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Enhancing Elementary Teachers' Pedagogical Competence through Malay Ethnomathematics-Based Deep Learning Pedagogy Integrated with a 360° Virtual Tour

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Kata Kunci:
Budaya Melayu, Deep Learning, Virtual Tour 360, Pembelajaran Matematika, Guru Sekolah Dasar

Abstrak

Kegiatan pengabdian kepada Masyarakat ini bertujuan untuk mendukung guru dalam mengembangkan kompetensi guru sekolah dasar setelah mengikuti workshop yang menggabungkan pembelajaran mendalam, etnomatematika budaya Melayu, dan Virtual Tour 360. Kegiatan PkM ini menggunakan pendekatan participatory action research dengan desain satu kelompok pretest–posttest terhadap 26 guru dan 25 indikator kompetensi. Rata-rata skor kompetensi meningkat dari 3,54 menjadi 4,08 setelah program pada skala 1–5. Peningkatan yang signifikan ditemukan pada dimensi etnomatematika dan Virtual Tour 360°. Sebaliknya, peningkatan pada dimensi pembelajaran mendalam belum signifikan. Sebanyak 22 guru mengalami peningkatan skor, sedangkan 4 guru mengalami penurunan. Hasil ini menunjukkan bahwa program ini berpotensi membantu guru mengembangkan pembelajaran matematika yang menghubungkan budaya, konsep matematika, dan teknologi digital. Namun, karena penelitian tidak menggunakan kelompok kontrol, hasilnya belum dapat membuktikan hubungan sebab akibat.

Keyword:
Malay Culture, Deep Learning, 360 Virtual Tour, Mathematics Learning, Elementary School Teacher

Abstract

This community service program aims to support teachers in developing the competencies of elementary school teachers after participating in a a workshop that combines deep learning, Malay cultural ethnomathematics, and a 360 Virtual Tour. The community service used participation action research with a one-group pretest–posttest design involving 26 teachers and 25 competency indicators. The average competency score increased from 3.54 to 4.08 after the program on a scale of 1–5. Significant improvements were found in the dimensions of ethnomathematics and Virtual Tour 360°. Conversely, the improvement in the dimension of deep learning has not yet been significant. As many as 22 teachers experienced an increase in scores, while 4 teachers experienced a decrease. These results indicate that this program has the potential to help teachers develop mathematics learning that connects culture, mathematical concepts, and digital technology. However, because the research did not use a control group, the results have not yet been able to prove a cause-and-effect relationship.

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INTRODUCTION

Mathematics education continues to evolve in line with the development of digital technology. This development demands an increase in competencies and a shift in learning orientation (Omer et al., 2025). This leaves behind the previous learning that focused on the delivery of procedures and conventional approaches (Taufikurrahman et al., 2026). Mathematics learning today requires students to master conceptual understanding and mathematical reasoning (F. G. Putra et al., 2024). Alghiffari et al. (2024) state that students today must master problem-solving and the understanding of mathematical concepts in real life, one of which is by integrating technology. The use of technology in learning helps in the exploration and construction of students' knowledge. In line with the study by Junger et al. (2026) technology should create interactive situations in learning. Technology does not work well if the teacher's competence is inadequate. Teachers must be able to design balanced learning and still utilize the availability of technology (Cirneanu & Moldoveanu, 2024).

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Technology should enhance mathematics learning (Hwang & Tu, 2021; Siller & Ahmad, 2024). One of the technologies that is being actively developed in education is Virtual Tour 360. According to Gunawan and Zainil (2026) this technology provides users with the potential to explore spaces and objects. This potential arises because Virtual Tour 360 is capable of presenting three-dimensional visuals. One of the benefits of using Virtual Tour 360 in mathematics education is that it facilitates virtual access to real objects (Concannon et al., 2019). Rodrigues et al. (2026) found that Virtual Tours can enhance student engagement in learning. With Virtual Tour 360, mathematics learning no longer relies on textbook materials. Students and teachers can explore and visualize mathematical concepts around them using Virtual Tour 360.

The integration of technology must be accompanied by competent teacher quality (Wijaya et al., 2022). Teachers must have the ability to select appropriate strategies, facilitate learning activities, and connect the material with the students' life context In Indonesia, teachers' readiness to adapt to technology is equally important in overcoming the limitations of learning infrastructure. Various studies have reviewed teachers' readiness to teach mathematics, especially in elementary schools (Nindigraha et al., 2026; Putra et al., 2020; Rahma & Nurlaelah, 2024). Wager (2012) stated that teachers must be able to bring relevant concrete experiences in teaching mathematics, such as cultural integration. On the other hand, teachers still face limitations in understanding deep learning in education (Zulkarnain & Hasim, 2026). Moreover, teachers still struggle to integrate technology with cultural contexts (Lehmann et al., 2026; Yuliandari, 2025). Preliminary studies that have been conducted also found that teachers still struggle to connect culturally-based approaches and technology integration in mathematics learning.

The Indonesian government has actually popularized the deep learning approach as an effort to improve the quality of education. There are 3 pillars of deep learning, namely Mindful, Meaningful, and Joyful (Lauzon, 2012). With deep learning, mathematics education enables students to build their understanding. In this study, deep learning is used as an approach to culture-based mathematics learning integrated with a 360 Virtual Tour. The culture used is Malay culture. Malay cultural objects such as the Siak Sri Indrapura Palace, Tuan Kadi's House, Senapelan Grand Mosque, Jamik Mosque, and Lontiok House are used as mathematical objects explored within the 360 Virtual Tour.

Although the integration of technology in culture-based mathematics learning using a deep learning approach has been extensively explored (Batubara et al., 2025; Negash et al., 2022; Wiryanto et al., 2025), Previous studies on ethnomathematics-based mathematics education have primarily focused on improving students' conceptual understanding and mathematical abilities. However, limited empirical evidence explains how ethnomathematics combined with immersive technology can strengthen elementary teachers' pedagogical competence, this gap is critical because teachers serve as the main agents who transform ethnomathematical ideas and digital technologies into meaningful classroom practices. Therefore, improving teachers' competence becomes a prerequisite for ensuring that cultural and technological innovations can be transformed into effective mathematics learning practices.Without adequate pedagogical competence, technological and cultural resources may remain disconnected from mathematics learning objectives. Particularly in designing culturally responsive mathematics learning. The same applies to developing the competencies of elementary school teachers. therefore, this study aims to investigate in depth the integration of Malay culture-based deep learning with the integration of Virtual Tour 360 in examining changes in teachers' pedagogical competence following the intervention. Based on that gap, this study aims to explore to what extent does the integration of Malay ethnomathematics-based deep learning pedagogy with 360° Virtual Tour contribute to changes in elementary school teachers' pedagogical competence? And which dimensions of teachers' pedagogical competence demonstrate the greatest improvement after participating in the Malay ethnomathematics-based deep learning pedagogy integrated with a 360° Virtual Tour program?

Deep learning Approach in Mathematics

Deep learning is present as a response from the Indonesian government to address the learning gap in Indonesia. In mathematics learning, deep learning is expected to be the answer to the gap of students who do not fully understand the mathematical thinking process behind it. According to Siregar et al. (2025) the three benefits of using deep learning are understanding the relationships between concepts, reflecting on learning experiences, and constructing knowledge more meaningfully. In mathematics education, it becomes important because it requires teaching strategies that connect with students' real-life experiences (F. G. Putra et al., 2024). This is a solution to address the character of mathematics that is considered abstract and difficult.

Mathematics learning in deep learning is built on three main principles: meaningful, mindful, and joyful. Erviana and Asmarani (2025) explain the three principles of deep learning: Meaningful in mathematics learning refers to the connection of new concepts with the knowledge and experiences that students already

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possess. Mindful in mathematics learning is the students' awareness of processing thoughts through reflection, cognitive stages, and evaluation. Meanwhile, Joyful in mathematics learning is the emotional involvement in the learning process. Deep learning in this study is related to culture-based mathematics education.

Many studies have found that culturally-based mathematics education provides deep meaning (Orey & Rosa, 2008; Rosa & Orey, 2011). Most research still focuses on the effectiveness of learning for students only, while the aspects of teachers and how to build their competencies are still underexplored In fact, the success of implementing learning innovations depends on the teacher's abilities. The teacher's understanding and the decision to use appropriate mathematical representations in creating suitable learning experiences remain crucial aspects of the teacher's role (Hadi, 2002). Through, deep learning is expected to strengthen mathematical knowledge and cultural identity, in this case, Malay culture. This study focuses on the development and evaluation of an approach through the integration of Malay culture into deep learning approaches and the use of Virtual Tour 360.

Virtual Tour 360 in Mathematics Learning

Virtual Tour 360 is an immersive technology that helps users explore an environment with 360-degree panoramic images. From a constructivist perspective, 360° Virtual Tours provide opportunities for teachers to construct mathematical representations through direct observation of cultural objects. Therefore, immersive technology does not merely function as a visualization tool but as a cognitive bridge connecting abstract mathematical concepts with contextual experiences. It is called immersive technology because users can observe a place, object, and phenomenon without direct physical presence. Mitra et al. (2022) explain that with Virtual Tour 360, it is capable of enhancing exploration-based learning experiences. Wagler and Hanus (2018) even found that Virtual Tour 360 enhances spatial presence. Virtual Tour 360 gives full control to the users. They can determine the direction of view, explore objects in detail, and even build understanding through visual experiences.

Research on Virtual Tour 360 continues to evolve. Initially used only as an alternative visit to overcome limitations of cost, distance, security, and access to learning (Dutta et al., 2024). However, now Virtual Tours continue to develop and are used at various levels of education, including elementary schools. Virtual Tour increases the learning motivation and spatial abilities of elementary school students (Maher & Buchanan, 2021). Garcia et al. (2023) show that Virtual Tour 360 enhances learning engagement better than regular videos. Research on Virtual Tours in mathematics education can enhance the spatial abilities of prospective teachers (Kurtuluş, 2013). Pada level Pendidikan dasar pengalaman virtual meningkatkan keterlibatan dan rasa ingin tahu siswa (Cheng et al., 2023). However, studies examining how elementary school teachers integrate 360 virtual tours with local culture and mathematics education are still limited.

METHODS

Design of Community Service Program

This community service program employed participatory action program with a quasi-experimental one-group pretest-posttest design. The design was selected because the program aimed to support teachers' pedagogical competence before and after participating in a professional development workshop. This was investigated after participating in the Melayu culture-based professional development program using deep learning integrated with a 360 Virtual Tour. The community service design was carried out through three main stages. The first stage involves identifying the initial conditions of teachers through a pre-test of pedagogical competence. The second stage involved a professional development program consisting of deep learning-based mathematics teaching training, exploration of Malay ethnomathematics concepts, and the use of a 360° Virtual Tour. The third stage is an evaluation through a post-test to measure changes in teacher competence.

Participants and Setting of the Community Service Program

This communty service program involves 26 elementary school teachers at one of the elementary schools in Kampar Regency, Indonesia. The selection of participants used purposive sampling technique because teachers are the main practitioners in the implementation of learning in elementary schools. this program aims to address teachers' limitations in integrating deep learning, Malay culture, and Virtual Tour 360 in mathematics education. The professional development program was developed from three components: Deep Learning Approach, Malay Ethnomathematics, Virtual Tour 360. The instrument consists of a teacher competency test administered before and after the intervention. The instrument is used to measure teachers' understanding and ability in developing mathematics instruction. Before being used, the instrument has undergone a quality testing phase. The teacher competency instrument consisted of three dimensions: (1) deep

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learning pedagogy, (2) mathematical content knowledge, and (3) 360° Virtual Tour integration skills. The instrument consisted of 25 items distributed across three dimensions: deep learning pedagogy (15 items), mathematical content knowledge (5 items), and 360° Virtual Tour integration skills (5 items). Three mathematics education experts evaluated content validity, while reliability analysis showed acceptable internal consistency (Cronbach's $\alpha = 0.87$). Content validity was evaluated by educational experts, while internal consistency reliability was examined using Cronbach's alpha coefficient. The validity analysis of the instrument is examined through the corrected item-total correlation value. This is done to ensure that the instrument is capable of measuring the targeted competency construct.

Data Analysis

Data analysis is conducted in several stages, namely descriptive statistics to obtain an overview of changes in teacher competency scores before and after the intervention. Second, a normality test is used as the basis for selecting statistical analysis. Third, analysis through A paired-samples t-test was conducted to examine differences between pretest and posttest scores. Statistical significance was determined at $p < .05$. Effect size was calculated using Cohen's d to determine the practical significance of the intervention. This study also calculates the normalized gain (N-gain) to determine the participants' improvement after following the program. The improvement categories were classified based on the magnitude of score improvement after participation in the program. Finally, the research also calculates the effect size using Cohen's d to see the magnitude of the observed difference between pre-test and post-test scores.

RESULTS AND DISCUSSION

Results

Workshop of Deep Learning integrated Malay Ethnomathematics and 360 Virtual Tour

The workshop on Malay culture-based mathematics deep learning, integrated with a 360-degree virtual tour, was conducted face-to-face; the Community Service (PkM) team met at SDN 042 Tambang, Kampar, to deliver the workshop material directly in the classroom. Prior to the presentation of the material, participants were asked to complete a survey regarding their knowledge of mathematics instruction. The workshop comprised three content delivery sessions: the first focused on deep learning, the second on Malay ethnomathematics, and the third on the creation of 360-degree virtual tours.

In the first session, the presenter outlined the concepts of deep learning in elementary school mathematics. The process was interactive, linking deep learning concepts to the needs and characteristics of elementary school students. The initial activity introduced the fundamentals of deep learning, covering principles of mindful, meaningful, and enjoyable learning. Subsequently, the presenter demonstrated examples of applying these concepts within the context of mathematics instruction. The presenter encouraged teachers to understand that mathematics learning extends beyond the mere mastery of procedures and the achievement of final results. Mathematics learning encourages students to grasp concepts, connect the material to their daily experiences, and explore diverse problem-solving strategies. The presentation of the first session's material is illustrated in Figure 1.



Figure 1. Delivery of deep learning material

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Subsequently, the presentation of ethnomathematics material and the 360° Virtual Tour linked mathematical concepts to the students' local Malay cultural elements. Teachers were introduced to ethnomathematics as an approach that utilizes cultural activities, shapes, patterns, and artifacts to understand mathematical concepts. This approach encompasses geometric shapes, patterns, symmetry, measurement, and spatial relationships. Teachers were then introduced to 360° Virtual Tour technology as a learning medium; this technology facilitates the virtual exploration of cultural environments or objects from various perspectives.

The third session focused on creating a simple 360-degree virtual tour of the SDN 042 Tambang school grounds. During this session, the presenter demonstrated the process firsthand and guided participants to follow along step-by-step starting with account creation and preparing tour materials by capturing panoramic photos with mobile phones, then uploading them to the Theasys platform to create hotspots and add various features. The presentation for the third session is shown in Figure 2.



Figure 2 Process of creating a simple 360-degree virtual tour.

During the practical session, participants were guided to observe objects in the vicinity of SDN 042 Tambang. They then identified mathematical concepts within those objects. Subsequently, they designed learning activities that integrated these cultural objects with elementary school mathematics curriculum content. The aim was to make mathematics learning more contextual, interactive, and meaningful, enabling students to grasp mathematical concepts through more tangible visual experiences. Figure 3 displays the simple 360-degree virtual tour media created by the workshop participants.



Figure 3 Results of the simple virtual tour created by participants

Participant Characteristics and Descriptive Statistics

Analysis of 26 teachers who participated in the measurement before and after the program was implemented. The participants consisted of 26 elementary school teachers with diverse teaching experiences. 25 pretest and posttest indicators grouped into 3 dimensions, namely deep learning, ethnomathematics, and virtual Tour 360. Each score is calculated as the average response of the indicator on a scale of 1-5.

Table 1. Descriptive statistics of competence before and after the program.

Dimension	N	Pretest Mean	Pretest Sd	Posttest Mean	Posttest SD	Mean Change
Deep Learning	26	3.94	0.74	4.21	0.66	0.26

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Ethnomathematics	26	3.23	0.67	3.85	0.72	0.62
Virtual Tour 360	26	2.65	0.95	3.92	0.71	1.27
Total Competence	26	3.54	0.64	4.08	0.66	0.54

Based on Table 1, the average total competence increased from 3.54 (SD=0.64) in the pretest to 4.08 (SD=0.66) in the posttest. There was an increase in competence scores on a scale of 1-5 after the program, as seen from the average change of 0.54. In each dimension, the deep learning score increased from 3.94 (SD=0.74) to 4.21 (SD=0.66). The ethnomathematics score increased from 3.23 (SD=0.67) to 3.85 (SD=0.72). The largest increase occurred in the Virtual Tour 360 dimension, which rose from 2.65 (SD=0.96) to 3.92 (SD=0.71).

The increase and decrease can be seen from the standard deviation in Table 1. The deep learning and Virtual Tour 360 dimensions decreased after the posttest, while the standard deviation of the ethnomathematics dimension increased. This change reflects a shift in the distribution of scores. However, caution is needed in drawing conclusions about the statistical significance that occurs.

Indicator-Level Comparison

After analyzing the total scores and scores in each dimension, the analysis continues at the Indicator Level. This is done to identify indicators that show changes between the pretest and posttest. The average indicators are calculated based on 26 respondents using the same 1-5 scale for both pretest and posttest.

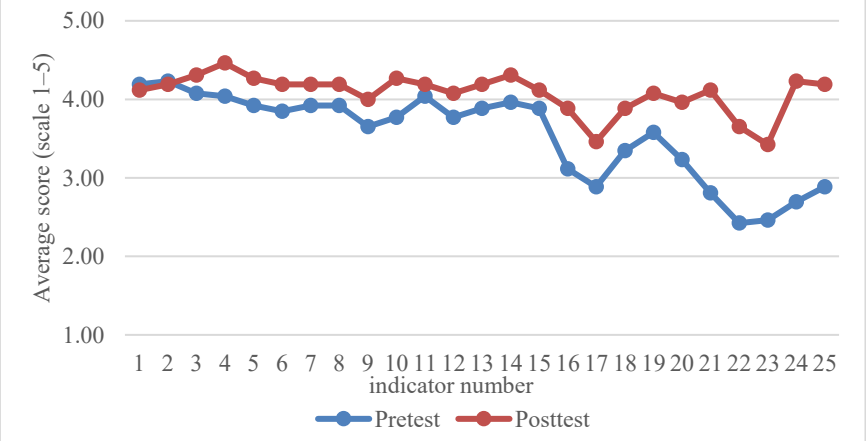


Figure 4. Comparison of the average of 25 indicators before and after the program on a scale of 1-5.

In Figure 4, it shows that most indicators are at a higher post-test average compared to their pre-test average. Based on 25 indicators, 23 indicators increased and 2 indicators experienced a slight decrease. Indicator 1 decreased from an average of 4.19 to 4.12, while indicator 2 decreased from 4.23 to 4.19. The largest increase is in indicator 24 with a score of 1.54, followed by indicators 21 and 25 with scores of 1.31 each. In the Virtual Tour 360 dimension, there was an increase with changes around 0.96 and 1.54 points. The same thing also happened to the indicators in the ethnomathematics dimension. In the deep learning dimension, there are two indicators that experienced a decline. However, the decline is not significant.

Distribution and Normality Testing

Before conducting the difference test, the distribution of change scores is performed to determine the correct use of the parametric test. Change scores are calculated by subtracting pretest scores from posttest scores in each dimension. Because the number of respondents is 26 people, the normality test used is the Shapiro-Wilk test.

Table 2. Distribution of change scores and Shapiro-Wilk normality test

Change score	Df	Mean	SD	Shapiro-Wilk	Significance Value (P)
Deep Learning	26	0.264	0.799	0.937	0.112
Ethnomathematics	26	0.623	0.785	0.971	0.658
Virtual Tour 360	26	1.269	0.941	0.984	0.947
Total Competence	26	0.537	0.671	0.966	0.526

The analysis results in Table 2 show that the distribution of change scores in the dimensions of deep learning, ethnomathematics, and 360 virtual tour do not show significant deviations from normality. Each of them obtained p = 0.112, p = 0.658, and p = 0.947 respectively.

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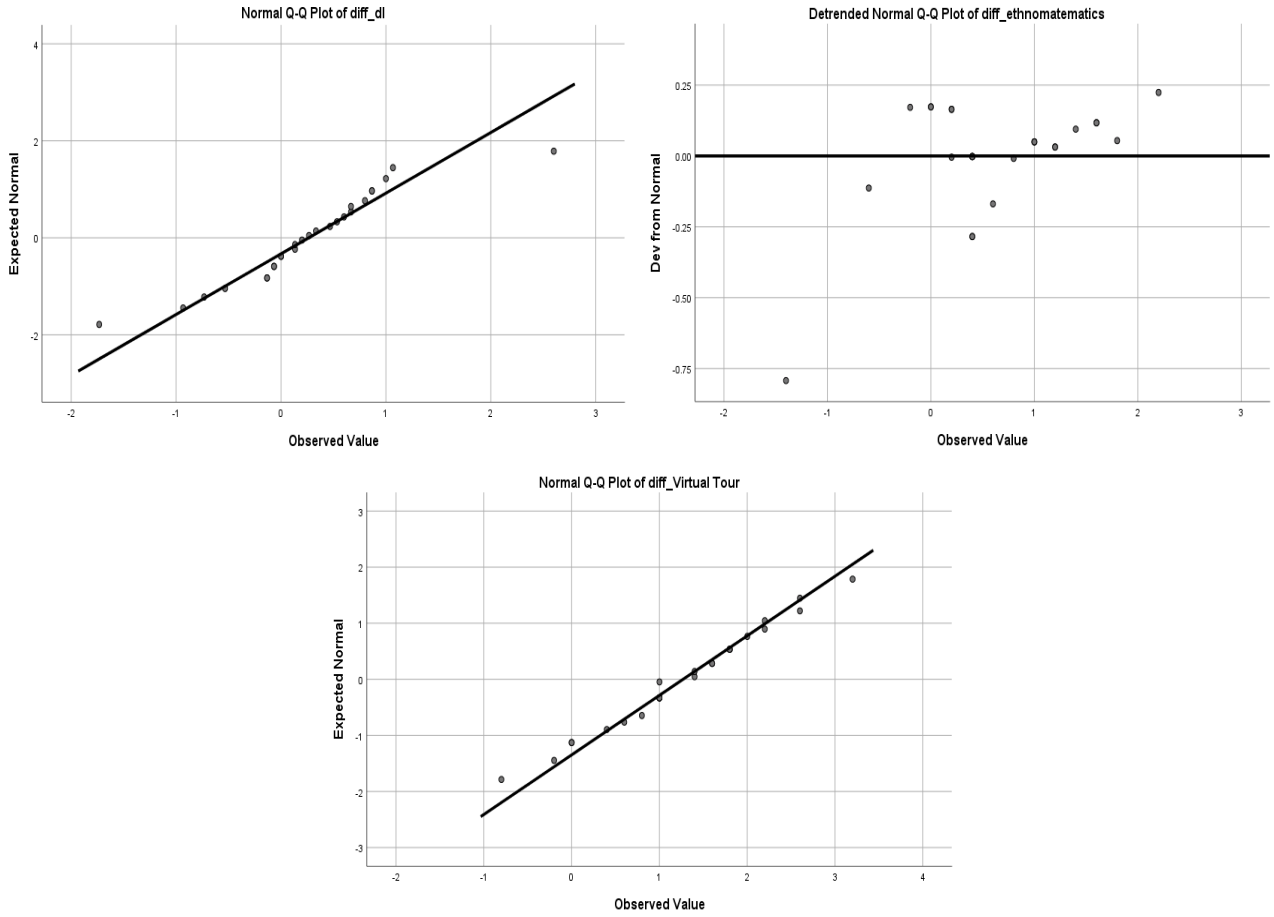


Figure 5. Histogram and Normal Q–Q plot of change scores in three dimensions and total competence.

Visual inspection through the Normal Q-Q plot (Figure 5) shows that most observations still follow a normal distribution pattern. Although some deviations occur in the tail of the distribution, since the Shapiro-Wilk values for all variables are >0.06, the change scores are considered adequate. Therefore, a paired sample t-test was used to analyze the differences between the pretest and posttest on those three dimensions.

Paired Difference Analysis Across Three Dimensions

A paired sample T-test was conducted to compare the pretest and posttest scores across three dimensions. The difference between the posttest and pretest is subtracted, so if the value is positive, it indicates an improvement after the program. All analyzes used 26 pairs of data.

Table 3. Paired difference analysis in three dimensions

Dimension	Pretest M (SD)	Posttest M (SD)	Post–Pre	Confidence Interval 95%	t	df	Sig. (2-tailed) / *p*	Cohen's dz
Deep learning	3.941 (0.741)	4.205 (0.664)	0.264	[-0.059, 0.587]	1.685	25	0.1045	0.330
Ethnomathematics	3.231 (0.669)	3.854 (0.717)	0.623	[0.306, 0.940]	4.050	25	p<0.001	0.794
Virtual Tour 360	2.654 (0.958)	3.923 (0.711)	1.269	[0.889, 1.649]	6.875	25	0.00	1.348

The results show different patterns in the three dimensions. The deep learning dimension increased with an average rise of 0.264 points. However, this change was not significant with a t-value of (25)= 1.685 and Cohen's dz of 0.330. The ethnomathematics dimension experienced a significant increase from 33.231 to 3.854 with a t-value of (25) = 4.050 and Cohen's dz of 0.794.

The strongest change after the correction for multiple testing was in Virtual Tour 360, while ethnomathematics followed afterward. However, the improvement in deep learning has not yet appeared significant. However, caution is needed when interpreting the data in Table 3, as lower initial scores have greater room for improvement.

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N-gain Analysis

N-gain analysis is used as an analysis to describe the variation in total score changes at the participant level. The score changes for each participant are calculated from the difference between the posttest score and the pretest score. The distribution of N-gain categories among 26 participants is presented in Figure 6.

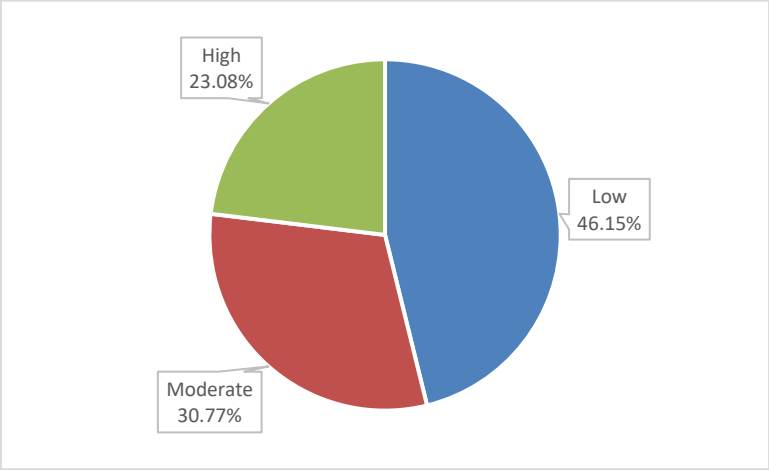


Figure 6. Distribution of participants based on N-gain categories

The low category is the largest group with 12 participants (46.15%), followed by the medium category with 8 participants (30.77%) and the high category with 6 participants (23.08%). Combined, 14 participants fall into the medium to high categories, accounting for 53.85%. Not all participants in the low category experienced a slight increase.

Table 4. Distribution of participants by direction of score change

Category	*Number of participants*	*Percentage*
Posttest higher	*22*	*84.62%*
Posttest lower	*4*	*15.38%*
No change	*0*	*0.00%*
Total	*26*	*100.00%*

Overall, as shown in Table 4, the posttest scores were higher than the pretest scores for 22 participants (84.62%), while 4 participants (15.38%) had lower posttest scores. This proves that there is variation in the direction and magnitude of score changes for each participant. Therefore, the increase in the average at the group level cannot be interpreted as an increase for all participants.

Discussion

Integrating Intervention as a Teacher Professional Development Model

This study shows changes in teacher competency scores after participating in a program that integrates deep learning approaches, ethnomathematics based on Malay culture, and a 360° Virtual Tour. The average total competency score increased from 3.54 on the pretest to 4.08 on the posttest on a scale of 1–5. At the indicator level, 23 out of 25 indicators showed a higher average posttest score, while two indicators experienced a slight decrease. This pattern indicates that the changes reflect a tendency at the group level only. However, not all participants experienced an improvement.

Analysis of the three dimensions shows uneven changes. The increase only occurred in the dimensions of ethnomathematics and Virtual Tour 360°, while the increase in the dimension of deep learning has not yet shown strong evidence. In the ethnomathematics dimension, the score increased by 0.623 points with a 95% confidence interval between 0.306 and 0.940, $t(25) = 4.050$. The effect size Cohen's dz of 0.794 indicates a significant change approaching a large category. In the Virtual Tour 360° dimension, the increase reached 1.269 points with a confidence interval between 0.889 and 1.649, $t(25) = 6.875$, and Cohen's $dz = 1.348$.

Local culture can provide a context to connect mathematical concepts with the social and environmental experiences of learners (Novikasari et al., 2024). Previous research also shows that a culture-based approach can contribute to the development of teachers' identity and competence in teaching mathematics (Owens, 2014; Verner et al., 2019). However, the design of this study does not allow for the separation of contributions from each component. Because the deep learning approach, ethnomathematics, and 360° Virtual Tour are provided

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as a package, improvements in one dimension cannot be considered as the specific effect of just one component.

Changes in the Dimension of Deep Learning

The average score of the deep learning dimension increased from 3.94 to 4.21 with a change of 0.264 points. However, the 95% confidence interval is between −0.059 and 0.587, $t(25) = 1.685$, $p = 0.1045$, and Cohen's $dz = 0.330$. Because the confidence interval includes the value zero and the p-value is greater than 0.05. These findings are important because the average increase alone is not sufficient to conclude that deep learning competence has improved. The initial score on this dimension was already quite high, at 3.94. This condition can limit the room for improvement in the posttest. In addition, two indicators experienced a decrease in the average.

One factor is that the ability to design deep learning requires a longer practice time than the ability to recognize or accept new concepts (Siregar et al., 2025). Competence does not always change quickly after a single intervention program. The teacher competency framework also requires the integration of knowledge, practice, and reflection on pedagogical and digital changes (Caena & Redecker, 2019). Therefore, the results of this study indicate a tendency for an average increase, but the evidence of change is still limited.

Changes in the Dimension of Ethnomathematics

The ethnomathematics dimension increased from an average of 3.23 on the pretest to 3.85 on the posttest, with a change of 0.623 points and a 95% confidence interval between 0.306 and 0.940. The results of the paired t-test showed $t(25) = 4.050$, $p = 0.0004$, and Holm's p around 0.0009. Cohen's $dz = 0.794$ indicates a substantial change. These findings indicate that the program has the potential to enhance teachers' ability to recognize and integrate cultural contexts into mathematics instruction.

The results are in line with the view that culture can be a source of context and representation in mathematics (Rosa & Orey, 2011). However, the standard deviation increased from 0.67 to 0.72, so the improvement was not uniform across all teachers. These findings are evidence of changes in ethnomathematics competence measured by the instrument, not evidence that all teaching practices have permanently changed.

Regarding cultural integration, this study highlights the cultural studies in mathematics. Local culture can serve as the foundation for developing teacher competencies. Many studies have explored culture in mathematics education (Verner et al., 2019), but few have tested it in building teacher competence (Owens, 2014). On the other hand, this study offers a model for teacher professional development that integrates deep learning, culture, and technology. This could be an alternative for elementary schools that want to develop mathematics learning relevant to the local culture.

Virtual Tour 360° as a Medium for Cultural and Mathematical Representation

The 360° Virtual Tour dimension showed the largest increase, from an average of 2.65 to 3.92 with a change of 1.269 points. The 95% confidence interval is between 0.889 and 1.649, $t(25) = 6.875$, $p < 0.001$, and Cohen's $dz = 1.348$. The magnitude of the change may be related to the initially lower scores, allowing for greater room for improvement for the teachers. Many studies have found that virtual environments can provide visual and spatial experiences that support the exploration of cultural objects and mathematical concepts (Garcia et al., 2023; Maher & Buchanan, 2021).

Data shows that the standard deviation decreased from 0.96 to 0.71, indicating that the posttest scores were more concentrated. However, these results do not prove that the Virtual Tour 360° is the main cause of the improvement because the intervention was provided alongside a deep learning approach and ethnomathematics. The Virtual Tour 360° dimension showed the greatest change in the measured competencies after participating in the integrated program.

Variation in Changes among Participants and Interpretation of N-gain

The distribution of individual changes shows that the posttest scores were higher than the pretest scores for 22 out of 26 participants or 84.62%. Four participants or 15.38% had lower posttest scores. These findings indicate that the average group improvement was not experienced by all participants. The distribution of N-gain also shows heterogeneity of change. As many as 12 participants fall into the low category, 8 participants into the medium category, and 6 participants into the high category. Thus, 14 participants fall into the medium to high category. However, the low category should not be directly interpreted as not experiencing improvement because this category can include small improvements and negative changes. Therefore, the distribution of N-gain should be treated as a descriptive summary of variation in change, not as a substitute for the paired t-test.

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The variation may be related to initial abilities, experience using technology, understanding of local culture, and teachers' readiness to modify lesson plans. However, this research has not tested these factors as moderators. Therefore, the explanation regarding the differences in responses among participants is still interpretative and needs to be tested through further analysis.

CONCLUSION

The community service program that integrates deep learning, Malay cultural ethnomathematics, and a 360° Virtual Tour is associated with an increase in the average teacher competency from 3.54 to 4.08. The strongest changes occurred in the dimensions of the 360° Virtual Tour and ethnomathematics, while the increase in deep learning has not yet been significant. Variations in scores among participants indicate that the benefits of the program are not uniform. However, this program only uses a one-group pretest-posttest design, so the interpretation needs to be done carefully. Further community service program involving a control group and a larger number of participants are needed to determine the sustainability of changes in teachers. Overall, the professional development of teachers with the integration of local culture and technology has promising potential to support culturally relevant mathematics learning in elementary schools.

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