Enhancing Mathematical Creative Thinking in Ethno-Geometry Learning Using Augmented Reality Technology

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Abstract: The purpose of this study is to develop an Android-based augmented reality learning media using Unity software to improve students' creative thinking skills in polyhedral ethno-geometry materials. The development of augmented reality learning media follows the ADDIE development model, which consists of five phases: analysis, design, development, implementation, and evaluation. The learning media developed must meet feasibility requirements such as effectiveness, practicality, and effectiveness. Data collection to measure students' creative thinking skills is currently done through written exams and documentation. We then analyzed the test data using a paired samples t-test. Based on the analysis, the results are shown to be effective and proven in improving creative thinking in mathematics. As a result of the questionnaire analysis regarding media usage, overall favorable evaluations were obtained. In summary, these results are consistent with the contribution of this study to making teaching-learning experiences effective, fun, and interactive.

Keywords: Augmented reality, mathematics creative thinking, ethno-geometry

INTRODUCTION

Learning is a process that enhances students' ability to acquire knowledge. This process involves specific steps that a teacher must take to ensure that students acquire knowledge, increase their attention and motivation in class, and become competent in this modern era. A teacher's teaching process may vary; some may focus on application, some may demonstrate concepts, while others may focus on understanding. However, the learning that takes place in the classroom depends on the teaching methods used by the teacher and the learning methods used by the students. Felder suggests that students learn through various methods such as hearing, seeing, visualizing, imagining, acting, or memorizing (Felder & Silverman, 1988). Additionally, objectivity and grammatical correctness are crucial, and any bias should be avoided. Mental visualization of concepts is crucial for understanding analogies (Gargrish et al., 2020). The success of education heavily relies on teachers' teaching methods, which include the use of technology. Efforts are made to improve the learning process, including implementing student-based learning and incorporating information technology into education.

Augmented reality is a form of technological advancement that can be integrated into the world of education with great potential benefits (Marrahí-Gómez & Jose Belda-Medina, 2023). Augmented reality is a technique that uses device technology to visualize graphical information adapted from an original or real part of the world (Marrahi Gomez & Belda-Medina, 2023). It is a technology that can be used to enhance users' interpretation of information about reality by overlaying digital information on the real world. Augmented Reality (AR) is becoming increasingly important in to-day's world. The concept of augmented reality refers to the integration of two-dimensional or three-dimensional virtual elements into the real world that are displayed or projected in real time using applications (Maulana et al., 2022). The purpose is to recreate real-life scenarios and add computer-generated virtual information, such as text, photos, 3D models, music, and videos (Chen et al., 2019).

Research by Gargrish et al., (2020) shows that the use of geometry applications provides students with a more comprehensive learning experience, allowing for better visualization and understand-ing of the subject matter. Mobile geometry applications have been designed to provide personalized assistance and enhance students' visualization of angles. Ibáñez et al., (2020) suggest that augment-ed reality technology can be an effective learning environment for students to practice basic princi-ples of geometry. The study found that students who utilized the augmented reality-based learning environment achieved higher post-test scores compared to those who used the web-based applica-tion. One advantage of using augmented reality for learning media is that students can interact with 3D objects from multiple angles. This is not possible with web-based media. Additionally, the augmented reality-based learning environment was more effective than the web-based learning en-vironment in schools. The study also discovered that the use of augmented reality-based learning environments increased students' learning motivation. The visualization in the use of augmented re-ality can facilitate the construction of shapes in the cognitive understanding process for students, particularly those with visual learning styles.

Augmented Reality

A real environment in real time augmented with virtual elements is the definition of augmented re-ality (Rossano et al., 2020). The purpose of using augmented reality (AR) is to add virtual elements to the data collected by the five senses (Koparan et al., 2023). These elements provide complemen-tary information that may not be available naturally (İbili et al., 2020). Many research papers have discussed augmented reality (AR) applications in many fields, such as history, biology, physics, math, and English. However, despite the abundance of research, only a few studies have been ap-plied in mathematics education, particularly in the area of geometry (Gargrish et al., 2021). Geome-try material covers fundamental concepts such as shape, volume, and area. These concepts can be abstract and challenging to comprehend in 3 dimensions (Lainufar et al., 2020). Augmented reality technology can serve as a tool for exploration, interaction, and communication among students in classroom education. The visualization produced by AR is expected to fill an important role in overcoming the limitations of traditional learning methods in teaching geometry (Nazar et al., 2020). When studying geometry, AR can present realistic 3-dimensional models of real-world objects, making it easier to understand complex concepts (Widada et al., 2021). The integration of virtual and real-world elements is expected to make the geometry learning process more effective and efficient when combined with their cultural environment (Guntur et al., 2020).

Ethno-Geometry

Mathematics is the product of human thought related to concepts, procedures, and reasoning. People often unconsciously use mathematics in their daily lives. D'Ambrosio first introduced the science that refers to mathematics as ethnomathematics in 1985. It is applied by certain cultural groups, such as ethnic groups, professional groups, labor groups, and certain age groups (D'Ambrosio, 1985). Multicultural education, which connects ethnicity and culture to learning, helps students better engage with the subject matter. Accounting for different cultural approaches can foster deeper understanding and understanding of mathematics (Meng & Liu, 2022). Jayadi et al., (2022) found that a multicultural educational paradigm that includes themes such as unity in diversity, equality, cultural identity, and social justice is important for improving scientific attitudes. Suherman & Vidákovich, (2024) found that ethnicity/culture and attitudes significantly contribute to creativity in mathematics. In particular, increased ethnic diversity leads to better attitudes toward mathematics and higher levels of mathematical creative thinking. Geometry is a branch of mathematics that studies the properties of two-dimensional (2D) and three-dimensional (3D) shapes and figures (Prahmana & D'Ambrosio, 2020). Geometry plays a crucial role in elementary and middle school education Flores-Bascuñana et al., (2019), as it offers multiple visualization tools to comprehend statistical, algebraic, and arithmetic concepts (Schutera et al., 2021). Ethno-geometry is a scientific field that explores how geometry is adapted by different cultures to express their unique relationships with it. Ethno-geometry learning is based on the surrounding culture and its relevance to everyday life. This research examines the application of AR in ethno-geometry material, with the aim of enhancing students' creative thinking abilities. Recent research highlights the diverse approaches to enhancing geometrical understanding. Sari et al. (2024) investigated the role of ethnomathematics in geometry education, exploring how cultural contexts and traditional practices can inform and enrich learning. Concurrently, Zakaria et al. (2024) explored the impact of integrating geometrical design with GeoGebra, a dynamic mathematics software, on secondary students' motivation and academic performance. These studies collectively underscore the ongoing efforts to develop innovative and effective pedagogical strategies in geometry.

Mathematical Creative Thinking

Creative thinking is the ability to generate possible solutions and approaches to problems based on available information, with emphasis on both quantity and appropriateness (Yaniawati et al., 2020). Creative thinking is important in learning because improving students' creative skills has a positive impact on academic performance (Kartika et al., 2019). Educating children about creativity can increase the meaning of learning (Maskur et al., 2020). According to Regier & Savic, (2020), creative thinking is a cognitive process that involves solving problems and generating new ideas through synthesis and application. Creative thinking is considered a higher-level thinking ability (Rahmawati et al., 2019). Creative thinking in mathematics is the use of creativity to solve mathematical problems in flexible, innovative, and open-ended ways, especially by making connections between different concepts and by using imagination to develop new solutions and perspectives. It is the ability to approach and the ability to explore (Sadak et al., 2022). The Mathematics Creative Thinking (MCT) test is used to assess students' mathematical creativity (Sahliawati & Nurlaelah, 2020). Creative thinking includes several important aspects such as fluency, flexibility, elaboration, and originality (Tanjung & Nasution, 2023). Creative thinking skills encompass several aspects that help individuals generate, develop, and refine ideas effectively. These aspects include fluency, flexibility, originality, and elaboration. Each plays a unique role in fostering creative thought: *Fluency* refers to the ability to produce a large number of ideas or solutions in response to a given problem or stimulus; *Flexibility* is the ability to think about a problem from multiple perspectives or to approach it in different ways; *Originality* is the capacity to produce ideas that are novel, unique, or unexpected; and *Elaboration* involves expanding on an idea by adding details, refining it, or making it more complete and actionable. The fluency indicator measures the student's ability to provide correct solutions to the given problems. The flexibility indicator measures the ability to solve problems using different methods so that solutions are not obtained from only one point of view. The elaboration indicator measures their capacity to develop and expand upon their solutions. Meanwhile, the originality indicator measures the student's ability to find unique solutions to the given problem (Habibi et al., 2020).

This research addresses two primary questions: (1) How can valid, practical, and effective learning devices based on ethnogeometry and augmented reality be developed? (2) Does the implementation of ethnogeometry and augmented reality-based learning devices influence students' creative mathematical thinking skills? The instruments employed to assess the validity, practicality, and effectiveness of these devices include tests, questionnaires, and observations.

METHOD

Participant

In this study, 188 students were randomly selected from secondary schools in Jember, East Java, Indonesia. From a total of 7 classes, we randomly selected 6 classes, centering on Jember's class 8. In summary, researching geometry learning with AR in 8th-grade junior high school is a promising endeavor because it directly addresses common learning difficulties in geometry, aligns with the cognitive development of adolescents, and leverages the unique capabilities of AR to create an engaging, interactive, and effective learning environment for complex spatial concepts. All participants provided informed consent before participating in this study and collecting data online via Google Forms (https://bit.ly/EthnoGeometry). One of the 188 participants, there were 87 males, mean age 14.11 ± 0.68, and 101 females, mean age 14.46 ± 0.81. The mean age of all participants was 14.28 ± 0.74.

Research Structure

This research uses the ADDIE framework (Analysis, Design, Development, Implementation, and Evaluation) which can be seen in Figure 1 below.

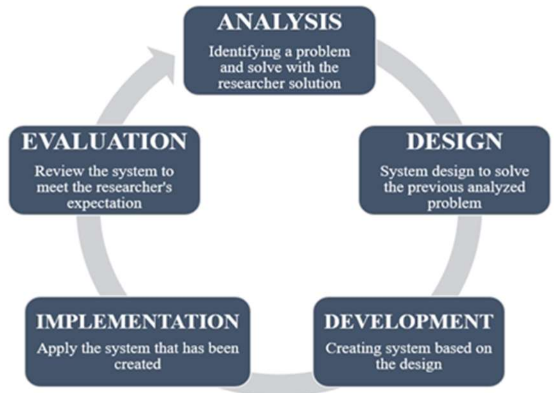

Figure 1: ADDIE model diagram

Data Collection Procedure

In this research, researchers obtained data based on the results of tests and questionnaires from 188 participating students. The test consisted of pre- and post-tests, each of which consisted of 5 questions. The purpose of the pretest was to measure students' competence before using augmented reality. Meanwhile, the posttest was used to measure the students' ability after applying augmented reality. Based on this, researchers can determine the effectiveness of augmented reality in learning geometry cube materials. In addition to the test, students also fill out a questionnaire that has been provided. Researchers also used a questionnaire that asked students about the utilization of Augmented Reality in learning, learning motivation, and student achievement. In addition, researchers took documentation in the form of student work as supporting material for data analysis. The pre-/post-test instrument can be found at (https://unej.id/PrePostTestInstrument). All instruments were used in the collection of research data.

Data Analysis

Normality tests and homogeneity tests were carried out on the pretest and posttest data as prerequisite tests for the Paired Sample Test. Data that has met the prerequisite tests is tested using the Paired Sample Test. This test is utilized to decide the distinction in the normal pre and posttest scores in the classes which apply learning using Augmented Reality. The formulation of the test hypothesis is as follows:

H_0: There is no difference between the mean pretest and posttest scores.

H_1: Average posttest scores are better than the pretest scores.

Meanwhile, the formulation of the test criteria is as follows:

a. If significance is > 0.05, then H_0 is accepted and H_1 is rejected.

b. If significance is ≤ 0.05, then H_0 is rejected and H_1 is accepted.

Furthermore, the study conducted the N-Gain or Normalized Gain test to measure the magnitude of students' creative thinking abilities before and after treatment. The N-Gain calculation formula was used to calculate the pretest and posttest values.

$$N - Gain = \frac{S_{posttest} - S_{pretest}}{S_{max} - S_{pretest}}$$

With:

$S_{pretest}$ = pretest score

$S_{posttest}$ = posttest score

S_{max} = maximum score

RESULT

Analysis

Primary data collected came from secondary schools in Jember, East Java Province, Indonesia. In this case, the researchers created a guidebook for using this technology, because most of the students studied were still not used to using augmented reality technology. Next, the researcher taught geometry material, namely about polyhedra related to ethno-geometry. Next, students take a test at the end of the lesson to get data that helps researchers compute the effectiveness of augmented reality. The tests students will take will be administered in the classroom and each test will have an estimated time of 30 minutes. Additionally, the scoring system for the test is based on 0-100, with each question having a value of 20. In addition to the rating system, the researchers conducted a questionnaire that was filled out online via Google Form regarding whether students liked the learning experience using applications or not, and found it difficult to use augmented reality technology or not. Based on the results of the questionnaire, researchers can provide information regarding the potential for implementation or not.

Design

Figure 2 illustrates the application structure utilizing a use case diagram created with draw.io. The diagram depicts the skills of both users and administrators when utilizing the structure.

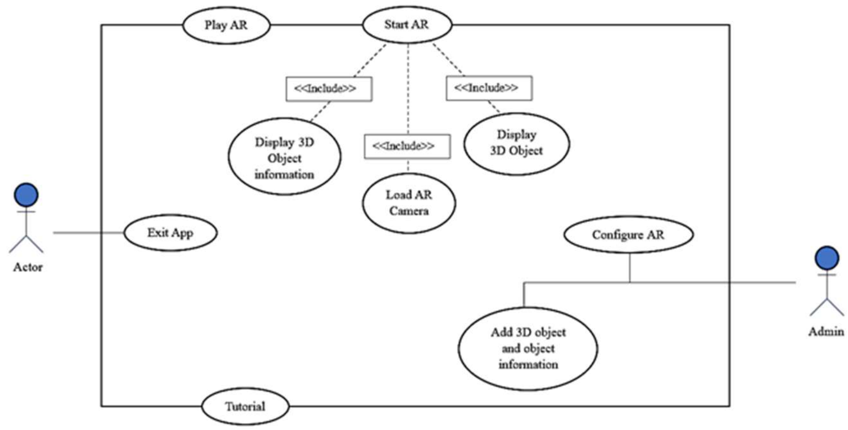

Figure 2: Use case diagram

The use case diagram illustrates the system's functional scope, outlining the interactions available to both users and administrators. Users are presented with five distinct menu options. The Competency menu displays information pertaining to media competencies. The Material menu provides access to content on surface area, volume, planar shape definitions, and augmented reality (AR) features. Within the AR menu, selecting this option activates the AR camera, allowing a 3D object relevant to a specific objective to appear when the user focuses on a designated image. The Instructional Exercise menu offers tutorials on application usage, primarily catering to experienced users. Finally, the About menu presents developer profiles and media creation references, while the Questions menu provides practice questions for students. Users can terminate the application by selecting the Exit option. In addition to these user functionalities, administrators possess elevated privileges, enabling them to configure augmented reality settings, incorporate new 3D models into the application, and perform all actions accessible to regular users, Figure 3 shows the class chart made beneath utilizing draw.io. explains class names, attribute names, and class functionality in the application. Also, all class names are connected to each other:

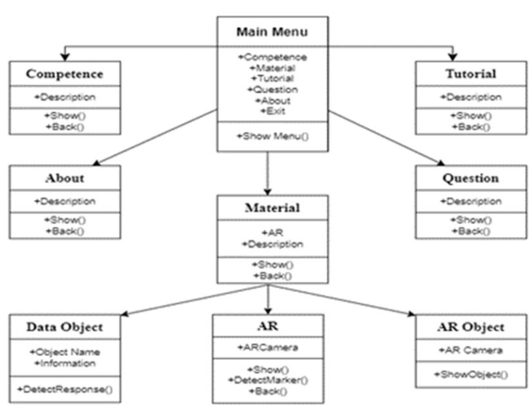

Figure 3: Class diagram

The initial class is the main menu, which includes all available menus for user selection. Following that is the tutorial, this section describes how augmented reality can be systematically used by students. After that, the competencies and media competencies are displayed. Next, you can view your developer profile and credentials. The following question provides a practice exercise. The 'Material' section displays information on area, volume, and aspect ratio. Use the 'back' function to return to the main menu in all sections. Finally, when the user selects the AR scan option in the material menu, the AR class is triggered and can perform several functions. One of these functions is the 'display' function, which can show 3D objects and detection marks. The camera detects the target image and then returns to the camera, leading the user back to the main menu.

Development

The initial class is the main menu, which includes all available menus for user selection. Following that is the tutorial, this section describes how augmented reality can be systematically used by students. After that, the competencies and media competencies are displayed. Next, you can view your developer profile and credentials. The following question provides a practice exercise. The 'Material' section displays information on area, volume, and aspect ratio. Use the 'back' function to return to the main menu in all sections. Finally, when the user selects the AR scan option in the material menu, the AR class is triggered and can perform several functions. One of these functions is the 'display' function, which can show 3D objects and detection marks. The camera detects the target image and then returns to the camera, leading the user back to the main menu.

Figure 4: Target image

A prerequisite for configuring a target image in Vuforia is obtaining a valid license. This license is essential for the proper functionality of the target image within the application. Next, enter your Vuforia license into your AR camera so the camera can recognize the target image and display your assets. The asset image appears in the scene, as shown in Figure 5.

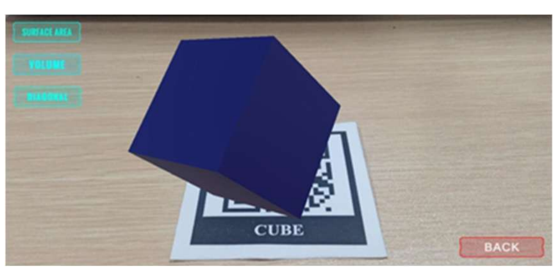

Figure 5: 3D object

After testing the application, it can be used for education or demonstration to help elementary school teachers understand surfaces and volumes of polyhedral figures. Not only can it be used as a learning medium for junior high schools, but you can also use the application to do research and listen to explanations of specific polyhedra by junior high school teachers. Why not even junior high school students install the app on their smartphones and try it out. However, the app can only be installed on smartphones that have been updated or are running Android OS 11.0 (API level 30). The gallery menu can be seen in Figure 6 until Figure 9:

Figure 6: Main menu

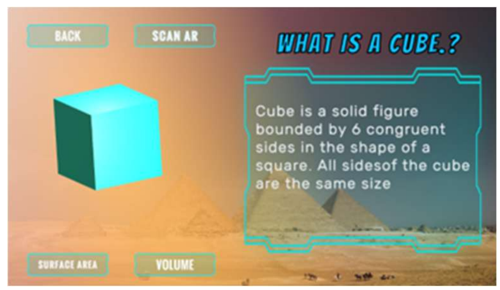

Figure 7: Material menu

Figure 8: Surface area

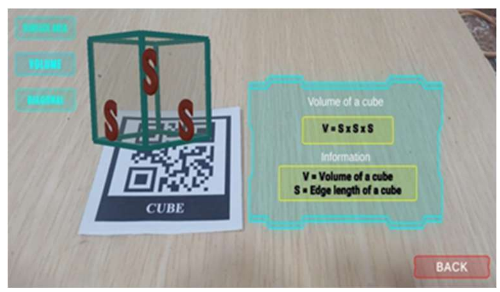

Figure 9: Volume

Implementation

During the implementation phase, the researchers conducted a baseline test at the school to evaluate students' knowledge of augmented reality. The results showed that most students had little to no understanding of the technology. Based on this finding, the researchers provided a brief introduction to the topic of augmented reality and administered a pretest to measure students' comprehension of polyhedrons. The students utilized augmented reality technology on the researcher's phone to test its effectiveness for learning. Subsequently, they completed a user experience survey to evaluate the technology's effectiveness and enjoyment. Finally, the students took a post-test to measure their understanding of polyhedrons.

Evaluation

Following the implementation process, the researcher evaluated the results of the tests and questionnaires that the students had completed. To ascertain the efficacy of the instructional media, the researchers conducted an analysis of students' pre- and post-test scores. This comparative approach allowed for the evaluation of the media's impact on enhancing student comprehension. Supplementary data from these assessments are available at (https://unej.id/TestResult). Table 1 below was obtained by entering data into SPSS, and the results can be seen below:

	Mean	N	Std. Deviation	Std. Error Mean
Pretest	63.8617	188	8.56757	0.62485
Posttest	80.2340	188	7.41429	0.54074

Table 1: Paired sample statistics of test results

The paired sample statistics table has an average value that represents the average of the pretest and posttest. The total number of students who took part in the experiment is shown in the first column (N). In this case, the average pretest score for the 188 students is 63.8617 and the average posttest score is 80.234. Next is the paired sample correlation or Table 2 below:

	N	Correlation	Sig
Pretest & Post-test	188	0.128	0.081

Table 2: Paired samples correlation of test results

The total number of students who took part in the experiment is shown in the first column (N), and the correlation between the pre-test and post-test data is shown in the second column. The data in this instance have a positive correlation (r = 0.128). The final column represents sig. or significance in this instance, it is 0.081. Table 3 is the paired sample test table shown below: The total number of students who took part in the experiment is shown in the first column (N), and the correlation between the pre-test and post-test data is shown in the second column. The data in this instance have a positive correlation (r = 0.128). The final column represents sig. or significance in this instance, it is 0.081. Table 3 is the paired sample test table shown below:

Mean	Std. Deviation	Std. Err Mean	95% Confidence		t	df	Sig. (2-tailed)
			Lower	Upper			
-16.37234	10.59107	0.77243	-17.89614	-14.84854	-21.196	187	0.000

Table 3: Paired samples test of test results

The Paired Samples Test Table 3 has eight columns: mean, standard deviation, standard error, 95% confidence interval (lower), 95% confidence interval (upper), t, df, and Sig (both sides). The first in Table 3 average value. The difference between the pre and post-test means is -16.37234. The Sig (2-tailed) results from the average results of each test and the 5% significance level were also used in this analysis. So in this case the Sig (both sides) is 0.000. If we evaluate the results in detail, the Sig value (two-tailed) < 0.05, the meaning is to reject the null hypothesis, stating that there is no significant difference between each test. If the Sig (two-tailed) value is more significant than 0.05, it means accepting the null hypothesis that there is no significant difference. Based on the evaluation results, it can be seen that the Sig (2-tailed) value is lower than 0.05, consequently showing that the utilization of augmented reality media is very powerful in increasing student understanding. The next evaluation is related to the effectiveness of increasing Mathematics Creative Thinking (MCT) with indicators of fluency, flexibility, originality, and elaboration. Table 4 was obtained by entering data into SPSS, and the results are.

MCT		Mean	Std. Deviation	Std. Error Mean
Fluency	Pretest	2.38	0.487	0.036
	Posttest	4.72	0.525	0.038
Flexibility	Pretest	2.30	0.653	0.048
	Posttest	4.47	0.665	0.049
Originality	Pretest	1.84	0.750	0.055
	Posttest	4.90	0.295	0.022
Elaboration	Pretest	1.97	0.837	0.061
	Posttest	4.43	0.496	0.036

Table 4: Paired sample statistics of MCT

The paired sample statistics table has an average value that represents the average of the pretest and posttest. There is also an N column that represents the number of students who participated in the experiment. In this case, the average score on the language proficiency pretest is 2.38, and the average score on the language proficiency posttest is 4.72. The mean score for the flexibility pretest is 2.30, and the mean score for the flexibility posttest is 4.47. The mean score for the originality pretest is 1.84, and the mean score for the originality posttest is 4.90. The mean elaboration pretest score is 1.97, and the mean elaboration posttest score is 4.43. Next is the paired sample correlation or Table 5 below:

MCT		N	Correlation	Sig
Fluency	Pretest & Posttest	188	0.103	0.161
Flexibility	Pretest & Posttest	188	-0.242	0.001
Originality	Pretest & Posttest	188	-0.069	0.344
Elaboration	Pretest & Posttest	188	0.272	0.000

Table 5: Paired sample statistics of MCT

From the output above, you can see that Table 5 contains three columns. The total number of students who took part in the experiment is shown in the first column (N), and the correlation between the pre-test and post-test data is shown in the second column. The data in this instance have a positive correlation with fluency (r =0.103). The final column represents sig. or significance in this instance, it is 0.161. The data show negatively correlated with flexibility (r = -0.242), the flexibility of significance is 0.001. The data show negatively correlated with originality (r = -0.069). The originality of significance is 0.344. The data show positively correlated with elaboration (r = 0.272). The elaboration of significance is 0.000. Table 6 is the paired sample test table shown below:

MCT	Mean	Std. Deviation	Std. Err Mean	95% Confidence		t	df	Sig. (2-tailed)
				Lower	Upper			
Fluency	-2.340	0.679	0.050	-2.438	-2.243	-47.262	187	0.000
Flexibility	-2.165	1.039	0.076	-2.134	-2.015	-28.568	187	0.000
Originality	-3.064	0.825	0.060	-3.183	-2.945	-50.929	187	0.000
Elaboration	-2.452	0.845	0.062	-2.574	-2.330	-39.634	187	0.000

Table 6: Paired samples test of MCT

The Paired Samples Test Table or Table 6 contains the following eight values: mean, standard deviation, standard error, 95% confidence interval (lower), 95% confidence interval (upper), t, df, and Sig (two-tailed). The results are obtained by calculating the difference between the pretest and posttest means: fluency is –2.340, flexibility is -2.165, originality is -3.064, and elaboration is -2.452.

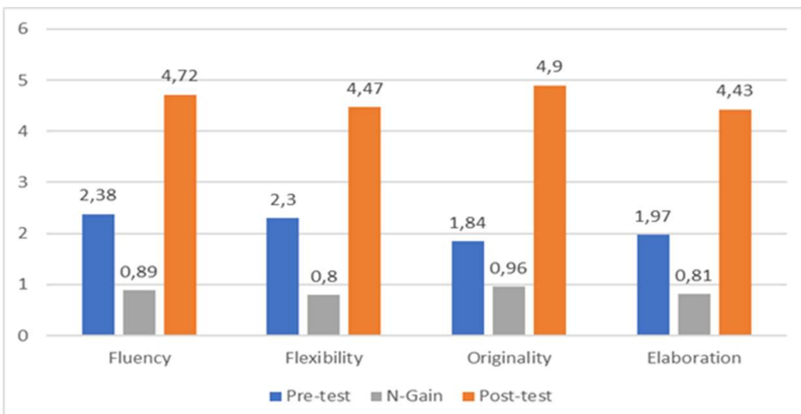

Figure 10: Average result of mathematical creative thinking

Based on Figure 10, it shows that there has been a significant increase in each indicator of mathematical creative thinking. The results of the analysis of students' creative mathematical thinking on the Fluency indicator before using learning media obtained a value of 2.38 and increased to 4.72 after using learning media, The N-Gain value was obtained at 0.89. The Flexibility indicator before using learning media obtained a value of 2.3 and increased to 4.47 after using learning media, The N-Gain value was obtained at 0.8. The Originality indicator before using learning media obtained a value of 1.84 and increased to 4.9 after using learning media, The N-Gain value was obtained at 0.96. The Elaboration indicator before using learning media obtained a value of 1.97 and increased to 4.43 after using learning media, The N-Gain value was obtained at 0.81.

To see the students' creative thinking skills, it is necessary to explore by displaying their work from the post-test results. The students' post-test results are as follows:

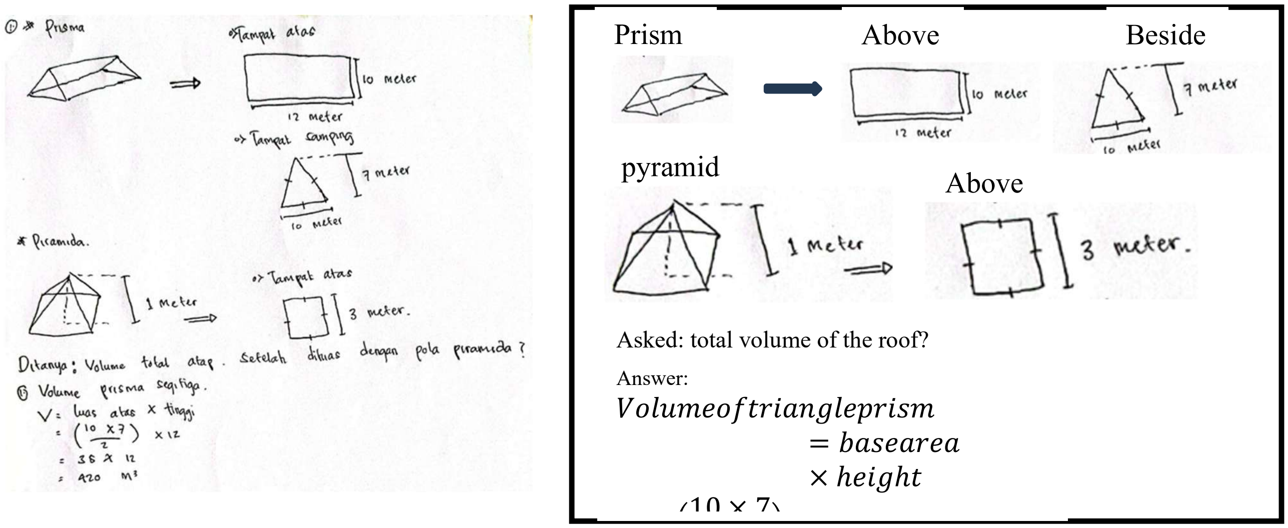

Figure 11: Example Sample snippets of student work related to creative thinking skills

Based on Figure 11, it shows that students have achieved 4 indicators of creative thinking skills, including fluency, flexibility, originality, and elaboration. Students achieve the fluency indicator by being able to draw real conditions in mathematical models in the form of geometric designs. Students meet the flexibility indicator by being able to use the volume formula of a room. The originality stage is demonstrated by students' ability to solve space volume problems from contextual problems. The elaboration stage is shown by the students' ability to answer the given problems by linking other concepts and to teach them to other students. In this way, all indicators of students' creative thinking ability can be shown in detail.

DISCUSSION

The findings indicate that integrating Augmented Reality (AR) technology within an ethno-geometric learning framework can significantly enhance students' creative thinking skills. This suggests that blending immersive digital experiences with culturally relevant mathematical contexts provides a promising avenue for fostering higher-order cognitive abilities in learners. For all aspect of creative thinking skills, namely fluency, flexibility, originality, and elaboration are improved after Augmented Reality (AR) technology with ethno-geometry learning process. It is in-line with the result given by (Thompson & Singh, 2020). The integration of Augmented Reality (AR) technology in ethno-geometry learning presents a unique blend of cultural heritage and modern technological advancements to enhance mathematical creative thinking. Augmented Reality (AR) brings an interactive dimension to learning, making abstract ethno-geometric concepts more tangible. Gonzalez & Hernandez (2023) also obtained that under AR media implementation, the interactivity can significantly increase students' engagement and motivation, since students are more likely to be intrigued by and invested in lessons that incorporate technology the find compelling. AR can visually represent 3D geometric shapes and patterns in real time, which can help students to develop a better spatial understanding of mathematical concepts. This visualization is particularly beneficial in ethno-geometry, where shapes and patterns are often embedded in cultural artefacts and symbols. Integrating ethno-geometry with AR technology can foster a deeper appreciation for cultural heritage. Furthermore, Kim & Choi, (2021) stated that by exploring geometric concepts through the lens of different cultures, students can connect with and appreciate the mathematical ingenuity and aesthetic beauty found in various cultural traditions. AR technology can offer personalized learning paths based on a student's progress, strengths, and areas for improvement. This adaptability can help cater to individual learning styles and paces, enhancing the overall effectiveness of the educational experience. However, the dependence on AR technology might limit access to ethno-geometry learning for students and schools with limited technological resources.

However, the digital engagement can exacerbate educational inequalities. Setting up AR technology for educational purposes can be expensive. Wright & Kanellos (2021) analysed that the cost includes not just the hardware (such as AR glasses or devices) but also the software development of educational AR applications, which can be a significant barrier for many institutions. Both educators and students may face a learning curve in effectively utilizing AR technology. Educators need to be trained to integrate AR into their teaching practices seamlessly, while students need to learn how to navigate and learn from AR applications effectively. There's a risk of overreliance on technology, where students might become too dependent on AR for learning, potentially hindering their ability to understand and apply mathematical concepts without technological aid, it was mentioned by (Sanchez & Young, 2019). Implementing ethno-geometry and augmented reality (AR) in a regular classroom can enhance student engagement, foster cultural appreciation, and provide interactive learning experiences. By merging ethno-geometry and AR, classrooms can become dynamic spaces where students learn not only math but also appreciate cultural diversity and cutting-edge technology.

CONCLUSIONS

We have done this study, and the result shows that the development of Augmented Reality (AR) technology with ethno-geometry learning process can enhance the students' creative thinking skills significantly. To develop valid, practical, and effective learning devices for ethno-geometry learning using augmented reality (AR), this study follows a systematic research and development (R&D) framework, which includes the following key phases: 1) analysis and needs assessment includes identifying the challenges in ethno-geometry learning and the potential of AR technology in enhancing mathematical creative thinking; 2) developing lesson plans, designing student worksheet, and creating AR-based learning media; 3) expert validation involving mathematics educators and technology specialists to evaluate content accuracy and AR integration; 4) gathering teacher and student feedback to evaluate usability, clarity, and engagement; 5) measuring student learning outcomes, particularly improvements in mathematical creative thinking to determine effectiveness.

The results of this study confirm that these learning devices meet the criteria of validity, practicality, and effectiveness. The validity was established through expert validation and alignment with pedagogical and technological principles. Practicality was assessed based on teacher and student responses, indicating ease of implementation and engagement. Effectiveness was demonstrated through improved student performance in mathematical creative thinking, as evidenced by test results and qualitative observations. Learning devices based on ethno-geometry and augmented reality that are valid, practical, and effective namely lesson plans, student worksheet, and Augmented Reality-Based Learning Media.

It also has a significant leap forward in education technology. By enhancing student engagement, improving spatial understanding, and providing a rich cultural context, AR technology has proven to be a powerful tool in the development of creative thinking skills. Since the educational practices evolving the integration of AR into learning environments ensure to unlock new possibilities for student achievement and innovation. The implication is that the research findings have significant implications for educational practice. Educators are encouraged to adopt AR technology in their teaching methodologies, particularly in subjects where abstract concepts can benefit from visual and interactive aids. Additionally, integrating cultural elements into the curriculum through ethno-geometry can provide a more holistic and engaging learning experience for students, promoting creativity alongside academic achievement. The results of this study are in the form of learning devices based on ethno-geometry and augmented reality that are valid, practical, and effective. The ability to think creatively in mathematics increased after the treatment of using learning devices based on ethno-geometry and augmented reality.

Embedding ethno-geometry learning using AR in the classroom entails several key approaches: (1) cultural exploration through augmented reality, in which students utilize AR applications to showcase 3D models of cultural artifacts; (2) interactive problem solving, where students engage in analytical tasks such as measuring angles, identifying geometric shapes, or exploring transformations using AR overlays on cultural patterns or artifacts; (3) virtual exhibits, enabling students to design cultural patterns or geometric models and present them in AR as interactive exhibitions; and (4) collaborative AR projects, where students work in groups to develop AR-enhanced presentations on cultural sites or artifacts, emphasizing their geometric properties.

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