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Ethno-STEM Integrated Digital Teaching Material with Augmented Reality to Promote Students' Learning Skills and Innovation

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Abstract

In the midst of the dynamics of globalization and the industrial revolution 4.0, the 21st century education is increasingly evident in equipping the younger generation with relevant and adaptive skills. These skills include critical thinking skills, creativity, collaboration, and effective communication. In an effort to improve the quality of students' 21st century skills, the use of ethno-STEM integrated digital teaching material assisted by augmented reality (AR) has emerged as a promising innovative solution. The purpose of the study was to determine the effect of ethno-STEM integrated digital teaching material with augmented reality (DTM-AR) to promote students' learning and innovation skills. The research method used was a quasi-experiment with a posttest only. The population in this study were all students of class XI SMAN 12 Padang. The sample consisted of two groups, namely the experimental group and the control group, each consisting of 34 students. The results of the study were that Ethno-STEM integrated digital learning material with augmented reality were able to improve students' learning skills and innovation. Student' learning skills and innovation that can be improved by DTM-AR are critical thinking skills, creative thinking skills and communication skills.

Introduction

Twenty first century skills are essential in education because they prepare students to face future global challenges with critical thinking, creativity, communication, and digital literacy skills. In this digital era, skills such as critical thinking, creativity, communication, and digital literacy are essential for success in various fields. Without these skills, individuals and organizations will struggle to adapt to rapid changes and the demands of an ever-evolving job market. Students should be at the heart of the teaching process, actively developing their interests and skills through hands-on learning that connects to real-world challenges (Asrizal et al, 2020). In the era of globalization and increasingly rapid technological development, learning skills are essential for individuals to master in order to compete in an increasingly competitive job market. These skills include critical thinking, creativity, collaboration, and effective communication (Sutarto, 2023; Lubis, 2023). With advances in technology, routine and repetitive jobs are increasingly being replaced by automation and artificial intelligence, so that humanistic and analytical skills are increasingly valuable. These 21st century skills are not only relevant to individuals, but also to the progress of the nation in facing global challenges (Mardhiyah, 2021). Therefore, it is important for educational institutions, governments, and the private sector to collaborate in developing programs that can improve learning skills.

Learning and innovation skills are essential for students in facing the challenges of a changing world. The ability to learn independently, think creatively, and develop new ideas allows students to adapt quickly to new situations and solve complex problems. Amid the dynamics of globalization and the industrial revolution 4.0, 21st-century education is increasingly evident in equipping the younger generation with relevant and adaptive skills. 21st-century education emphasizes the development of competencies that include not only academic knowledge, but also critical thinking skills, creativity, collaboration, and digital literacy (Arifin, 2024; Irawan, 2023). The traditional education system that focuses on memorization and passive understanding must now evolve to create more active and contextual learning (Agustina, 2023). The ability to adapt to rapid change and lifelong learning is essential in facing future challenges (Jaya, 2023). Learning and innovation skills are the main foundation that strengthens and connects the development of 4C skills critical thinking, communication, collaboration, and creativity in facing future challenges (Tang, 2020). Research has shown that contextual teaching can enhance students' thinking and literacy skills (Asrizal et al, 2018). In this context, educational technology plays an important role in expanding access and improving the quality of learning. 21st century education not only prepares students for the job market, but also to become responsible citizens and be able to think critically in dealing with global issues (Rizal, 2024). Therefore, investment in 21st century education is an investment for a better future, both individually and collectively.

Information and Communication Technology (ICT) plays an important role in 21st century learning as access to information and global interaction. ICT not only facilitates access to extensive educational resources, but also enriches the learning process by enabling more interactive and collaborative learning methods. In the ever-evolving digital era, the application of Information and Communication Technology (ICT) in learning is becoming increasingly important to prepare a competent and adaptive future generation. The use of ICT in education enables more interactive, engaging, and personalized learning, as well as opening up access to unlimited global resources and information (Widayat, 2024). ICT can foster student-centered learning by stimulating interaction, enhancing basic skills, igniting curiosity, transforming the learning environment, and ensuring wide and efficient access to educational resources (Asrizal et al, 2022). With ICT, teachers can develop innovative teaching methods, while students can learn in a more flexible and independent way (Hattarina, 2022). In addition, ICT helps in developing learning skills such as digital literacy, problem solving, and online collaboration that are essential in the modern workplace (Aksenta, 2023; Saputra, 2024). By utilizing ICT, education can become more inclusive and equitable, bridging the digital and social divide. Therefore, investment in ICT in the education sector not only improves the quality of learning, but also equips students with relevant skills to face future challenges.

The initial research problem found that students' learning skills and innovation. Physics learning certainly requires high learning skills scores from students (Afradiska, 2020). Students are expected to master critical thinking skills, creative skills and communication skills (Putri, 2021; Geissler, 2012). Critical thinking skills were scored 50 in the low category. Creative thinking skills were scored 49 in the low category. And communication skills were scored 46 in the low category. Students' learning skills for the three skills were in the low category. Students still have difficulty applying critical thinking strategies in complex situations (Amin, 2020). Students tend to be less creative in completing tasks that require innovation (Ummah, 2020). Students often do not have good communication skills, which can be seen from the clarity in conveying information (Alshumaimeri, 2021). These findings highlight the urgent need to integrate the development of these skills into the education curriculum.

The solution proposed in this study is the use of DTM-AR to improve students' critical thinking, creative, and communication skills. By utilizing AR, these teaching materials provide an interactive and immersive learning experience, allowing students to connect STEM concepts with their local cultural context. In an effort to improve the quality of students' 21st-century skills, the use of DTM-AR has emerged as a promising innovative solution. Ethno-STEM, which combines ethnographic approaches with science, technology, engineering, and mathematics, offers a new way to link learning with local cultural contexts (Al-idrus, 2022; Inayah, 2022; Nurhasnah, 2022). Etno-Stem can be included in learning to become a novelty and a learning combination that motivates students. Unlike previous studies that often focus on technology applications separately, this study combines ethnographic and STEM approaches to create a more holistic and contextual learning experience. In addition, this approach offers advantages in visualization and engagement that are not found in traditional learning methods. Thus, this research not only improves the effectiveness of teaching but also provides innovative solutions to existing educational challenges.

Digital learning materials have become an essential tool in modern education, offering flexibility and accessibility that traditional methods cannot match. Digital learning materials enable more interactive and engaging delivery of materials, using multimedia such as videos, animations, and simulations (Tanujaya, 2021; Liu, 2021; Sinaga, 2022). Research shows that digital learning materials can increase student engagement and facilitate self-directed learning (Juliana, 2024; Zakharova, 2022). Integrating digital learning materials with technologies such as AR and Ethno-STEM approaches can create a fun learning environment and enhance students' skills (Marrahi, 2022; Shaaban, 2024). It also enables more inclusive learning, bridging the access gap between students in different geographic locations.

Augmented reality is able to visualize abstract concepts to be more real and interactive, thus improving student understanding (Hermawan, 2024; Tohir, 2024). Previous studies have shown that the use of AR in education can significantly increase learning motivation, student engagement, and understanding of the material (Carolina, 2023; Fauziah, 2024). These studies also indicate that teaching materials that integrate cultural context can make learning more relevant and interesting for students (Wero, 2021; Widiantari, 2021). By combining these two approaches, AR-assisted Ethno-STEM digital teaching materials not only develop students' technical and academic skills but also enrich their understanding of cultural heritage (Sartika, 2022; Kinasih, 2023). The implementation of this technology requires close collaboration between content developers, educators, and local communities to ensure that the material presented is accurate and meaningful (Hidayat, 2020). With a strong research foundation, AR-assisted Ethno-STEM integrated digital teaching materials are expected to be a breakthrough in education, providing a richer and more meaningful learning experience for future generations.

Ethno-STEM digital teaching materials assisted by augmented reality (AR) include several important aspects that underlie its effectiveness in education. First, Ethno-STEM is an approach that combines local cultural elements with science, technology, engineering, and mathematics, thus providing a more relevant and interesting context for students (Sumarni, 2023; Zan, 2023). Research shows that the relevance of learning materials to local culture can increase student engagement and motivation to learn (Saputra, 2022). Second, augmented reality technology has the ability to make abstract concepts more real and interactive, which can improve understanding and retention of the material (Apriani, 2021). AR allows students to interact with 3D objects and simulations, which enriches their learning experience (Resti, 2024). Previous studies have shown that the use of AR in education can improve academic achievement and critical thinking skills (Ashari, 2023; Saadiyah, 2022). The integration of Ethno-STEM and AR in digital learning materials also enables a more meaningful learning approach bridging the gap between traditional and modern knowledge (Destiara, 2021; Nurroniah, 2023). With a strong research foundation, AR-assisted Ethno-STEM digital learning materials are expected to create a more dynamic and effective learning environment, preparing students to face future challenges with relevant and in-depth skills.

Digital learning materials that integrate ethnographic and STEM approaches can facilitate learning that is not only academically relevant but also contextual and cultural. This study aims to optimize the use of Augmented Reality (AR) technology in creating a more interactive and engaging learning experience. Through this approach, it is expected that students can develop critical thinking skills, creativity, and collaboration more effectively. This study makes a significant contribution to improving the quality of education in the digital era. The purpose of this study is to produce digital teaching materials integrated with Etno-STEM that can improve students' learning skills and innovation. Thus, digital learning materials, especially those integrated with AR and Etno-STEM, can be an effective solution in improving students' skills and preparing students to face future challenges.

Method

This research design uses a quasi-experiment with a posttest only pattern. The experimental group and control group were selected to measure the effectiveness of the treatment given. At the beginning of the study, initial measurements were taken to determine the initial conditions of the research participants. The initial conditions of students that were seen were students' initial skill scores, students' use of digital teaching materials, and the use of ICT in student learning. After that, the experimental group was given treatment while the control group was not. The final measurement was carried out to determine the changes that occurred in students' skill scores. The population in this study were all students of class XI SMAN 12 Padang. The sample consisted of two groups, namely the experimental group and the control group, each consisting of 34 students. Sample selection was carried out to ensure good representation of the population. The selection of the experimental class and control class was through the ANOVA test stage. Thus, the results of the study can be generalized to a wider population.

The research on the use of integrated digital teaching materials Ethno-STEM to improve students' learning skills and innovation went through several series of studies. The first step in this study was to determine the objectives and formulate hypotheses. Next, the researcher selected samples and divided them into experimental and control groups. The treatment of using digital teaching materials was then given to the experimental group for some time, while the control group did not receive the use of digital teaching materials. After the treatment was completed, measurements were taken of students' 21st century skills. The data obtained from this measurement were then analyzed to test for an increase in students' skill scores.

The instrument used in this study was student performance assessment. This assessment was designed to measure student skills before and after treatment was given. This instrument was developed based on skill indicators. The skills assessed were critical thinking skills, creative thinking skills and communication skills. This performance assessment was carried out by researchers using an assessment rubric that was appropriate to the problem. The performance assessment instrument used to assess each student skill was critical thinking skills, creative thinking skills and communication skills. The data obtained were analyzed using parametric statistical techniques of the t-test and the Mann Whitney test. The t-test is used to compare the means of two different groups to see if there is a significant difference. Meanwhile, the Mann Whitney test is used as a non-parametric alternative to test the difference between two groups if the data is not normally distributed. The results of this statistical analysis will determine whether the proposed hypothesis can be accepted or rejected. With this technique, researchers can obtain valid and accountable conclusions.

Results

Effect of Ethno-STEM Integrated DTM-AR on Knowledge Ability

Assessment of the student's knowledge aspect was carried out by giving a posttest to both samples, namely the experimental group and the control group. The instrument used was a written test in the form of multiple-choice questions. There was a difference in the value of the knowledge aspect in the experimental group and the control group in the use of integrated digital fluid teaching materials Etno-STEM. The results of the analysis of the differences in the knowledge aspects of the experimental and control groups can be seen in Table 1.

Table 1. Knowledge Statistical Data

Statistical Parameter	Control Group	Experimental Group
Mean Score	73.02	82.94
Standard Deviation	9.32	11.65
Median	70.00	80.00
Standard Deviation	9.32	11.65
Variance	86.91	135
Highest Score	100	100
Lowest Score	66.00	66.00
Range	34.00	34.00
	Normality Test	
Shapiro-Wilk p-value	0.028	0.028
	Homogeneity Test	
Sig. Value	0.039	

Mann-Whitney U	
Mann-Whitney U	290.000
Wilcoxon W	920.000
Z	-3.964

In Table 1, there are differences in statistical values from the results of the evaluation of teaching materials in the knowledge aspect for the control and experimental classes. The average value of the control class is 73, while the experimental class is 82, indicating a significant difference in knowledge. The next analysis of the knowledge aspect is the normality test using the Liliefors test. Table 1 shows that the data of the two classes are not normally distributed, with the Shapiro-Wilk p-value of 0.000 and 0.003, greater than the critical value of 0.05. The knowledge value data of class XI that is not normally distributed will be further analyzed using the homogeneity test and non-parametric test.

Homogeneity test was conducted to see whether the data of the knowledge aspect values of the two groups came from homogeneous or heterogeneous variances, using the F test. Table 1 shows that both classes have heterogeneous knowledge data, with a p-value of 0.028 smaller than the critical value of 0.05. Furthermore, the non-parametric Mann Whitney test was conducted as a solution for sample data that was not normally distributed and heterogeneous. The results of the Mann Whitney test in Table 4.8 show a U test value of 290 and a W value of 920, which when converted to a Z value is -3.964, smaller than -0.833 and greater than 0.833, so H0 is rejected and H1 is accepted. This indicates a significant difference in knowledge between the control and experimental classes, supporting the hypothesis that the integrated Ethno-STEM fluid digital teaching materials improve students' knowledge.

Effect of Ethno-STEM Integrated DTM-AR on Critical Thinking Skills

The effectiveness of digital teaching materials on critical thinking skills is assessed in a performance assessment in the form of a performance assessment sheet. The performance assessment sheet contains critical thinking components in it. The critical thinking component has four indicators. The indicators of critical thinking skills are interpretation (IP), analysis (AN), information and discovery (ID), and argument (AG). The instrument for critical thinking skills is using a performance assessment instrument. Performance assessment is carried out in completing student worksheets during the learning process. Performance assessment is assessed using critical thinking skills indicators on the performance assessment sheet. The results of the analysis of differences in knowledge aspects of the experimental and control groups can be seen in Figure 1.

Based on Figure 1, it is stated that there is a gap between the experimental class and the control class in the value of critical thinking skills. The experimental class has a higher value based on 4 indicators of critical thinking skills. The experimental class has a value of 77, 77, 75 and 80 for the four indicators of critical thinking skills higher than the control class. This states that the value of skills in the experimental class is influenced by the use of integrated digital teaching materials Etno-STEM. Table 2 presents statistical data related to critical thinking skills. This data covers various aspects measured using certain indicators, which are then analyzed to describe the level of critical thinking skills in the tested group. This table provides a comprehensive overview of the distribution of values, averages, and differences that emerge between groups based on the critical thinking skills that have been identified. The results of the analysis of critical thinking skills can be stated in Table 2.

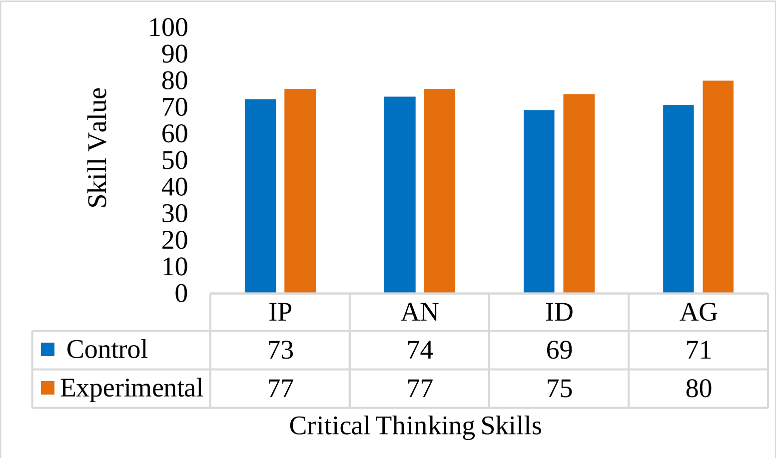


Figure 1. Critical Thinking Skills

Table 2. Statistical Data on Critical Thinking Skills

Statistical Parameter	Control Group	Experimental Group
Mean Value	72	77
Standard Deviation	11.67	8.2
Median	68.75	75.00
Variance	136.35	67
Highest Value	93.75	93.75
Lowest Value	50.00	62.50
Range	43.75	31.25
Normality Test		
p-value Shapiro-Wilk	0.121	0.060
Homogeneity Test		
Sig. Value	0.046	
T-Test or Independent Sample Test		
t-calculated	1.86	
t-table	1.68	

Table 2 shows that the average value of critical thinking skills of students in the experimental group is higher than the control group. The assessment instrument uses a scale of 4 for each indicator, with the average values of the two groups being 72 and 77, respectively, which are classified as good. Based on descriptive statistics, there is a difference in values between the experimental group and the control group. Furthermore, the analysis of critical thinking skills aspects was carried out through a normality test using the Liliefors test. The results of the normality test at a significance level (α) of 0.05 indicate that the critical thinking skills data from both groups come from a normally distributed population. The Shapiro-Wilk p-value for the control class is 0.121 and the experimental class is 0.060, both of which are greater than the critical limit of 0.05.

The next test is the homogeneity test to see whether the critical thinking skills value data from the two groups come from homogeneous or heterogeneous variances. The homogeneity test using the F test was carried out with SPSS analysis. Based on the results of the analysis in Table 2, both sample groups have heterogeneous variances with a p-value of 0.048 which is smaller than the critical limit of 0.05. Although the data from both samples are heterogeneous, because the data is normally distributed, the analysis is continued with a parametric test. The comparison test of two independent sample means (t-test) was used to analyze the differences in critical thinking skills between the control and experimental groups.The results of the t-test in Table 2 show that the value of -1.86 is smaller than -1.68 and 1.86 is greater than 1.68, so H0 is rejected and H1 is accepted. This indicates a significant difference in critical thinking skills between the control and experimental groups. The use of integrated STEM and Ethnoscience digital fluid teaching materials has been proven effective in improving students' critical thinking skills. With a p-value of the T test of 0.046 which is smaller than the critical limit of 0.05, it can be concluded that the use of Etno-STEM integrated digital fluid teaching materials is effective in improving the critical thinking skills of grade XI students.

Effect of Ethno-STEM Integrated DTM-AR on Creative Thinking Skills

The effectiveness of digital teaching materials on creative thinking skills is carried out using performance sheets. The creative thinking component has four indicators. The indicators of creative thinking skills are fluent thinking ability (FL), flexible thinking ability (FE), original thinking (OR) and elaboration (EL). The results of creative thinking skills can be seen in Figure 2 as follows.

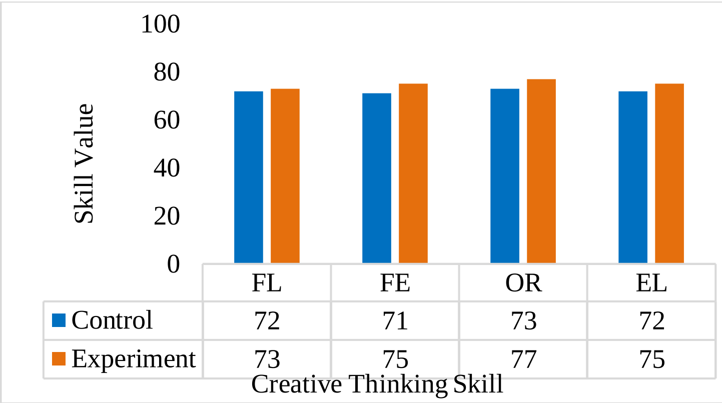


Figure 2. Creative Thinking Skills

Based on Figure 2, it can be stated that there is a gap in value between the experimental class and the control class. The gap applies to the four indicators of creative thinking skills. The experimental class value is 73 for fluent thinking ability, which is higher than the control class. The experimental class value is 75 for flexible thinking ability, which is higher than the control class. The experimental class value is 77 for original thinking. And the experimental class has a value of 75 for elaboration ability, which is higher than the control class. This states that the use of digital teaching materials affects students' creative thinking skills.

Table 3 presents statistical data on creative thinking skills. These data include various metrics used to measure the level of creativity in thinking, such as the ability to generate new ideas, originality, and flexibility in problem solving. This table provides a detailed description of the distribution of values, averages, and comparisons of creative thinking skills between the groups analyzed. These results are important for understanding the variations and tendencies in creative thinking skills in the subjects studied. The results of the analysis of the creativity components for the control group and the experimental group can be seen in Table 3.

Table 3. Statistical Data on Creative Thinking Skills

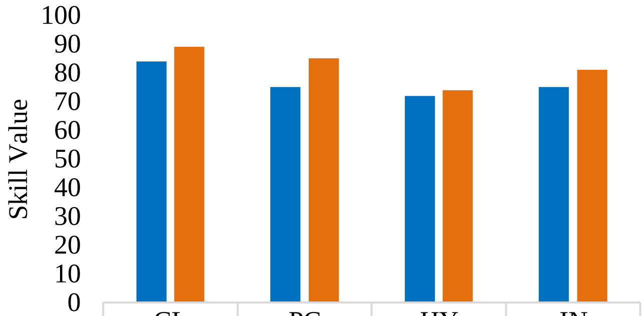
Statistical Parameter	Control Group	Experimental Group
Mean Value	72.5	75.53
Standard Deviation	9.84	8.35
Median	68.75	75.00
Variance	96.96	69.78
Highest Score	93.75	93.75
Lowest Score	56.25	62.50
Range	37.50	31.25
Normality Test		
p-value Shapiro-Wilk	0.107	0.002
Homogeneity Test		
Sig. Value	0.370	
Mann-Whitney U Test		
Mann-Whitney U	503.500	
Wilcoxon W	1133.500	
Z	-1.314	

Table 3 shows that the average value of creative thinking skills of students in the experimental group is higher than the control group, with average values of 75.53 and 72.5 respectively. Both are included in the good category, but there is a difference in values between the experimental and control groups based on descriptive statistics. Furthermore, the analysis of creative thinking skills aspects was carried out through a normality test using the Lilliefors test. The results of the normality test at a significance level (α) of 0.05 indicate that the critical thinking skills data from both groups come from a normally distributed population. The Shapiro-Wilk p-value for the control class is 0.107, greater than the critical limit of 0.05, so the data is normally distributed, while the p-value for the experimental class is 0.002, smaller than the critical limit of 0.05, so the data is not normally distributed. The next test is the homogeneity test to see whether the creative thinking skill value data from both groups comes from homogeneous variance or not. The homogeneity test using the F test is carried out with SPSS analysis. Based on Table 3, the results of the analysis show that both sample groups have heterogeneous variances with a p-value of 0.037, greater than the critical limit of 0.05. Because the data of both samples are homogeneous but not normally distributed, the analysis is continued with a non-parametric test. The Mann Whitney test or U test was chosen to test the difference in creative thinking skill values between the control and experimental groups.

The results of the Mann Whitney test or U test in Table 3 show a U test value of 503 and a W value of 1133, which is converted to a Z value of -1.314. The Ztable value for two alphas of 0.05 is Z 0.975 of 0.833. The calculation results show that Zcount is greater than -Ztable, so there is a significant difference obtained in the use of integrated DTM-AR to improve creative thinking skills. Thus, the use of integrated DTM-AR is effective in improving students' creative thinking skills.

Effect of Ethno-STEM Integrated DTM-AR on Communication Skills

The communication thinking component has four indicators. The communication skill indicators are capital letters (CL), using the correct punctuation (PC), using the correct hyphen (HY) and summarizing information in symbols and words (IN). The communication thinking skill instrument is in the form of student performance assessment. The communication skill assessment focuses on the assessment of students' scientific writing. The assessment is carried out on students' scientific writing in completing student worksheets. Students are assessed with the four criteria above to get the maximum score. The results of communication skills can be seen in Figure 3 as follows.



	CL	PC	HY	IN
Conttrol	84	75	72	75
Experiment	89	85	74	81

Figure 3. Communication Skills

Based on Figure 3, it can be stated that there is a gap in students' communication skills. Communication focuses on oral communication, namely the use of capital letters, punctuation, hyphens and summarizing information. The experimental class has superior values, namely 89, 85, 74 and 81 for the four indicators of oral communication. This states that there is an influence of the use of digital teaching materials on students' communication skills.Table 4 displays statistical data related to communication skills. These data include various indicators used to measure communication skills. This table provides a comprehensive picture of the distribution of values, means, and variations in communication skills among the groups studied. This analysis is important to understand how communication skills develop and vary in different contexts. The results of the communication component analysis for the control group and the experimental group can be seen in Table 4.

Table 4. Statistical Data on Communication Skills

Statistical Parameter	Control Group	Experimental Group
Mean Score	76.96	82.5
Standard Deviation	7.69	8.69
Median	81.25	81.25
Standard Deviation	7.695	8.68
Variance	59.21	75.36
Highest Score	87.50	93.75
Lowest Score	62.50	68.75
Range	25.00	25.00
	Normality Test	
p-value Shapiro-Wilk	0.000	0.002
	Homogeneity Test	
Sig. Value	0.431	
	Mann-Whitney U Test	
Mann-Whitney U	390.500	
Wilcoxon W	1020.500	
Z	-2.685	

Table 4 shows that there is a difference in the average value of the creative thinking skills aspect of the experimental group students which is higher than the control group. The average value of both groups is 82.5 for the experiment and 68.8 for the control, both in the good category. Based on descriptive statistics, there is a significant difference in value between the two groups. The next analysis for the creative thinking skills aspect is to conduct a normality test. The normality test is carried out using the Liliefors test at a significance level (α) of 0.05. Based on Table 4, the creative thinking skills data of both groups come from a population that is not normally distributed. This can be seen from the Shapiro-Wilk p-value of 0.000 and 0.002, which is smaller than the critical limit of 0.05, so the data is not normally distributed. Data that is not normally distributed is continued with a homogeneity test and a non-parametric test.

The homogeneity test was conducted to see whether the critical thinking skill value data of the two sample groups came from homogeneous variance or not. The homogeneity test used was the F test. Based on Table 4, the results of the analysis showed that the two sample groups had homogeneous variance. This is indicated by the p-value of 0.431, which is greater than the critical limit of 0.05. Because the data of the two samples are homogeneous but not normally distributed, the analysis was continued with a non-parametric test. The Mann Whitney test or U test was chosen to test the difference in creative thinking skill values between the control and experimental groups.The results of the Mann Whitney test or U test are stated in Table 4, showing a U test value of 390 and a W value of 1020. When converted to a Z value, the result is -2.685. The Ztable value for two alphas of 0.05 is Z0.975 of 0.833. Based on the calculation in Table 4, Zcount is smaller than Ztable, which indicates a significant difference. This significant difference indicates that the use of integrated DTM-AR is effective in improving students' creative thinking skills. Thus, it can be stated that integrated DTM-AR improve students' creative thinking skills.

The significant value or p-value of 0.007 is smaller than the critical limit of 0.05, indicating a significant difference between the two groups, so H0 is rejected and H1 is accepted. H1 states that there is a significant difference in the results of communication skills for the control and experimental classes. There is a difference in the value of the communication skills of the DTM-AR to improve students' 21st century skills. Thus, the use of DTM-AR is effective in improving students' communication skills.

Discussion

The use of DTM-AR assisted by augmented reality (AR) can significantly improve students' critical thinking skills. These teaching materials combine local cultural elements with science, technology, engineering, and mathematics, which provide relevant and in-depth context for students in understanding the subject matter. The use of AR in education facilitates real-time analysis and evaluation of information, so that students are more involved in solving complex problems (Wibowo, 2023; Waliulu, 2023). Students can interact with virtual objects and simulations, which helps them develop critical thinking skills through exploration and experimentation.

The Ethno-STEM approach allows students to connect academic concepts to their daily lives and cultures, which enriches understanding and practical applications. AR in the context of STEM education enhances students' engagement and their ability to think analytically and critically (Asrizal, 2022; Oktaviyanti, 2023; Rahmayani, 2024). By utilizing AR technology, students can view and manipulate data from multiple perspectives, which deepens their understanding and encourages critical reflection (Iqliya, 2019; Suryanti, 2020; Virijai, 2023). In addition, the integration of cultural contexts in learning makes students more interested and motivated, which directly contributes to the development of critical thinking skills. With strong research support, it is clear that DTM-AR have great potential to effectively develop students' critical thinking skills.

The use of Ethno-STEM integrated digital teaching materials assisted by augmented reality (AR) has great potential in developing students' creative thinking skills. This approach combines local cultural contexts with science, technology, engineering, and mathematics, which provide a rich and meaningful background for students. AR can enhance students' imagination by providing an immersive learning environment, allowing them to explore new and innovative ideas (Sanabrina, 2017; Papanastasiou, 2019). AR allows students to see, manipulate, and create 3D objects in relevant contexts, thus encouraging them to think beyond traditional boundaries.

The Ethno-STEM approach also challenges students to connect scientific concepts to their daily lives, which stimulates creative thinking in finding contextual solutions. AR in STEM learning enhances students' ability to generate creative ideas and innovative solutions (Asrizal, 2023; Sari, 2020; Kennedy, 2014; Muntean, 2019). With AR, students can collaborate on projects that require creative and critical thinking, enriching their learning process. In addition, the use of AR allows for personalization of learning, where students can follow a learning path that suits their interests and learning styles, which in turn enhances creativity (Muhammad, 2024; Midak, 2021). Support from previous studies indicates that AR-assisted Etno-STEM digital teaching materials can effectively foster students' creative thinking skills, preparing them to face future challenges and opportunities with innovation and creativity.

The use of DTM-AR can significantly improve students' communication skills. These teaching materials, with a combination of AR technology and Etno-STEM approaches, create an interactive and collaborative learning environment (Izzah, 2023; Sumarni, 2020). AR enhances social interaction and collaboration in the classroom, which are important components in developing communication skills (Aziz, 2021; Hidayah, 2024). Students are encouraged to work in groups, discuss, and share ideas while using this technology, which helps them develop their speaking and listening skills effectively. The Ethno-STEM approach that links academic concepts with local culture also enriches the context of discussions, making communication more meaningful and relevant to students. In addition, AR provides an engaging visual platform, making it easier for students to convey complex ideas and concepts more clearly and interestingly (Iftene, 2018; Romano, 2023). Students who learn with the help of AR show significant improvements in communication skills as they are more engaged and motivated to participate in learning (Khowaje, 2019; Tran, 2020). These digital learning materials also allow students to collaborate on problem-based projects, which strengthens their ability to work together and communicate effectively (Pidel, 2020). Thus, DTM-AR not only improve academic skills but also communication skills that are essential for future success.

By integrating AR-assisted digital teaching materials and the Ethno-STEM approach, education not only becomes more interactive and engaging, but also more effective in developing important skills for students. The collaboration between technology and local culture creates a holistic learning environment, where students can develop critical thinking, creative, and communication skills in a more natural and contextual way (Rahayu, 2023; Fadli, 2020). Support from previous studies shows that ethno-STEM has great potential to improve the quality of education and prepare students for future challenges. The use of DTM-AR can improve students' critical thinking, creative, and communication skills.

Conclusion

Based on data analysis and discussion, the research conclusions are obtained. First, using DTM-AR has an effect on students' knowledge. Second, using DTM-AR can affect students' critical thinking skills. Third, the use of DTM-AR can affect students' creative thinking skills. Fourth, DTM-AR can affect students' communication skills. In general, the use of DTM-AR can affect the improvement of students' learning outcomes in students' 21st century knowledge and skills. Students' 21st century skills can be improved in the use of DTM-AR, namely students' critical, creative and communication thinking skills. Students' 21st century knowledge and skills can help change the implementation of learning skills and inovation education for the better.

Recommendations

The researcher acknowledged the limitations in this study, namely the use of DTM-AR has not included all ethno-STEM in physics material limited to fluid material only. Other researchers should continue for broader physics material. The application of DTM-AR is limited to the application of fluids. Other studies should include more AR so that students can master technology better and improve student skills.

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