher than that in the conventional learning group and is significantly different. There is a significant interaction effect between learning and mathematical ability ($p<0.05$, effect size $\lambda = 0.996$), the main effects of time periods pretest, posttest-1, & posttest-2 were significant ($p< 0.05$, effect size $\lambda = 0.217$), the main effects of mathematical ability on culture and technology based learning and conventional learning were also significant ($p< 0.05$, effect size $\lambda = 0.215$). These findings suggest that integrating technology and culture is an effective approach for providing a positive learning experience that promotes improved mathematical skills and longer-term knowledge retention. This sustained information retention is important for educational practice because it enables students to transfer and apply the concepts they have learned to future learning situations.

Keywords:
Culture, Knowledge retention, Technology

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1. INTRODUCTION

21st-century learning is an educational concept aimed at developing comprehensive student competencies with the goal of adapting to change and supporting students to become active participants in global competition. There are four competencies that characterize 21st century learning, namely communication, collaboration, critical thinking, and creativity, which must be systematically integrated into the curriculum and classroom learning (Trilling & Fadel, 2009; Voogt & Roblin, 2012). In addition to these four competencies, recent developments emphasize information literacy, digital literacy, and the ability to apply conceptual knowledge to real-world problem solving as a measure of learning success (National Research Council, 2012). These competencies can be achieved through student-centered learning approaches, using or based on problems, project-based learning, and utilizing technology that has been proven to be effective in developing higher-order thinking skills, social skills, and other higher or more significant aspects of 21st-century skills (Hmelo-Silver, 2004; OECD, 2018; Wijaya et al., 2024). From these various learning approaches, the use of technology has become a greater concern due to its development trend, which has changed teachers' perspectives on how to use it in designing learning, implementing teaching practices, and evaluating learning at various levels of education.

Technology is no longer a supplement to learning but an integral part of the overall learning process due to the increasingly massive connections between learning environments. This transformation requires teachers to continuously develop themselves and their professional attitudes from the concept of Pedagogical Content Knowledge (PCK), which is a combination of mastery of subject matter and pedagogical strategies, to Technological Pedagogical Content Knowledge (TPACK), which is a conceptual framework that makes technology an equal part of learning or a complete combination of the subject matter to be delivered, the pedagogical approach used, and the technology that is effectively and meaningfully integrated into learning. The TPACK conceptual framework is an idea from Mishra and Koehler (2006), which is a development of the Pedagogical Content Knowledge (PCK) concept proposed by Shulman (2015), where technology is also an essential part that cannot be separated from pedagogy and content in modern learning practices. Technological Pedagogical Content Knowledge (TPACK) is the intersection of the domains of Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK) integrative knowledge for a teacher (Koehler et al., 2014).

Technological pedagogical content knowledge (TPACK) emphasizes that effective learning is the use of technology that depends on the characteristics of the content and the pedagogical strategies that are established (Voogt et al., 2013). Thus, the use and integration of technology in learning is seen as a reinforcement of contextual, adaptive pedagogical practices and a transformation of current learning, rather than merely a replacement for conventional learning media (Alptekin & Taneri, 2025; Hidayat et al., 2025). Furthermore, current developments emphasize a shift from the integrative TPACK model to a transformative model in which technology helps shape new models of education, represents knowledge, and facilitates more innovative and meaningful learning activities (Schmid et al., 2020). In mathematics learning, the TPACK model is important for teachers to design learning activities in a harmonious combination of content, pedagogy, and technology that makes learning more interactive, meaningful, produces new learning experiences, and increases longer knowledge retention stored in long-term memory (Sartika et al., 2025; Smiling & Hollebrands, 2025). Especially with the emergence of various technology-based media such as dynamic geometry software, computer algebra systems, interactive visualization applications, and online learning platforms.

Various studies on the integration of technology in mathematics learning practices strengthen and improve mathematical representation skills, supporting the visualization of abstract concepts so that students can perform various dynamic manipulations of mathematical objects, there by visualizing the relationships between concepts. These activities support better cognitive development and contribute positively to the development of mathematical thinking skills and act as cognitive tools that support problem-solving and higher-order thinking processes (Drijvers et al., 2010; Li & Ma, 2010; Pierce & Stacey, 2010; Samo, 2019). Thus, adapting to technological developments and integrating them into mathematics learning is not only for procedural technical assistance but also reflects a paradigm shift in mathematics learning towards learning that is oriented towards the development of adaptive and transformative thinking skills .Nevertheless, most of these studies still focus on the role of technology as a tool for visualization and general cognitive support, and few have explicitly examined how technology is integrated with culturally meaningful learning contexts to foster contextual and transformative mathematical understanding. Thus, there remains a need to examine mathematics learning designs that not only utilize technology as a tool for representation but also integrate it with cultural contexts as a source of learning meaning

Along with this, technology provides space for representation, exploration, and formalization of real contexts, which ultimately strengthens the relationship between cultural contexts and their integration into mathematics learning. Culture can be represented using technology that strengthens its integration into mathematics learning. A number of studies show that the use of dynamic mathematics software and the integration of culture or the local learning environment, which are cognitive and cultural tools, greatly support the visualization, manipulation, and orientation towards mathematical structures contained in cultural practices (Drijvers et al., 2010; Hoyles & Lagrange, 2010). With these pedagogical actions, the integration of technology and culture not only increases engagement and mastery of mathematical concepts but also ultimately supports the development of higher-order thinking skills, making mathematics learning relevant to the demands of 21st-century learning.

Previous studies have shown that both technological and cultural approaches contribute positively to motivation, engagement, and understanding of mathematics. However, most of these studies still focus on the role of technology as a tool for visualization and cognitive exploration in general, and few have explicitly examined how technology is used to transform cultural practices into pedagogically structured objects of mathematical learning. In other words, there remains a gap in research examining the simultaneous integration of technology, local culture (ethnomathematics), and pedagogical design as a unified mathematics learning intervention, rather than merely the use of technology within a cultural context in isolation. This gap is significant because 21st-century mathematics learning demands not only conceptual mastery but also the ability to construct mathematical meaning that is contextual, reflective, and relevant to students' cultural experiences. Furthermore, few studies have examined the combined effects of both on knowledge retention. Most research focuses on the direct impact on learning outcomes, while analysis of how students retain knowledge after a certain period remains limited. This research is needed to address the existing gap.

This study investigates how the integration of culture and technology can shape a more meaningful mathematics learning experience and support knowledge retention among junior high school students. The findings are expected to enrich the literature on modern mathematics learning and provide new directions for teachers in designing contextual, relevant, and effective learning. The culture and technology based learning intervention in this study is an operational manifestation of the integration of content knowledge, pedagogy, and technology as described in the TPACK framework. The culture- and technology-based learning design used in this study represents the integration of the three main domains of TPACK, namely content knowledge (quadrilaterals), pedagogical knowledge (contextual, scientific, and culture-based experiential learning), and technological knowledge (the use of Android and GeoGebra). Thus, this intervention directly operationalizes TPACK through the alignment of what is taught (content), how concepts are constructed through cultural contexts (pedagogy), and how technology is used to strengthen conceptual understanding (technology).

2. METHOD

This research is quantitative, employing a quasi-experimental design. A quasi-experimental design was used in this research because: 1) The intervention was implemented in classes that had already been administratively formed at the school. From an ethical standpoint, individual randomization could disrupt class cohesion, the continuity of the learning process, and the established socio-pedagogical dynamics; 2) Class structure, lesson scheduling, and school policies limit the possibility of redistributing students into new treatment groups; therefore, a quasi-experimental design is considered more appropriate because it allows for a comparative evaluation of the effects of the two learning approaches and the control group within the context of real classrooms, while maintaining the ecological validity of the research so that the results are more relevant to learning practices in schools, 3) the researchers would like to gain knowledge about the development of mathematical ability (conceptual understanding and problem solving) through the application of the two types of learning (Culture and technology based learning and conventional learning); and 4) the researchers controlled many variables, such as student characteristics, learning environment conditions, and other factors that occur during what is considered normal instruction, which affected the students' mathematical ability, except the learning variable as a single independent variable that would be measured for its effect on the dependent variable, namely mathematical ability. The quasi-experimental design can be presented as follows.

$$\begin{array}{lllll} R & O_1 & X_1 & O_2 & O_3 \\ R & O_1 & X_2 & O_2 & O_3 \end{array}$$

Description

R : Random selection

O_1 : Pretest

O_2 : Posttest 1
O_3 : Posttest 2
X_1 : Culture and technology based learning
X_2 : Conventional learning

Culture and technology based learning designed in this study used Android learning media. Based on the research design, instruction was conducted for both groups using different treatments; the pretest was administered before the instructional treatment, and the posttest was administered at the end of the third learning, in accordance with the instructional design. After five weeks, a second post-test was conducted to determine information retention among students. The population of this research included all seventh-grade students at SMPN 1 Kupang. The samples were two groups, A and B, which were randomly selected from the population of 10 groups. The samples were divided into two groups: a culture and technology based learning group comprising 30 students (5 high ability, 17 medium ability, and 8 low ability); and a conventional learning group comprising 30 students (4 high ability, 20 medium ability, and 6 low ability). The experimental groups were taught with culture and technology based learning and conventional learning. The research variables consist of the independent variable, dependent variable, and control variable. Independent variables are technology-based learning and conventional learning. The dependent variable is students' mathematical ability. The control variables are gender and individual ability (high, medium, and low). The instrument used in this study is a mathematical ability test (pre-test and post-test). The test used assessed conceptual understanding and problem-solving skills at the analytical level of Bloom's taxonomy of cognitive domains, focusing on quadrilateral geometric shapes. There were a total of 7 essay-type questions. The test instrument was developed in two stages: expert judgment and empirical validity, by testing the questions on a sample outside the research sample at a different school and analyzing their validity and reliability. Data analysis used 1) descriptive statistics; 2) hypothesis prerequisite tests; 3) N-Gain (high if the N-Gain value >0.7, medium if the N-Gain value $0.3 < g \leq 0.7$, low if the N-Gain value ≤ 0.3) (Hake, 1999); 4) average difference tests using the Mann-Whitney U Test and t-Test; 5) interaction effect tests using two-way ANOVA; and 6) MANOVA tests to determine the effect of treatment on students' mathematical ability.

3. RESULTS AND DISCUSSION

Learning activities are conducted using a scientific approach based on culture and technology. The learning stages and how technology plays a role are presented in the following Figure 1.

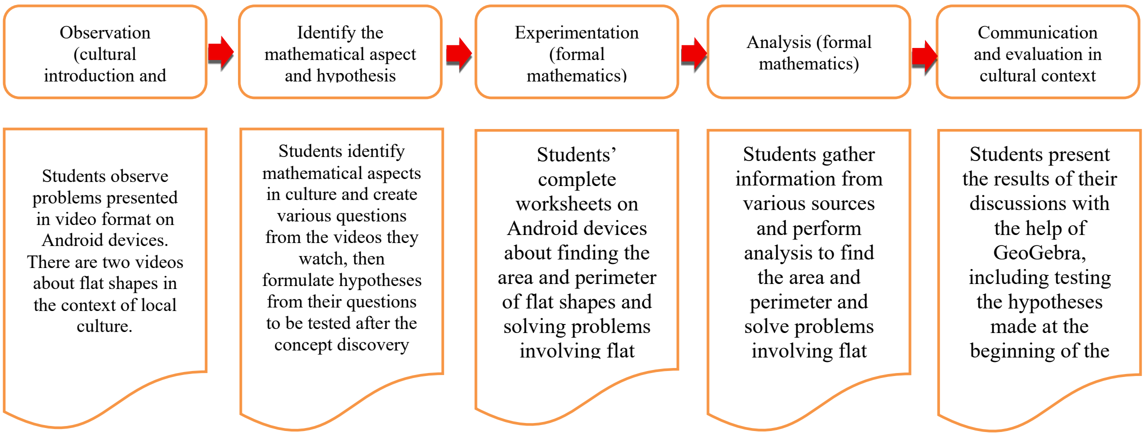
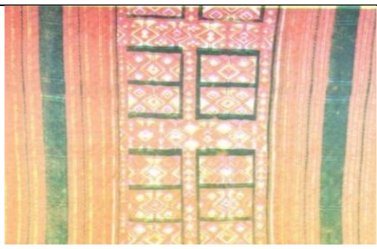
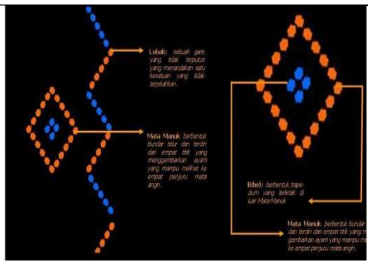
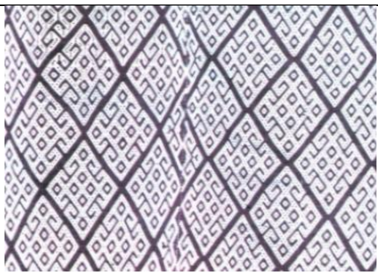


Figure 1. Learning Phases

The learning outcomes related to this material are that students can determine the surface area of flat shapes, the effect of proportional changes in length and area, and solve related problems. These learning outcomes are broken down into three learning objectives in accordance with the content hierarchy, namely 1) finding the area and perimeter of flat shapes, 2) determining the area and perimeter of flat shapes, 3) solving problems related to the perimeter and area of flat shapes. The mathematical ability measured in this study include conceptual understanding and problem solving. The indicators of mathematical concept understanding are: generating examples and non-examples, using multiple mathematical representations, and applying concepts flexibly in non-routine situations. Meanwhile, the indicators of mathematical problem-solving are: representing or modeling problems in an appropriate mathematical form, solving problems systematically, logically, and accurately, and interpreting the results of the solution in the context of the problem. Cultural aspects and mathematical content are presented in Table 1.

Table 1. Cultural aspects and mathematical content

Mathematical Content	Culture and its description	
Square and Rectangle		Hinggi cloth (Sumbanese men's woven cloth). Hinggi is a large cloth pproximately 200–300 cm long, intended for men and can be worn as a blanket, shawl, or belt. Sumbanese woven fabrics generally feature geometric motifs, fauna, flora, traditional objects, and elements from local history, religion, and mythology.
Square and Rectangle		Tais is another name for cloth in the Belu community, while mane is another name for men. Therefore, Tais Mane is a men's cloth. It is rectangular in shape with fringes at both ends. This cloth's uniqueness lies in the combination of three decorative techniques on a single piece. The patterns are square and rectangular.

Mathematical Content	Culture and its description	
Rhombus		Songke Cloth with Mata Manuk Motif. One of the elements contained in the Mata Manuk motif is Mata Manuk itself consisting of the Bible and Mata Manuk. The rhombus-shaped Bible is located outside the Eye of Manuk.
Rhombus		Mau is another name for blanket in the Dawan language of South Central Timor. Mau/blankets are typically worn by men. These blankets are made from cotton thread using the sotis I lotis technique. The base color of this woven fabric is black with a hook/kaif pattern that fills the entire surface. The motif is shaped like a diamond, with the inner part also consisting of smaller diamonds.

3.1. Results

The pretest, posttest 1, and posttest 2 data, differentiated by gender and students' mathematical ability, are presented in Table 2.

Table 2. Descriptive statistics

Group	Category	n	Average pretest	Average Posttest 1	Average Posttest 2	Average N-gain	N-gain Category
Experiment	High	6	27.000	84.667	75.1667	0.789	Medium
	Medium	18	26.277	80.055	70.833	0.730	Medium
	Low	8	19.250	74.625	64.000	0.685	Medium
	Male	12	25.750	83.583	73.250	0.781	Medium
	Female	20	24.000	77.150	67.950	0.700	Medium
	Total	32	24.656	79.562	69.950	0.730	Medium
Control	High	4	26.000	78.750	68.000	0.712	Medium
	Medium	20	22.850	76.450	65.300	0.659	Medium
	Low	6	23.333	70.333	56.667	0.657	Medium
	Male	13	22.625	77.846	67.7692	0.715	Medium
	Female	17	20.411	73.764	61.000	0.670	Medium
	Total	30	21.266	75.533	61.933	0.689	Medium

The normality test as a prerequisite for testing the difference increase (N-Gain) in mathematical ability between the two groups is presented as follows (see Table 3). The hypothesis tested is:

H_0: The sample comes from a normally distributed population.
H_1: The sample does not come from a normally distributed population.

With this criterion, if the probability value (sig.) > 0.05 then H_0 is accepted.

Table 3. Testing the normality

Group	Category	n	Average N-gain	Normality test	Sig.	Decision
Experiment	High	6	0.789	0.142	0.200	Normal
	Medium	18	0.730	0.147	0.200	Normal
	Low	8	0.685	0.178	0.200	Normal
	Male	12	0.781	0.206	0.170	Normal
	Female	20	0.700	0.099	0.200	Normal
	Total	32	0.730	0.133	0.158	Normal
Control	High	4	0.712	0.902	0.440	Normal
	Medium	20	0.659	0.172	0.122	Normal
	Low	6	0.657	0.264	0.200	Normal
	Male	13	0.715	0.143	0.200	Normal
	Female	17	0.670	0.116	0.200	Normal
	Total	30	0.689	0.105	0.200	Normal

The results of the normality test for the prestest to post-test 1 data indicate that all categorical data values come from a normally distributed population. Next, the homogeneity of variances will be tested to determine the appropriate statistical test for hypothesis testing. Next, the homogeneity of variance will be tested to determine the statistics used for hypothesis testing. The homogeneity test of the pretest and posttest data variance of the average N-Gain of both groups is presented in Table 4.

Table 4. Test of homogeneity

Category	Statistik Levene	Sig.	Decision
High Experiment vs. High Control	0.634	0.449	Homogen
Medium Experiment vs. Medium Control	0.362	0.551	Homogen
Low Experiment vs. Low Control	1.229	0.289	Homogen
Male Experiment vs. Male Control	4.081	0.055	Homogen
Female Experiment vs. Female Control	1.273	0.267	Homogen
Experiment Group vs. Control Group	0.230	0.633	Homogen

3.1.1. The difference between two groups

Based on the results of the normality test of the average increase of the two groups, it was found that data are normally distributed and homogeneous; therefore, the difference in mean increases is tested using a t-test. The hypothesis tested is:

H_0 : There is no difference in the average increase of students' mathematical ability between students who receive culture and technology based learning and conventional learning.

H_1 : There is a difference in the average increase of students' mathematical ability between students who receive culture and technology based learning and conventional learning.

The results of the test the increase in mathematical ability between the two groups are presented in Table 5.

Table 5. Results of the test of differences in average increase in mathematical ability

Category	Statistic value	Sig.	Decision
Increase in Experiment Group vs. Control Group	t = 2.657	0.010	There is a significant difference

The Table 5 shows that the probability value (sig.) is < 0.05, so H_0 is rejected, which means that there is a significant difference in the average increase in mathematical ability between the culture and technology based learning and the conventional learning. The difference in the average increase between the two learning groups is 0.03959, with the average increase in mathematical ability in the culture and technology based learning being greater than the average increase in mathematical ability in the conventional learning.

3.1.2. The difference in average increase in mathematical ability based on category differences

Testing the difference in average increase in mathematical ability based on category differences, namely high, medium, low, and female gender categories, using the t-test. The hypotheses tested are:

H_0 : There is no difference in the average increase in students' mathematical ability between students based on category differences.

H_1 : There is a difference in the average increase in students' mathematical ability between students based on category differences.

The results of the test of differences in improvements in mathematical ability using an independent samples t-test by category are presented in Table 6.

Table 6. Results of the test for differences in the increase in mathematical ability of the two classes based on category

No	Category	Statistic value	Sig.	Decision
1	High Gain Experiment vs. High Control	t = 2.034	0.076	There is no significant difference
2	Medium Increase (N-Gain) Experiment vs Medium Control	t = 1.890	0.067	There is no significant difference
3	Low Increase (N-Gain) Experiment vs Low Control	t = 1.192	0.256	There is no significant difference
4	Increase (N-Gain) Male Experiment vs Male Control	t = 3.380	0.003	There is a significant difference
5	Increase (N-Gain) Female Experiment vs Female Control	t = 1.680	0.102	There is no significant difference

3.1.3. Interaction between learning and ability differences on the increase of mathematical ability

The following is a significance test of the interaction between learning and student ability on the increase of students' mathematical ability. The hypothesis formulation is:

Learning Factor Effect Test

H_0 : $\alpha_1 = \alpha_2$ (no learning factor effect).
H_1 : $\alpha_1 \neq \alpha_2$ (there is an effect of the learning factor).

With the criterion that if the probability value (sig.) > 0.05, then H_0 is accepted.

Student Ability Factor Effect Test

H_0 : $\beta_1 = \beta_2$ (there is no effect of the student ability factor).
H_1 : $\beta_1 \neq \beta_2$ (there is an effect of the student ability factor).

With the criteria that if the probability value (sig.) > 0.05, then H_0 is accepted.

Interaction of Learning and Student Ability Factors

H_0 : $\alpha_i\beta_j = 0$ (there is no effect of the learning factor and student ability factor).
H_1 : one of $\alpha_i\beta_j \neq 0$ (there is an effect of learning and student ability factors).

With i = 1,2, and j = 1,2. The criterion is that if the probability value (sig.) > 0.05, then H_0 is accepted; otherwise, H_0 is rejected. The two-way ANOVA output is presented in Table 7.

Table 7. Results of the homogeneity test of mathematics ability increase data based on learning interaction and student ability

F	df1	df2	Sig.
0.646	5	56	0.666

Table 7 shows that the probability value (sig.) > 0.05, thus H_0 is accepted, or the variance of the interaction data between learning and gender factors on the increase of students' mathematical ability is homogeneous.

Table 8. Results of the Two-Way ANOVA Test of data on the increase of mathematical ability based on the interaction between learning and student ability

Source	Type III Sum of Squares	df	Average Square	F	Sig.
Corrected Model	0.065[a]	5	0.013	4.045	0.003
Intercept	21.466	1	21.466	6671.237	0.000
Ability	0.031	2	0.015	4.771	0.012
Learning	0.024	1	0.024	7.386	0.009
Ability * Learning	0.005	2	0.002	0.711	0.495
Error	0.180	56	0.003		
Total	31.582	62			
Corrected Total	0.245	61			

a. R Squared = 0.265 (Adjusted R Squared = 0.200)

Based on the analysis results, it can be seen that, for the learning factor effect test, because the probability value (sig.) < 0.05, H_0 is rejected, which means that there is an effect of the learning factor on students' mathematical ability. For the student ability factor effect test, because the probability value (sig.) < 0.05, H_0 is rejected, which means that there is an effect of the student ability factor on the increase of students' mathematical ability. Furthermore, for the learning and ability interaction test, because the probability value (sig.) >

0.05, H_0 is accepted, which means that there is no interaction effect of the learning and student ability factors on the increase of students' mathematical ability. Figure 2 clarifies the interaction between learning and student ability on the increase of students' mathematical ability.

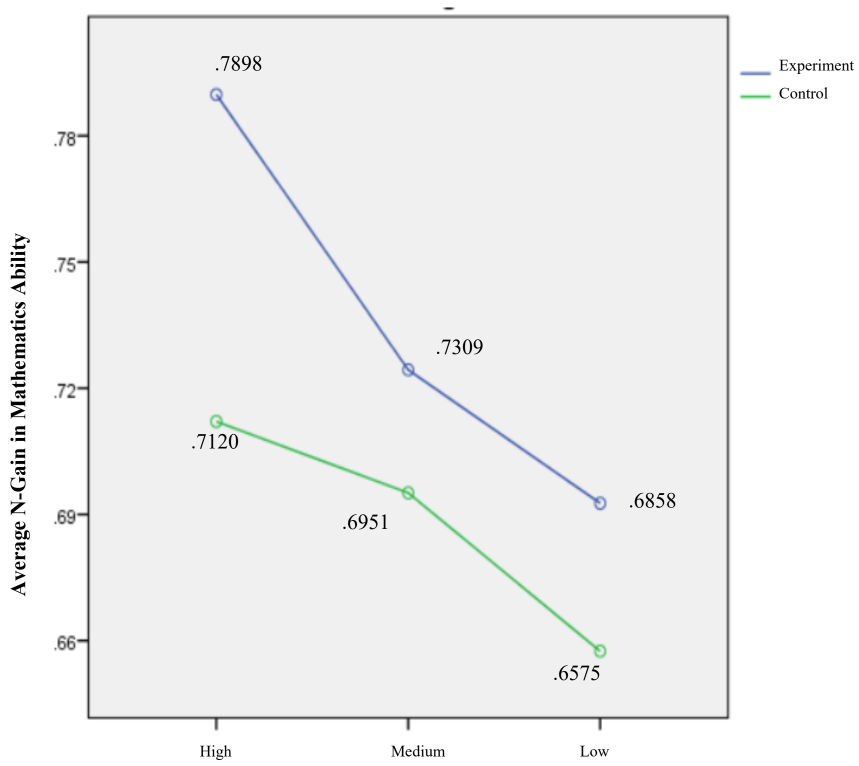


Figure 2. Interaction between learning and student ability on increasing student mathematics ability

Figure 2 shows the average increase in students' mathematics ability by ability category (high, medium, and low) in relation to culture and technology based learning and conventional learning. Overall, based on the statistical analysis in Table 8, there is no significant interaction between the three ability levels and the two learning categories in terms of the increase in mathematics ability. In culture and technology based learning and conventional learning, each review of student ability has varying differences but in small values. The largest difference between these two types of learning is in high ability, which is 0.077. Thus, it can be said that culture and technology based learning is more effective for high-ability students.

3.1.4. Interaction between learning and gender differences on the increase of mathematical ability

The following is a significance test of the interaction between learning and gender on the increase of students' mathematical ability (see Table 9).

Table 9. Results of the Two-Way ANOVA test of data on the increase of mathematical ability based on the interaction between learning and gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.090[a]	3	0.030	11.301	0.000
Intercept	30.557	1	30.557	11450.280	0.000
Learning	0.034	1	0.034	12.880	0.001
Gender	0.059	1	0.059	22.174	0.000
Learning * Gender	0.005	1	0.005	1.936	0.169
Error	0.155	58	0.003		
Total	31.582	62			
Corrected Total	0.245	61			

a. R Squared = 0.369 (Adjusted R Squared = 0.336)

Based on the analysis results, it can be seen that, for the learning factor effect test, because the probability value (sig.) < 0.05, H_0 is rejected, which means that there is an effect of the learning factor on students' mathematical ability. For the gender factor effect test, because the probability value (sig.) < 0.05, H_0 is rejected, which means that there is an effect of the gender factor on the increase of students' mathematical ability. Furthermore, for the learning and gender interaction test, because the probability value (sig.) > .05, H0 is accepted, which means that there is no interaction effect of the learning factor and student ability on the increase of students' mathematical ability.

3.1.5. Effect of Culture and Technology Based Learning (CTBL) on Student Mathematics Ability

Based on the results of multivariate analysis in Table 10, there was a significant interaction effect between Culture and Technology Based Learning (CTBL) and Conventional Learning (CL) on mathematical ability (Wilks' Lambda = 0.004, sig. <0.05). This interaction effect is an ordinal interaction because teaching using Culture and Technology Based Learning and conventional teaching resulted in an increase in mathematical ability, and this relationship is positive (pre to post-1). Table 10 shows the value of Wilks' Lambda for the mathematical ability factor = 0.783, sig <0.05, which means Culture and Technology Based Learning increased students' mathematical ability. Based on Cohen's D effect size, it was concluded that Culture and Technology Based Learning was effective in enhancing mathematical ability with the effectiveness value, according to Cohen, in the high category (λ = 0.996).

Table 10. Multivariate test for culture and technology based learning and conventional learning

Effect		Value	F	Hypothesis df	Error df	Sig.	λ
Learning * Group	Pillai's Trace	0.996	4906.476[b]	3.000	58.000	0.000	0.996
	Wilks' Lambda	0.004	4906.476[b]	3.000	58.000	0.000	0.996
	Hotelling's Trace	253.783	4906.476[b]	3.000	58.000	0.000	0.996
	Roy's Largest Root	253.783	4906.476[b]	3.000	58.000	0.000	0.996
Learning	Pillai's Trace	0.217	5.352[b]	3.000	58.000	0.003	0.217
	Wilks' Lambda	0.783	5.352[b]	3.000	58.000	0.003	0.217
	Hotelling's Trace	0.277	5.352[b]	3.000	58.000	0.003	0.217
	Roy's Largest Root	0.277	5.352[b]	3.000	58.000	0.003	0.217

The results of the between-subjects effect test in Table 11 show that the differences in mathematical ability in post test 1, and posttest 2 are significant ($p < 0.05$). This indicates a main effect between mathematical ability in the culture and technology based learning and the conventional learning. The between-subjects effect shows an effect size ($\lambda = 0.125$; $\lambda = 0.215$; $\lambda = 0.062$) that supports the significance of the study. From the results of the between-subjects ANOVA, it is clear that the interaction effect between culture and technology based learning group and the conventional learning on mathematical ability is significant (Wilks' lambda = 0.004, $F(2,62) = 4906.476$, $p < 0.05$, $\lambda = 0.996$), and the main effects of mathematical ability based on time on pre, post-1, and post-2 were also significant (Wilks' lambda = 0.783, $F(2,61) = 5.352$, $p < 0.05$, $\lambda = 0.217$). The main effects of mathematical ability based on learning, culture and technology based learning and conventional learning were also significant ($p < 0.05$, $\lambda = 0.125$; $\lambda = 0.215$) and not significant for pretest ($p > 0.05$, $\lambda = 0.062$).

Table 11. The between-subject effect for the culture and technology based learning and conventional learning

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	λ
Intercept	Post1	372460.142	1	372460.142	12659.08	0.000	0.995
	Post2	277492.645	1	277492.645	8162.582	0.000	0.993
	Pretest	32796.524	1	32796.524	774.055	0.000	0.928
Learning	Post1	251.368	1	251.368	8.543	0.005	0.125
	Post2	558.194	1	558.194	16.420	0.000	0.215
	Pretest	167.557	1	167.557	3.955	0.051	0.062
Error	Post1	1765.342	60	29.422			
	Post2	2039.742	60	33.996			
	Pretest	2542.185	60	42.370			

The effect of culture and technology based learning on tests in three time periods, pre-test, post-test 1, and post-test 2, as shown in Figure 3.

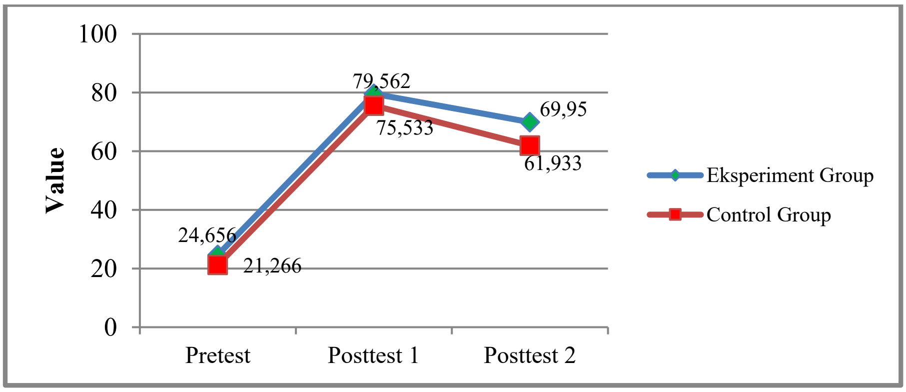


Figure 3. Result of pre-test, post-test 1, and post-test 2

Note that the average mathematics ability scores on the pre-test for the experimental group ($M = 24.656$, $SD = 6.548$) and the control group ($M = 21.366$, $SD = 6.467$). An inter-subject ANOVA was also conducted to assess the effect of the two different groups (control & experiment with cultural and technology based learning) on students' math ability scores in three time periods (pre-test, post-test 1, and post-test 2). There was a significant interaction between group type and time period, Wilks Lambda = 0.004, F (2,62) = 4906.476, $p < 0.05$, partial eta square (λ) = 0.996). The main effects of mathematical ability based on learning, culture and technology based learning and conventional learning were also significant ($p<0.05$, λ = 0.125; λ = 0.215) and not significant for pretest ($p > 0.05$, λ = 0.062), indicating a difference in the effectiveness of culture and technology based learning on mathematical ability.

3.2. Discussion

The first objective of this study was to describe the differences in mathematical ability increase between students taught using culture and technology based learning and those taught using conventional learning, including differences based on gender and mathematical ability. The results of this study indicate that there is a significant difference in the increase of mathematical ability between students in the culture and technology based learning group compared to the conventional learning group. These results show that the integration of cultural context as students' prior knowledge and technological support can create an effective and meaningful learning experience in the development of students' mathematical ability. Theoretically, these findings are in line with sociocultural theory, which places mathematics learning as a process of constructing meaning through the interaction between cultural experiences and formal mathematical symbolic representations (Anderson-Pence, 2015; Bishop, 1991; D'Ambrósio, 2006; Radford, 2014). When cultural context is used as a bridge connecting informal mathematical knowledge to formal mathematics, and mediated by technology as a cognitive tool, students will have a greater chance of building a deep understanding of concepts compared to general mathematics learning, which emphasizes calculation or procedural skills. The advantages of learning that is in line with research findings significantly improve mathematical ability and are also consistent with previous studies that reveal that the integration of culture in mathematics learning can increase student participation, motivation, mathematical literacy, and conceptual understanding (Gerdes, 1998; Leton et al., 2025; Nasir et al., 2008; Rosa & Orey, 2011). Furthermore, the use of technology in mathematics learning practices enriches representative knowledge, supports deeper concept exploration, and improves reasoning quality, communication and connection skills, and higher-order thinking skills (Drijvers et al., 2010; Hoyles & Lagrange, 2010; Pierce & Stacey, 2010; Samo et al., 2018). Thus, the results of this study and its findings reinforce the theoretical argument that the synergy between culture and technology is not only a pedagogical innovation but also a good approach to improving the quality of mathematics learning.

From a gender perspective, the results of the study show that culture and technology based mathematics learning has a more significant impact on improving mathematical ability in male students than in female students. This finding can be explained through the perspective of cognitive and affective engagement, where technology-based learning environments are often more responsive to exploratory and visual-spatial preferences, which in some studies are more dominant in male students (Hong et al., 2014; Li & Ma, 2010; Theophilou et al., 2024). Previous research also shows that the integration of technology in mathematics learning can either reduce or increase gender differences, depending on the pedagogical design and type of activities provided (Forgasz & Leder, 2008; Hyde et al., 2008). In the context of this study, the use of technology that emphasizes exploration and dynamic manipulation is likely to provide greater benefits for male students.

In addition to gender factors, the results also show that culture and technology based learning has a more significant impact on students with high mathematical ability. These findings are in line with research stating that high-ability students tend to be better able to utilize technological affordances to explore, generalize, and reflect on mathematical concepts at an advanced level (Drijvers et al., 2010; Ruthven et al., 2009). Technology enables high-ability students to move more quickly from concrete-cultural contexts to abstraction and formalization, allowing their cognitive potential to develop optimally. However, these results also indicate the need for differentiation strategies so that culture and technology based learning can have a balanced impact on students with Medium and low ability.

Overall, the results of this study confirm that culture and technology based mathematics learning is more effective than conventional learning in improving students' mathematical ability, both in general and when viewed from the perspective of gender differences and mathematical ability. These findings expand on previous research by showing that the integration of culture and technology not only improves learning outcomes but also influences patterns of mathematical ability increase in different groups of students. Thus, this study provides empirical contributions to the development of contextual, inclusive, and relevant mathematics learning models that meet the demands of 21st-century education.

The second objective is to to describe the effects of both types of learning on student knowledge retention. The results show that the average increase of the culture and technology-based learning group is higher than that of conventional learning and is significantly different. There is a significant interaction effect between learning and mathematical ability ($p<0.05$, effect size $\lambda = 0.996$), the main effects of time periods pretest, posttest-1, & posttest-2 were significant ($p< 0.05$, effect size $\lambda = 0.217$), the main effects of mathematical ability on culture and technology based learning and conventional learning were also significant ($p< 0.05$, effect size $\lambda = 0.215$). The results of this study indicate that culture based and technology based mathematics learning is significantly more effective in improving students' mathematical knowledge retention than conventional learning. These findings indicate that the integration of cultural context and technological support not only contributes to short-term concept mastery but also strengthens the storage and retention of knowledge in long-term memory. Theoretically, this is in line with the sociocultural constructivist view, which emphasizes that learning will be more lasting when new knowledge is linked to students' initial schemas derived from meaningful cultural and social experiences (D'Ambrósio, 2006; Nasir et al., 2008; Radford, 2014).

From an ethnomathematics perspective, culture functions as an epistemological bridge that facilitates the transition from informal mathematical knowledge to formal representation, so that the concepts learned become more meaningful and easier to remember (Bishop, 1991; Gerdes, 1998; Rosa & Orey, 2011). A number of international studies report that mathematics learning that links local cultural practices (Utami et al., 2022) with abstract concepts can increase students' cognitive engagement and strengthen conceptual retention compared to conventional procedural approaches (Averill et al., 2009; Barton, 2008; Makgato &

Ramaligela, 2012). Thus, cultural context not only serves as a learning backdrop, but also as a cognitive structure that supports mathematical meaning-making and memory consolidation.

Culture and technology based learning significantly improves mathematical skills, but when culture and technology based learning was discontinued, that advantage diminished on Posttest 2, although it remained higher than that of the conventional class on Posttest 2. This indicates that, pedagogically, CTBL is effective, but its effects need to be sustained through ongoing implementation, not just a brief intervention.

In addition, the integration of technology in learning acts as a cognitive tool that strengthens retention through dynamic visualization, interactivity, and opportunities for repeated exploration of mathematical concepts (Drijvers et al., 2010; Hoyles & Lagrange, 2010; Pierce & Stacey, 2010). Previous research shows that technology-based learning environments support deeper information processing, which is significantly correlated with improved long-term retention (Ruthven et al., 2009). Meta-analyses in the field of educational technology also confirm that technology-assisted mathematics learning has a stronger positive impact on retention than traditional methods, especially when technology is integrated pedagogically and contextually (Cheung & Slavin, 2013; Li & Ma, 2010).

The findings of this study reinforce the evidence that the synergy between culture and technology creates a cognitively and contextually rich mathematics learning environment, thereby supporting the formation of lasting conceptual understanding. Compared to conventional learning, a culture and technology-based approach allows students to construct meaning, represent ideas in diverse ways, and engage in continuous reflection, all of which are important prerequisites for mathematical knowledge retention. Thus, the results of this study contribute empirically to the mathematics education literature by confirming that contextual and technology integrated learning is an effective strategy for improving the quality and sustainability of student mathematics learning outcomes however, the findings of this study are particularly favorable for male and high-ability students. This certainly warrants attention for future research, which should implement differentiation strategies that benefit all student groups, including female students and those with low and medium ability.

4. CONCLUSION

Culture and technology based mathematics learning is a combination of learning concepts in line with technological developments and student cognition, as well as cultural aspects as students' prior knowledge. This learning practice is currently trending because it facilitates contextual situations that have been free from mathematical aspects and are in line with the mathematical mindset that must be taught from concrete situations to formal mathematics. This study integrates culture and technology and compares it with conventional learning, aiming to describe the increase in mathematical ability for all students as well as based on gender and mathematical ability categories. Another objective is to describe the retention of knowledge possessed by students after participating in two different learning activities. The results show that there is a significant difference in the increase of mathematical ability between students in the culture and technology based learning groups compared to conventional learning, where the average increase of the culture and technology based learning groups is higher than that of conventional learning. From a gender and mathematical ability perspective, there was a significant difference in the increase in mathematical ability between students with high, medium, and low ability, where the average increase of male students in culture and technology-based learning was higher than in conventional learning, and the average increase of students with high ability in culture and technology based learning was higher than in conventional learning. This indicates that culture and technology based mathematics learning facilitates high-ability male students better. In the second objective, namely student knowledge retention, the results show a significant difference in the effectiveness of culture and technology based learning on students' mathematical ability, with higher knowledge retention in culture and technology based learning than in conventional learning.

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