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AR-Poster Assisted Tic Tac Toe: A Game-Based Learning Approach for Mathematical Communication

Khairunnisa Zulfa Alifah[a], Fery Muhamad Firdaus[b]
[a]Universitas Negeri Yogyakarta, Yogyakarta, Indonesia, khairunnisazulfa.2025@student.uny.ac.id
[b]Universitas Negeri Yogyakarta, Yogyakarta, Indonesia, fery.firdaus@uny.ac.id
*Correspondence: Khairunnisa Zulfa Alifah, khairunnisazulfa.2025@student.uny.ac.id

Abstract
This study examines the effectiveness of AR-Poster Assisted Tic Tac Toe as a game-based learning approach to improve primary students' mathematical communication. A quasi-experimental pretest–posttest control group design was applied with 60 fifth-grade students in Sleman, Yogyakarta. The experimental group (n = 30) received instruction through AR-assisted Tic Tac Toe, while the control group (n = 30) followed conventional teaching. Data were collected using a mathematical communication test, motivation questionnaire, and classroom observations. The results showed significant improvements in the experimental group's posttest scores (M = 85.6) compared to the control group (M = 72.4), with a large effect size (Cohen's d = 1.64). Students engaged in AR-based learning also demonstrated higher motivation and more active collaboration during classroom activities. These findings suggest that integrating AR with simple game structures provides an effective model for student-centered mathematics instruction. The study contributes to digital pedagogy by highlighting AR-assisted games as both engaging and pedagogically sound, with potential applications across other mathematical topics.

Keywords:
Augmented reality,
Game-based learning,
Mathematical communication,
Primary education,
Student motivation

1. Introduction

Over the past two decades, advances in digital technology have reshaped the landscape of education. Technology is no longer viewed merely as a supporting tool but has become a driving force in shifting learning practices toward approaches that are more interactive, adaptive, and contextual (Prensky, 2001; Anderson, 2010; Gee, 2003). Within this transformation, digital game-based learning has gained wide attention because it applies game mechanics to stimulate student motivation, engagement, and achievement (Prasetyo, 2014; Cordova et al., 2016). According to Prensky (2001), digital games are especially powerful for digital natives since they offer challenge, immersion, and immediate feedback.

At the same time, augmented reality has emerged as another promising innovation that enhances learning by blending real-world environments with virtual objects in real time (Milgram et al., 1995; Azuma, 2017; Fuhrt, 2011). In mathematics education, AR provides significant opportunities to bridge abstract and concrete understanding, for instance by enabling the visualization of geometric figures or fractions (Ibáñez & Delgado-Kloos, 2018; Cai et al., 2021). Empirical studies have shown that DGBL can strengthen memory and problem-solving skills (Schell, 2008; von Borries et al., 2007; Hamari et al., 2016), while AR has been reported to create more immersive and meaningful learning experiences (Wu et al., 2013; Akçayır & Akçayır, 2017).

Nevertheless, most prior works have examined DGBL and AR in isolation, and relatively few studies have explored their integration in formal learning, especially in mathematics classrooms (Ibáñez & Delgado-Kloos, 2018; Cai et al., 2021). This is a crucial gap since mathematics continues to be

perceived as a difficult subject that often generates anxiety and low motivation among students (Al Mutawah, 2015; Ramirez et al., 2016; Clarkson, 2003; Hadi et al., 2018). Leveraging the combined potential of DGBL and AR may help overcome these persistent challenges while also cultivating 21st-century skills such as critical thinking, collaboration, and digital literacy (Trilling & Fadel, 2009; Aeni & Supadi, 2020).

Despite increasing attention to both approaches, little is known about how the integration of DGBL and AR directly contributes to conceptual understanding and academic performance in mathematics (Cordova et al., 2016; Hamari et al., 2016; Akçayır & Akçayır, 2017). To address this gap, the present study investigates the development and implementation of AR-based DGBL in mathematics learning. Specifically, this research aims to examine its effects on students' conceptual mastery, motivation, and learning achievement, while offering both theoretical insights and practical implications for digital pedagogy.

2. Method

This study adopted a quasi-experimental design with a pretest–posttest control group. The design was selected to examine the effectiveness of AR-Poster Assisted Tic Tac Toe as a game-based learning approach in enhancing primary school students' mathematical communication.

The participants were 60 fifth-grade students from a public primary school in Sleman, Yogyakarta. They were divided into two equal groups: the experimental group (n = 30), which received mathematics instruction through the AR-Poster Assisted Tic Tac Toe game, and the control group (n = 30), which followed conventional lecture-based instruction. Purposive sampling was applied to ensure balanced initial abilities between groups, as verified by pretest results.

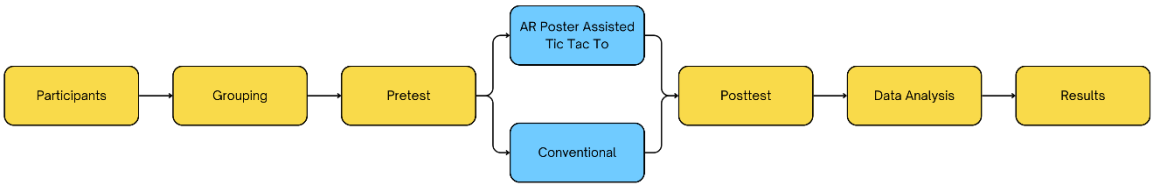
Data collection employed three instruments: (1) a mathematical communication test, consisting of open-ended problems to assess students' ability to express, explain, and justify their mathematical reasoning; (2) a motivation questionnaire adapted from validated scales to capture students' engagement during the learning process; and (3) classroom observation sheets to record teacher–student and peer interactions. Content validity was reviewed by experts, while Cronbach's alpha coefficients were calculated to confirm reliability.

Data analysis involved both descriptive and inferential statistics. Descriptive measures (mean and standard deviation) were used to summarize performance, while paired sample t-tests examined improvements within each group. An ANOVA test was applied to determine differences between the experimental and control groups. In addition, effect size was calculated using Cohen's d, as shown in Equation (1).

Table 1. Research Design Overview

Description	Results
Research Design	Quasi-experimental (Pretest–Posttest Control Group)
Participants	60 students (Grade 5, Primary School)
Groups	Experimental (n = 30, AR-Poster Assisted Tic Tac Toe), Control (n = 30)
Sampling Technique	Purposive Sampling
Instruments	Mathematical Communication Test, Motivation Questionnaire, Observation
Data Analysis	Descriptive Statistics, t-test, ANOVA, Effect Size (Cohen's d)

Figure 1. Research Framework



3. Results and Discussion

3.1 Results

The results of this study summarize the effectiveness of AR-Poster Assisted Tic Tac Toe in improving fifth-grade students' mathematical communication.

Assumption Testing

Before conducting inferential analysis, tests of assumptions were carried out. The Shapiro Wilk test showed that the distribution of pretest and posttest scores in both experimental and control groups was normal ($p > 0.05$). Levene's test also indicated that the data met the homogeneity of variance assumption ($p > 0.05$). These findings confirmed that the dataset fulfilled the requirements for parametric analysis.

Table 2. Descriptive Statistics of Pretest and Posttest Scores

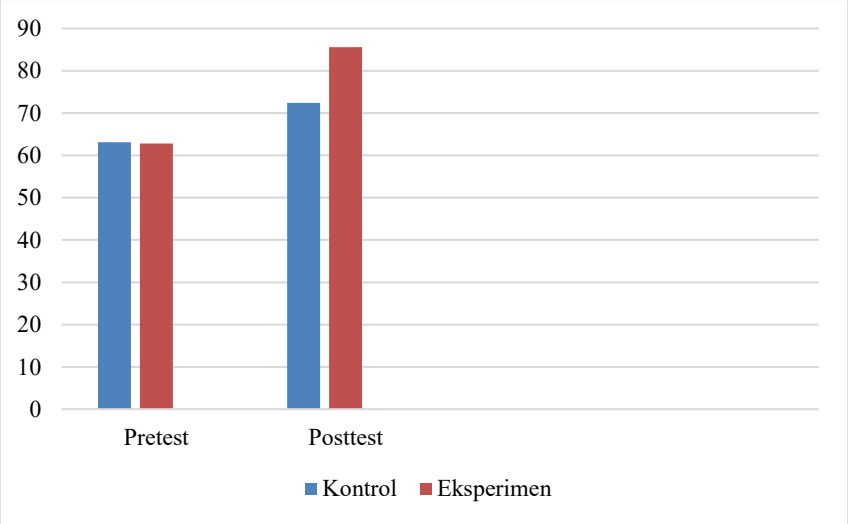
Group	Test	Mean (M)	Std. Deviation (SD)	N
Experimental	Pretest	62.8	6.4	30
	Posttest	85.6	5.2	30
Control	Pretest	63.1	6.1	30
	Posttest	72.4	6.1	30

The descriptive data indicate that both groups improved from pretest to posttest, but the experimental group outperformed the control group.

Table 3. Summary of Inferential Statistical Analysis

Analysis	Value	p-value	Effect Size
t-test (Exp)	$t(29) = 12.45$	< 0.001	
t-test (Ctrl)	$t(29) = 4.32$	< 0.01	
ANOVA	$F(1,58) = 48.37$	< 0.001	
Cohen's d			1.64 (large)

Figure 2. Comparison of Pretest and Posttest Scores



The chart illustrates the differences in learning outcomes between the experimental and control groups. Both groups improved from pretest to posttest, but the increase was much more substantial in the experimental group. Students taught with AR-Poster Assisted Tic Tac Toe improved from a mean of 62.8 to 85.6, while those in the control group improved only from 63.1 to 72.4.

This visualization reinforces the statistical findings: the experimental group not only achieved higher posttest performance but also demonstrated greater learning gains compared to conventional instruction. The clear gap in posttest scores highlights the effectiveness of integrating AR-based game learning in enhancing mathematical communication.

In addition, motivation questionnaire results indicated higher engagement levels in the experimental group ($M = 4.3$, $SD = 0.5$) compared to the control group ($M = 3.5$, $SD = 0.6$). Classroom observations also noted more active peer discussion and teacher student interactions in the AR-assisted

sessions, providing further evidence that AR-based learning positively influenced both cognitive and affective aspects of learning.

3.2 Discussion

The findings of this study reveal that AR-Poster Assisted Tic Tac Toe significantly improved fifth-grade students' mathematical communication skills compared to conventional teaching. The experimental group demonstrated higher posttest scores (M = 85.6) than the control group (M = 72.4), with a large effect size (Cohen's d = 1.64). This result confirms the effectiveness of integrating augmented reality (AR) into game-based learning environments to strengthen both cognitive and affective learning outcomes.

The study provides evidence that AR-Poster Assisted Tic Tac Toe not only enhances mathematical communication but also positively influences students' motivation and collaboration. Students were more engaged and active in expressing and justifying mathematical reasoning, which aligns with previous research emphasizing the role of digital and game-based environments in enhancing learning engagement (Gan et al., 2015; Perdana et al., 2020). The novelty of this study lies in combining AR with the familiar Tic Tac Toe game, creating an immersive learning context that supports visualization, peer discussion, and active participation (Agaton & Cueto, 2021; Prayudha, 2021).

Furthermore, the development of the Tic Tac Toe model in this study adopted the Time Collection, Team Collaboration, and Think Cooperation framework. This framework emphasizes the 6C competencies needed in the 21st century critical thinking, creativity, collaboration, communication, citizenship, and character. Specifically, *Time Collection* was adapted from Problem Solving and Course Review Horray to emphasize effective time management and task organization. *Team Collaboration* built upon Project Based Learning principles to encourage cooperative knowledge construction. *Think Cooperation* was derived from Time Token Arends to foster shared responsibility and balanced participation. Together, these dimensions positioned AR-Poster Assisted Tic Tac Toe as more than a simple game, but as a structured pedagogical model that develops higher order skills.

This approach is also relevant in the context of home-based learning during the COVID-19 pandemic, when students needed interactive and meaningful learning experiences to remain motivated. The model additionally addressed real-world contexts, such as household waste management, thereby strengthening the link between mathematics, daily life, and environmental awareness.

The large effect size highlights the strong practical significance of this instructional model, confirming that AR-assisted games can serve as effective strategies in primary mathematics education. The results resonate with Indonesia's educational vision (Republic of Indonesia, 2003) that emphasizes student-centered, innovative, and technology-integrated learning. Beyond local implications, these findings also contribute to global perspectives on technology-enhanced pedagogy, suggesting that AR-Poster Assisted Tic Tac Toe offers a pedagogically sound, scalable, and sustainable approach to mathematics learning.

However, this study is not without limitations. The use of a purposive sampling technique may introduce potential sampling bias, and the research context was limited to a single school, which constrains the generalizability of the findings. In addition, the implementation relied on the availability and functionality of AR devices, which may not be uniformly accessible across different educational settings. Acknowledging these limitations is essential to provide a balanced academic perspective and to guide future studies toward broader and more diverse contexts.

4. Conclusion

The study demonstrates that AR-Poster Assisted Tic Tac Toe significantly improves primary students' mathematical communication, motivation, and collaborative learning. The integration of AR with a simple game structure provides a meaningful bridge between abstract concepts and concrete understanding, offering a practical model for student-centered mathematics instruction.

This work advances the field by showing that AR-assisted game-based learning is not only engaging but also pedagogically effective, with a large effect size indicating strong practical significance. The findings suggest that such approaches can be applied more broadly in mathematics classrooms to foster active learning and 21st-century skills. Future studies are recommended to investigate the sustainability of learning gains, the applicability to other mathematical topics, and the integration of AR with additional emerging technologies.

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