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Students' Creative Thinking Ability Using Project-Based Learning based on Augmented Reality (AR)

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ABSTRACT: *Education aims to enhance students' mathematical abilities in alignment with the demands of the 21st century. Essential to these contemporary skills are the 4C competencies, among which is the capacity for creative thinking - a fundamental skill enabling students to critically analyze problems and devise various innovative solutions. This study endeavors to assess whether the application of Project-Based Learning (PjBL) combined with Augmented Reality (AR) enhances creative thinking abilities more effectively than PjBL alone. Employing a quasi-experimental research design, two distinct classes were subjected to different instructional treatments. The study participants comprised eighth-grade junior high school students, with each class consisting of 140 students, divided into control and experimental groups. The research instrument utilized was a test assessing mathematical creative thinking abilities. Data analysis commenced with prerequisite tests for normality and homogeneity, followed by hypothesis testing using the t-test, facilitated by SPSS 21 software. The findings revealed that that there is an influence on students' creative thinking abilities in using PjBL using AR than PjBL without AR. This underscores the efficacy of Augmented Reality (AR) media in cultivating the creative thinking abilities of junior high school students, particularly in geometric contexts. The positive impact of PjBL augmented with AR can be attributed to the immersive nature of AR technology, which encourages students to engage creatively with projects, thereby enhancing their capacity for innovative problem-solving.*

KEYWORDS: Creative thinking ability, Geometry, Project-based learning.
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1. Introduction

Thinking skills are typically categorized into two types: low-order thinking skills (LOTS) and high-order thinking skills (HOTS). High-order thinking skills encompass problem-solving abilities, critical thinking skills, and creative thinking skills (Fauzan & Arifin, 2017; Mahmuzah, 2017; Permana, 2019). The ability to think at a higher level is seen as indicative of an increase in human resources in the field of education in the 21st century. However, research suggests that students' high-order thinking skills are often underdeveloped due to factors such as limited exposure to Higher-Order Thinking Skills (HOTS) questions (Hadi & Faradillah, 2020), disinterest in the material, and a tendency to rely on teacher assistance (Fauzi, Rahmatih, et al., 2021). Additionally, the 2018 PISA results for Indonesian students ranked 74th out of 79 countries (OECD, 2019), highlighting the ongoing challenge of achieving a high level of thinking ability in solving PISA questions among Indonesian students.

Another contributing factor to low creative thinking ability is the continued use of conventional teaching models by teachers, which often prioritize teacher-centered approaches, as well as reliance on traditional learning media (Hadi, 2016; Ratnawati et al., 2020). Previous research suggests that to enhance creative thinking skills, a learning model emphasizing student-centered approaches, inquiry-based learning, problem identification, and problem-solving is needed (Ratnawati et al., 2020). One such model that places a strong emphasis on problem-based projects is project-based learning (PjBL). Learning models aligned with 21st-century educational principles, such as problem-based learning, project-based learning, and guided discovery learning, have shown to influence and improve students' creative thinking skills (Aminullah, 2017; Noviyana, 2017). Project-Based Learning has emerged as an alternative to traditional models, promoting active engagement and practical application of knowledge (Fitriyah & Ramadani, 2021). Initially, the ability to think creatively is considered a fundamental human skill, as it encourages students to explore various creative solutions to problems, leading to the generation of new and useful ideas for their lives (Fauzan & Arifin, 2017).

In addition to the learning model, learning media play a crucial role in supporting teachers in conveying information to students. Current learning media, integrated with Technological, Pedagogical, Content, and Knowledge (TPACK), place a strong emphasis on technology, with augmented reality (AR) emerging as a prominent medium aligned with 21st-century learning objectives. Augmented Reality (AR) is a learning medium that is currently being developed and utilized in the teaching and learning process in classrooms. AR combines images with a camera to create three-dimensional images, offering immersive and interactive learning experiences (Billinghurst, 2019). Despite its potential, the integration of AR into GeoGebra, a mathematical software widely used in classrooms, remains underexplored, particularly concerning its impact on critical and creative thinking skills (Maulana Arifin et al., 2020).

Therefore, this research aims to investigate the effect of augmented reality-based Project-Based Learning (AR-based PjBL) on students' creative thinking skills. The research question guiding this study is: Does the use of augmented reality in project-based learning enhance students' mathematical creative thinking skills compared to traditional project-based learning without augmented reality? This study represents an innovative approach to integrating 21st-century technological media, AR, with essential 21st-century skills, specifically mathematical creative thinking within the framework of the 4Cs (communication, collaboration, critical thinking, and creativity).

2. Literature review

2.1. Creative Thinking Ability

Creative thinking ability, according to Martin (Aminullah, 2017), refers to the capacity to generate novel ideas or innovative solutions to complex problems. Ennis (1875) identifies five indicators of critical thinking abilities, each comprising sub-indicators that are conceptually related. These indicators include: 1) Elementary clarification, which involves focusing questions, analyzing arguments, and posing or responding to clarifying or challenging inquiries; 2) Basis for decision-making/support, encompassing the evaluation of source credibility, observation, and assessment of observational reports; 3) Inference, involving deduction, induction, value statement formulation, and assessment.; 4) Advanced clarification, which entails definition and assessment of definitions, as well as assumption identification.; 5) Strategy and tactics, covering action determination and interaction with others.

According to Jazuli (2009), creative thinking includes cognitive skills, metacognitive skills, and attitude skills. Creative thinking is encompassed within the realm of creativity and reflects the deeper and broader nature of ideas. Cognitive skills in creative thinking include 1) identifying problems and opportunities; 2) asking better and different questions; 3) assessing relevant from irrelevant data; 4) separating productive problems and opportunities; 5) prioritizing competition of choice and information; 6) generating ideas proficiently (fluency); 7) strategizing problems with various ideas (flexibility); 8) finding a different solution than others (originality); 9) finding another solution with a different alternative (alternative); 10) stopping natural thought patterns and habits; 11) creating a new connection; 12) detailing, developing, or refining an idea, situation, or plan (elaboration); 13) looking carefully at the criteria; and 14) evaluating options. The indicators of creative thinking are 1) fluency, namely being able to fluently provide many ideas to solve a problem (including many examples); 2) flexibility, namely being able to come up with new ideas (to try another way) in solving the same problem; 3) originality, namely being able to produce extraordinary ideas to solve a problem (can answer it in his own way); and 4) elaboration, namely being able to further develop ideas from existing ideas or break down problems into simpler problems.

2.2. Project-Based Learning (PjBL) based on Augmented Reality (AR)

Project-Based Learning (PjBL) based on Augmented Reality (AR) Project-Based Learning is one of the learning models used in the 2013 curriculum. The use of Augmented Reality (AR) means that students are able to develop the media used to communicate. The use of AR is included in technology and information media skills. So, these skills need to be developed in the 21st century. Continuing the implementation of learning in the 21st century is the educator as a facilitator, as a learning friend, student-centered, learning is more flexible and according to needs, learning is project and problem-based, real (because it is directly applied by students), process, and reflection and can find (discovery), collaborative, and more creative learning. Project-based learning consists of five criteria, namely centrality, directing questions, inquiry, constructivism, autonomy, and realism (Kemdikbud, 2014); 1) The project-are central, not peripheral to the curriculum; 2) PjBL projects are focused on questions or problems that encourage students to learn the core or main concepts and principles of the subject. Projects are usually carried out by asking questions whose answers cannot be determined (ill-defined problem); 3) The project engages students in constructivist inquiry. An investigation can be a process design, decision making, problem discovery, problem solving, discovery, or model development process; 4) Projects are student-driven to some significant degree; and 5) The characteristics of the project provide authenticity to the students. The PjBL learning syntax (Kemendikbud, 2014) is as follows:

Phase 1. Start with the essential question Learning begins with essential questions, namely questions that can assign students to carry out an activity. Questions are prepared by taking topics that correspond to real-world realities and starting with an in-depth investigation. The questions that are prepared should not be easy to answer and can lead students to create projects. Such questions are generally open (divergent), provocative, challenging, require high-order thinking skills, and are related to students' lives. Teachers try to make the topics raised relevant to students.

Phase 2. Design project Planning is done collaboratively between teachers and students. In this way, students are expected to feel "ownership" of the project. Planning contains the rules of the game, selecting activities that can support answering important questions, by integrating various possible materials, and knowing the tools and materials that can be accessed to help complete the project.

Phase 3. Create schedule Teachers and students collaboratively prepare a schedule of activities to complete the project. Activities at this stage include: making a schedule for completing the project, (2) determining the final time for completing the project, (3) bringing students to plan new ways, (4) guiding students when they make ways that are not related to the project, and (5) ask students to make an explanation (reason) about how to choose the time. The agreed schedule must be agreed together so that teachers can monitor learning progress and work on projects outside the classroom.

Phase 4. Monitoring the students and progress of the project The teacher is responsible for monitoring student activities while completing the project. Monitoring is carried out by facilitating students in each process. In other words, the teacher plays the role of mentor for student activities. To simplify the monitoring process, a rubric was created that can record all important activities.

Phase 5. Assess the outcome Assessments are carried out to assist teachers in measuring the achievement of competency standards, play a role in evaluating each student's progress, provide feedback on the level of understanding that students have achieved, and assist teachers in developing subsequent learning strategies.

Phase 6. Evaluation The Experience At the end of the learning process, teachers and students reflect on the activities and results of projects that have been carried out. The reflection process is carried out both individually and in groups. At this stage students are asked to express their feelings and experiences while completing the project. Teachers and students develop discussions in order to improve performance during the learning process, so that in the end a new finding (new inquiry) is found to answer the problems raised in the first stage of learning.

The project produced by students in this research is the use of AR in building materials. Students can explore and develop projects using their creative thinking skills in completing projects. So, with this experience, students can improve their critical and creative thinking skills using the PjBL model and the latest technology, namely AR, in producing projects. Augmented reality (AR) is a technology that combines the real world with the virtual (digital) by displaying three-dimensional objects in the real world through a camera and displaying illustrations that are difficult and can be seen concretely so that they can be used in learning activities (Maulana Arifin et al., 2020). The use of AR technology has many advantages, including being more interactive, using it effectively, can be implemented widely, modeling objects that are simple, manufacturing that does not require a long time and cost, and is easy to operate. The teacher only needs to bring the marker in the Geogebra software and the marker will be read via the smartphone camera to then display the 3D shape of the desired spatial shape. The relationship between PjBL and Creative Thinking Ability using AR Currently, students must be required to create something to solve a problem. By being able to create something, it is hoped that students will be able to create innovation that is creative of the results of the project being carried out. The project-based learning model in this research is to improve students' ability to think at a high level in terms of creating a solution to a given problem using AR. In the process of making products, students are expected to be able to think creatively in finding and making the product/project. This will create students' ability to think creatively. The media that will be used by students is Augmented Reality (AR) to help with the problems that will be given. The AR in this research is AR in geogebra form so the researcher did not create an application from scratch related to AR.

3. Methodology

This research is quantitative and includes quasi-experimental research. This is because in the study, the subjects were not randomly grouped, but the researchers accepted the condition of the subjects as they were, with a non-equivalent posttest control group design (Ruseffendi, 2010).

X	O
	O

Information:

X: Learning using AR-based PjBL

O: Post-test The ability to think creatively is given to the experimental and control classes

…: Samples are not randomly grouped.

The population in this study were all students of state School in Depok. The sample in this study was class VIII students who received geometrical material. The sampling technique was obtained through purposive sampling technique. Purposive sampling is used when determining the experimental class and control class because the research subjects were directly selected by the mathematics teacher in 2 classes for the researcher. So that one class was obtained, namely the experimental class, the class that was given treatment using PjBL based on AR, and the control class, namely the class using PjBL without AR. The instrument used in this study is an instrument for mathematical creative thinking skills in the form of essay tests. This instrument will be validated by spatial material expert validators by Mathematics Education Study Program Lecturers, as well as language experts by Indonesian Language lecturers. Data analysis techniques for students' critical and creative thinking skills begin with prerequisite tests, namely normality and homogeneity tests. Then test the research hypothesis using the t-test. Data analysis calculations were performed using SPSS 21 software. The independent variable in this research is project-based learning using augmented reality, while the dependent variable is the ability to think creatively. First, the normality

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test of the data distribution was carried out. The test was carried out using the Kolmogrov-Smirnov test statistic with a significance level of 0.05. The formulation of statistical hypotheses to test the normality of the distribution of post-test data ability to solve mathematical problems is:

H0: Mathematical Creative Thinking Ability data is normally distributed.

H1: Mathematical Creative Thinking Ability data is not normally distributed.

With the following test criteria:

If the sig value (p-value) < α (α = 0.05), then H0 is rejected

If the sig value (p-value) ≥α (α=0.05), then H0 is accepted

if two data are normally distributed then the homogeneity test is continued, however, if one of the data is not normally distributed then the homogeneity test is not carried out and continued with a non-parametric test using Mann Whitney.

The formulation of the statistical hypothesis to test the difference between the two average post-test data for the ability to think creatively mathematically with a one-sided test is:

H0: $\widehat{\mu_1} = \widehat{\mu_2}$ There is no significant difference between the results of the mathematical creative thinking ability of PjBL class students with AR and without AR.

H1: $\widehat{\mu_1} > \widehat{\mu_2}$ Rank results the mathematical creative thinking ability of PjBL class students with AR is significantly better than the results of the PjBL class students' mathematical creative thinking without AR.

4. Results and Discussion

Data analysis of mathematical creative thinking abilities aims to test one of the research hypotheses, namely the mathematical creative thinking abilities of students who receive PjBL learning with AR are better than students who receive PjBL learning without AR. Based on Table 1, it can be seen that the average mathematical creative thinking abilities of the experimental and control class students are clearly different. Visually, the descriptive data for the second student's mathematical creative thinking ability in learning can be seen in Table 1.

Table 1. Descriptive statistics of mathematical creative thinking ability

Descriptive Statistics	Project-based learning with AR Class	Project-based learning without AR Class
Mean	0.83	2.39
Standar Deviation	0.699	0.844
Variance	0.489	0.712
Minimum	0	0
Maximum	2	3

From Table 1, it can be seen that there is a difference between the average data on mathematical creative thinking abilities of students in the control and experimental classes. Similar to the previous analysis, the data will carry out appropriate statistical test stages to see whether the differences in the mathematical creative thinking abilities of PjBL class students using AR and not using AR are significant or not. The mean of the project-based learning class using AR is lower than the project-based learning class without using AR, namely 0.83 and 2.39, respectively. In detail from the data in Table 1, the project-based learning class without using AR is higher than the project-based learning class using AR. This is because students are still not used to using AR as a geometry learning medium. Next, the data continues to be tested for normality tests. The results of the normality test for data distribution for the creative thinking skills of the two learning classes are presented in Table 2.

Table 2. Normality Test of Data Distribution for Mathematical Creative Thinking Ability

Class	Statistic	df	Sig.
Project-based learning with AR	0.315	31	0.000
Project-based learning without AR	0.216	30	0.000

Based on Table 2 above, it can be seen that the significance values for the Kolmogorov-Smirnov test for students in the project-based learning with AR and without AR class are 0.000 and 0.000, respectively. The significance value for students in both classes is less than 0.05, so H0 is rejected. Significance values for experimental and control class students are not normally distributed. Therefore, a two-difference test will be carried out on the average post-test data for students' mathematical creative thinking abilities using the non-parametric test, namely the Mann-Whitney. The results of the two-difference test on average data on students' creative thinking skills are presented in Table 3.

Table 3. Two Differences Test Average Mathematical Creative Thinking Ability Data

Test Statistics[a]	
	Creative thinking Ability
Mann-Whitney U	90.000
Wilcoxon W	555.000
Z	-5.595
Asymp. Sig. (2-tailed)	.000
a: Grouping Variable: Kelas	

From Table 3, it appears that the significance value of the one-tailed Mann-Whitney test is 0.000. The value of 0.000 is less than 0.05. This means that the results of the mathematical creative thinking ability of PjBL class students with AR are significantly better than the results of the PjBL class students' mathematical creative thinking results without AR. Thus, the mathematical creative thinking ability of students who received PjBL learning with AR was significantly better than students who received PjBL learning without AR. Furthermore, an effect size test was carried out to see the effect of Augmented Reality (AR) media on the ability to think creatively, namely:

$$\text{Effect Size} = \frac{\text{mean exp} - \text{mean control}}{\text{SD combine}}$$

$$\text{Effect Size} = \frac{0.83 - 2.39}{0.844} = -1.849$$

It was found that the effect size value was negative because the mean of the project-based learning with AR class was lower than the mean of the project-based learning without AR class, although the creative thinking abilities of students who use project-based learning using AR are better than those who do not use AR, meaning that augmented reality is not the only tool to assist in creative thinking abilities, but what learning methods are used. In this research, both classes used project-based learning. This is different from the findings compared with the conventional method. Findings indicated that AR applications increase students' academic achievement in the learning process compared to traditional methods (Sahin & Yilmaz, 2020). In testing the hypothesis, there was an influence but negative effect of Augmented Reality (AR) on the based learning with AR class. These results contradict the findings from (Altinpulluk, 2019) It has been determined that the most positive influence of AR on education is academic success and learning motivation. There are several things that cause the mean score for the experimental class to be lower than the control class due to internal and external factors. Internal factors because students are still not used to using AR applications, spatial abilities in drawing are still low as seen from researchers observing projects created by students and the use of AR is This activity was carried out for the first time by students, so students needed longer assistance, this meeting only lasted 8 meetings so students still had difficulty drawing geometric shapes. External factors occur due to limited internet quota so that students have difficulty drawing because of the quota, then the use of gadgets, there are several students who have cellphones that are not compatible, making it difficult for students to carry out experimental activities. Based on the results of the data analysis that has been presented previously, the following will describe the description and interpretation of the research data. Descriptions and interpretations of research data were analyzed based on the ability to think creatively and PjBL learning with AR. Augmented Reality (AR) is a mathematics learning media that already exists in the GeoGebra application. So, researchers do not make from scratch related to AR design. In Project-Based Learning learning

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in experimental classes that use AR students are directed to have a project at the end after students are taught to use AR applications in the classroom with designs tailored to students. In this material is geometry, where in the experimental class students are freed to make at least two geometric shapes combined using GeoGebra in AR form and then the calculations can be displayed in a notebook. Figure 1 is a student project in making a geometric design based on the creativity of the students. In the experimental class students download GeoGebra on their gadgets and then design according to their wishes.

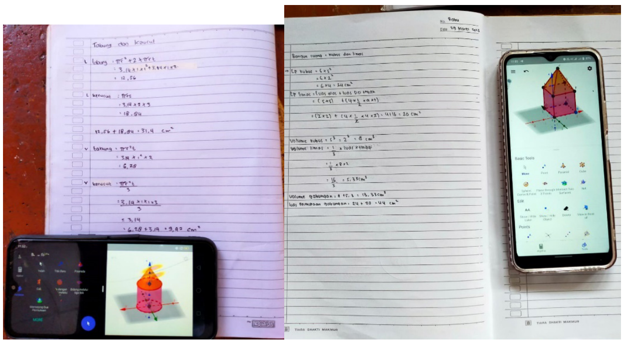

Figure 1. Project-Based Learning with AR

In Figure 1, students work on project-based learning using Augmented Reality (AR), then the teacher monitors student work by checking all the results done by students. The syntax for project-based learning using AR in project-based learning can help visualize junior high school students in imagining a spatial structure when viewed from 3D, namely (AR) and can be moved 360 degrees according to the wishes of students. In this case, students' creative abilities emerge by making projects and being able to calculate the volume of a geometric shape if there are other geometric shapes in it. Unlike the case with the project-based learning without AR class, they could only draw on paper because they did not use any media to support the visualization of junior high school students. In this case, the use of learning media is very important to be able to improve students' mathematical abilities, especially in the ability to think mathematically creative thinking abilities. Using AR for learning stimulates students' creative thinking, improves their understanding in the domain of concrete subjects, and enhances their understanding of spatial space (Ivanova & Ivanov, 2011). Project-based learning (PjBL) is an important factor for generic (problem-solving, communication, creative thinking, decision-making, management) (Thomas, 2020).

5. Conclusions

Based on data analysis calculations, it can be concluded that there is an influence on students' creative thinking abilities in using project-based learning using augmented reality than project-learning without AR. Even if there is a negative size effect value, it does not affect the conclusion that the creative thinking ability of students who use project-based learning with AR is compared to project-based learning without AR. Several factors cause the first negative size effects value to be mean and the student's initial ability is unknown, which results in a lower creative thinking skill score of students in the classroom who use AR than those students who do not use AR. The limitation on the research is the non-maximum use of AR due to lack of internet access due to the need to use Internet quotas as well as the limitation of students in using Geogebra tools to be able to be AR and the time limitation in the experiment. The materials used are limited to geometry have not been tested for other materials such as algebra or function equations. As well as the ability measured is the ability to think creatively has not been compared to other mathematical abilities.

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