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PAPER

Improving Students' Literacy and Numeracy Using Mobile Game-Based Learning with Augmented Reality in Chemistry and Biology

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ABSTRACT

The purpose of the current study is to enhance students' literacy and numeracy using mobile game-based learning with augmented reality (ARGBL) in chemistry and biology. In this quasi-experimental design, 714 10th and 11th grade students from five high schools in Indonesia were recruited as participants. To gather the data, the Chemical Literacy and Numeracy Test (C-LNT) and the Biological Literacy and Numeracy Test (B-LNT) were administered to the treatment and control group (CG) students. Quantitative data were then analyzed using descriptive statistics and *t*-tests. The results highlighted that the treatment group students who were instructed using ARGBL had higher literacy and numeracy scores than the comparison group students who were taught using PowerPoint (PPT) slides. This indicates that ARGBL is effective in promoting literacy and numeracy among high school students in chemistry and biology. Thus, we suggest teachers apply ARGBL to elevate students' literacy and numeracy to a satisfactory level.

KEYWORDS

augmented reality (AR), science literacy, numeracy, game-based learning (GBL)

1 INTRODUCTION

Undoubtedly, the use of digital technologies cannot be separated from human life. Along with the rapid growth of the Internet and mobile technology, new technologies are becoming increasingly accessible to students in various countries. Due to the increasingly massive advancements in mobile technology, such as smartphones and tablets, augmented reality (AR) is one of the emerging technologies that has been used massively in various levels of education in recent years, one of which is secondary education. AR is generally considered a new technology involving the mixing of virtual objects and real-world environments to enhance students' imaginations [1]. By blending virtual objects instantly, AR offers a real learning experience.

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This is because AR is filled with simulation [2] and relates the phenomena students see in reality to their prior knowledge [3]. Until now, AR applications have been widely used as interactive digital learning vehicles to make it easier to learn complex and abstract concepts [4]. In the literature, AR technology is effective in increasing learning effectiveness and interest [5], helping students understand abstract concepts and improving cognitive abilities [6], and promoting achievement [7]. Therefore, AR technology provides benefits for students and makes it easier for teachers to convey learning content during instruction.

The use of appropriate teaching approaches plays an important role when applying AR technology during instruction. By enabling students to experience digital content in real-world settings, this new technology has the potential to become a powerful medium for delivering learning content. One effective approach to apply is game-based learning (GBL). In the literature, a game is described as an important process in which students engage in artificial conflict and obey rules, which leads to measurable outcomes [8]. At a simple level, Shapiro [9] revealed that GBL is seen as the use of digital games as an educational tool to create an interactive learning environment. In the GBL setting, teachers integrate well-developed teaching content into educational games and incorporate digital games into their lessons to achieve learning goals [10]. In other words, GBL is a pedagogic strategy that utilizes games; it is not only entertainment-oriented but also focuses on learning outcomes [11]. In the literature, GBL also has a positive impact on students' achievement [12][13][14][15], attitudes [12][14], self-efficacy [13], motivation [13][15], retention of knowledge [14], and their engagement and perception [15]. GBL is gradually emerging as a new trend in learning at all levels of education around the world.

Nowadays, the use of ARGBL is increasingly widespread and useful for increasing student involvement in learning. Integrating AR into GBL turns real-world visualizations into an enjoyable learning experience [16]. Numerous studies have found that combining a game approach with AR technology can improve attitudes and achievement [2], promote motivation and decrease cognitive load [17], enhance cognitive skills [18], and increase collaboration skills and interest in science [19]. Unfortunately, prior studies mixing GBL and AR to improve students' literacy and numeracy were very limited. In fact, the United Nations [20] targeted that by 2030 all youth and the majority of adults achieve literacy and numeracy to ensure equal access for all men and women. This is due to the fact that literacy and numeracy are essential skills that a student needs to meet the demands of life and participate in modern society.

In general, experts conceptualize literacy as a person's ability to read, write, and communicate effectively with others. Specifically, the concept of literacy refers to the ability to read and write to interpret information, make decisions, and solve unstructured problems in personal life, work, and society [21]. According to Shukla and Mishra [22], literacy refers to "a context-bound continuum of reading, writing, and numeracy skills, acquired and developed through a process of learning and application in school and in other settings appropriate to youth and adults." This indicates that literacy is an aspect that students really need in the process of solving problems. This is because literacy is seen as a means of communication that allows individuals to interact through language. In particular, the term scientific literacy is extensively used in science education and is postulated as a person's skill to interact with messages that contain elements of science [23]. In literature, literacy and numeracy are interrelated in all essential subjects taught in schools.

Numeracy refers to the basic mathematical abilities that a student needs to communicate with others in society or further learn mathematics [24]. Numeracy is considered a part of numerical literacy. Numerical literacy is seen as a student's ability to understand numerical information [25]. In addition, numeracy is also conceptualized as an

individual's ability to use and communicate mathematical ideas in a variety of situations [26]. Furthermore, ACARA [27] explains that numeracy includes the knowledge and behaviors needed by students to use mathematics in different contexts. A numerately literate student should be able to evaluate a complex situation, decide whether mathematics would be useful, determine in which area it is most appropriate, and then use mathematics in that area. In other words, understanding numerical situations includes knowledge and dispositions that involve decoding numbers and understanding relationships that vary in accordance with the context in which they are entered [28]. When students have numeracy skills and dispositions, they will work harder to produce better academic results. Unfortunately, previous evidence showed that students' literacy and numeracy tended to be low and decreased throughout the year [29][30][31].

In previous studies, introducing students to the concepts of literacy and numeracy before entering school had a positive and significant effect on the development of further academic abilities [32]. As mentioned by Windisch [21], students who have weak numeracy and literacy skills tend to have poorer levels of health and community involvement. They are also more likely to be in low-paying jobs and less likely to upgrade their skills through education and training [21]. This is due to the fact that learning new skills is difficult without strong basic skills, while students with good literacy and qualifications are associated with higher performance in the world of work [33]. Therefore, it is important to improve literacy and numeracy among students using mobile game-based learning with augmented reality.

2 METHOD

2.1 Design

In order to achieve the above-mentioned goal, we adopted a post-test-only non-equivalent comparison group design. In this quasi-experimental study, we used two entire classes. One class was randomly assigned as a treatment group, and another class was assigned as a comparison group. Then, students in the experimental group (EG) were taught using mobile game-based learning with augmented reality, while students in the CG were instructed using PowerPoint slides. After the intervention, a post-test was administered to both groups in order to determine its effect. Each group was given the same period of time during the treatment.

2.2 Participants

This study involved 714 10th and 11th grade students in five high schools in Yogyakarta and Lombok, Indonesia. They were between 15 and 18 years old. All respondents voluntarily participated in this study.

2.3 Instruments

The Chemical Literacy and Numeracy Test (C-LNT). The C-LNT was developed by Muntholib et al. [34] to measure students' literacy and numeracy in chemistry. After modification, the instrument consisted of 20 multiple-choice questions. The reliability value of the test measured by Cronbach's alpha, was found to be 0.78, indicating good reliability. Each item was given a score between 0 and 1. The minimum and maximum scores were 0 and 20, respectively. Students took about 90 minutes to complete this test.

The Biological Literacy and Numeracy Test (B-LNT). In order to assess students' literacy and numeracy in biology, we designed and developed the B-LNT. The instrument covered 15 multiple-choice items. After being validated, the reliability value of Cronbach's alpha was 0.75, indicating that the instrument was reliable. Each item was given a score between 0 and 1. The minimum and maximum scores were 0 and 15, respectively. It took about 90 minutes to complete the B-LNT.

2.4 Procedures

The intervention was carried out for 90 minutes. After obtaining official permission, the research was then carried out. The current study was conducted in the first semester of the 2022–2023 academic year. Both the experimental and CGs consisted of 357 students each. In chemistry class, 357 eleventh graders studied the definition and equation of reaction rates, reaction order, collision theory, and factors affecting reaction rates. In biology, 357 tenth graders studied the definition, characteristics, structure, classification, and impact of viruses on human life. To avoid instructor bias, all students in each group were taught by a research assistant.

Treatment in the treatment group. In the beginning, students were introduced to mobile learning, including how to download and operate it, and then the teacher introduced the subject matter of mobile learning. After all students the downloaded mobile learning app, the teacher explained the topics to be studied (see Figures 1–2). After that, the teacher gave directions to the students to open the mobile learning app, study the topic, and watch the videos to be discussed at the next meeting. During the treatment, students scanned AR markers that had been provided by researchers to see 3D objects (see Figure 3). Also, the teacher asked the students what they had learned through mobile learning and how chemistry relates to their local culture.

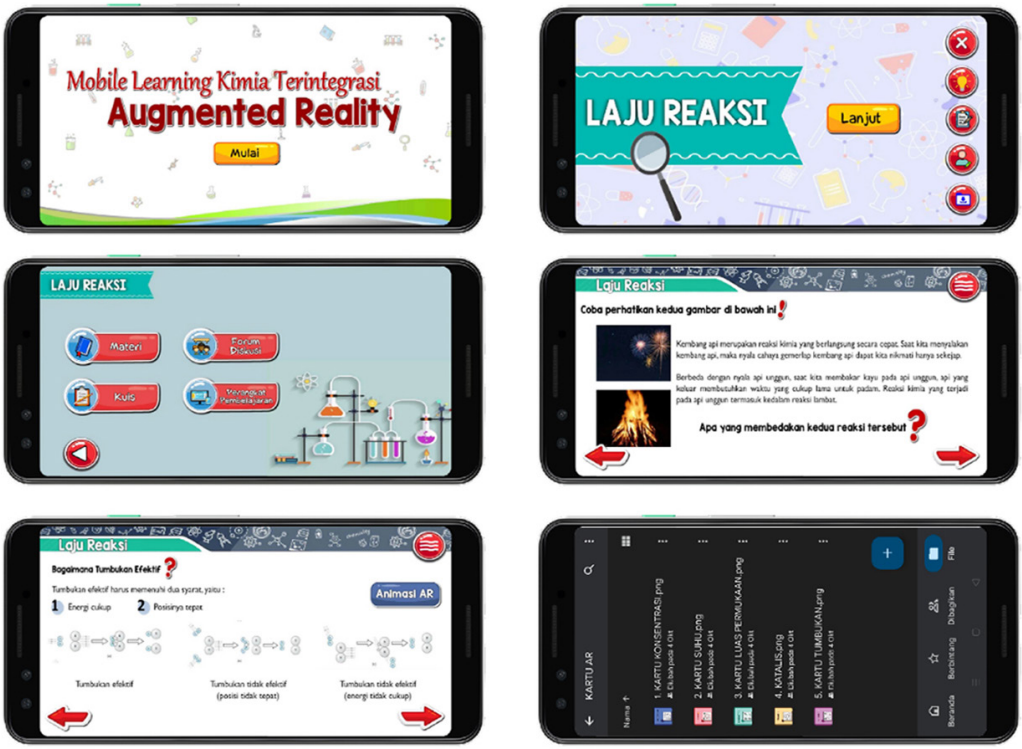

Fig. 1. Display of the topic of reaction rate in mobile learning (chemistry)

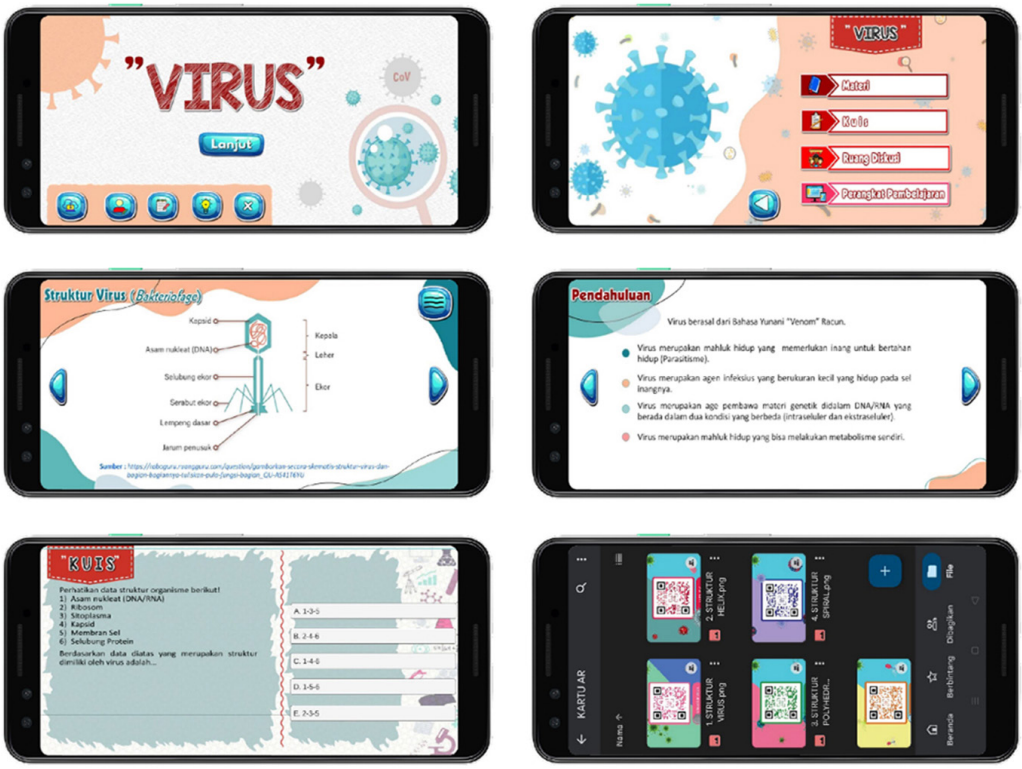

Fig. 2. Display of the topic of viruses in mobile learning (biology)

The teacher also provided other examples related to their culture that could be related to chemistry and biology. Then, students respond according to their experiences and link their life experiences to the chemistry and biology topics being studied. The teacher then provided reinforcement about the concepts being explored. At the end of the lecture, all students completed the post-test.

Fig. 3. Students scanning augmented reality markers and watching videos

Treatment in the control group. In this setting, the teacher explained the topic to be studied using PowerPoint slides. Then, the teacher gave examples of chemistry and biology topics related to their culture and daily life. Students were then given the task of observing the environment or the surrounding culture and then instructed to relate it to chemistry and biology. After that, the teacher and all students discussed the topics. Students then completed the post-test.

2.5 Data analysis

To analyze quantitative data, descriptive statistics, including mean (M) and standard deviation (SD), were employed. After fulfilling the assumption tests—the data were homogeneous and normally distributed because the *p*-value was more than 0.05—inferential statistics were employed. An independent sample *t*-test was performed to test the significant gap between intervention and comparison groups in relation to literacy and numeracy. For the data analysis process, IBM SPSS version 25 was used. In the study, the level of significance was set at 0.05.

3 FINDINGS

The findings obtained in the current study are outlined below. To evaluate the students' numeracy and literacy scores after the intervention, the C-LNT and B-LNT were administered in both groups. Then, quantitative data were analyzed using an independent group *t*-test. In general, the results of the analysis are summarized in Tables 1 and 2.

3.1 Effect on students' literacy and numeracy in chemistry

Aiming to explain the gap in the mean scores of students' literacy and numeracy on the topic of reaction rate, a post-test was distributed after the instructions.

Table 1. Comparison of scores between the control and experimental groups (chemistry)

Region	Group	N	Mean	SD	*t*	*p*
Lombok	CG	58	63.137	7.685	–12.538	0.000
	EG	58	80.448	7.174		
Yogyakarta	CG	182	69.351	16.025	–12.023	0.000
	EG	182	85.208	7.732		

According to Table 1, a statistically significant gap was found between the literacy and numeracy scores of the treatment group applying ARGBL and the comparison group using traditional learning. In both Lombok and Yogyakarta, students in the treatment group were superior to those in the comparison group regarding literacy and numeracy. This reflects that the use of ARGBL is effective in enhancing students' literacy and numeracy in reaction rate.

3.2 Effect on students' literacy and numeracy in biology

To see the differences in students' literacy and numeracy scores on the topic of viruses, a post-test was given after the treatment. Table 2 summarizes the independent group *t*-test results for the data obtained.

Table 2. Comparison of scores between the control and experimental groups (biology)

Region	Group	N	Mean	SD	*t*	*p*
Lombok	CG	68	58.970	14.104	–10.626	0.000
	EG	68	79.764	7.840		
Yogyakarta	CG	49	71.346	13.156	–5.572	0.000
	EG	49	83.408	7.513		

As observed in Table 2, a statistically significant gap existed between students who studied with ARGBL and conventional teaching methods. When analyzed region-wise, students in the treatment group were more dominant in literacy and numeracy than students in the comparison group. It can be inferred that the use of ARGBL is effective in increasing students' literacy and numeracy on the topic of viruses.

4 DISCUSSION

In this study, we found that students' literacy and numeracy in both chemistry and biology can be improved using augmented reality game-based learning (ARGBL). The results of the present study were consistent with prior studies [35][36][37]. The use of mobile technology to support literacy programs in education is based on the fact that students need autonomy and flexibility to encourage their self-regulation. Students can easily take their mobile devices and they can study wherever they are. Mobile devices, such as iPads and smartphones, can be utilized to collect scientific information, read textbooks, and learn about numeracy and literacy using educational applications during the teaching and learning process [38]. Flewitt and colleagues [39] used iPads in elementary schools to develop literacy among students ages 3 to 13, which includes writing and recording video stories to share in class. Another reason behind this positive effect may be that during implementation, students in the intervention group used an AR application in inquiry activities and interacted with this technology in a GBL setting. The existence of AR technology makes learning more meaningful [40] and increases students' interest in learning science. Furthermore, this finding may be related to the fact that ARGBL has the potential to combine the virtual world with the real-world environment to give a more realistic effect. In turn, information and facts that students can easily understand play an important role in improving their literacy and numeracy skills.

The use of mobile learning apps to enhance students' literacy and numeracy has been documented. In previous research, Attewell [41] reported that mobile learning is proven to enhance students' literacy and numeracy, encourage collaborative learning experiences, allow students to focus more on learning, and increase their self-efficacy. Brown [42] also revealed that there was an increase in ninth-grade students' vocabulary comprehension using a vocabulary frontloading technique

designed through mobile learning. Similarly, Adelore and Akintolu [43] examined the impact of cellular technology on learning outcomes and the benefits adult learners derive from its use in literacy programs. They found that students in the treatment group who learned using mobile technology had greater average achievement scores compared to students in conventional classes. In addition, Leu et al. [44] reported that students' reading skills could be significantly improved through their continuous interaction with web-based literacy activities. Digital educational applications are seen as an increasingly attractive tool for improving students' literacy and basic math skills [45]. In other words, the use of mobile technology is very effective and encourages students to see immediate progress in their literacy skills. With the effective use of mobile phones [46], students are expected to read and understand subject matter thoroughly, so mobile technology can facilitate students' learning experiences both in and out of the classroom [47].

5 CONCLUSIONS AND RECOMMENDATIONS

In the present study, the impact of ARGBL on students' literacy and numeracy was examined. The results of the study emphasize that there are significant differences in literacy and numeracy scores between the group using ARGBL and the other two groups. The treatment group that used AR as a game-based learning tool in chemistry and biology subjects achieved much better post-test results than the CG. This shows that ARGBL has a significant impact on the literacy and numeracy of high school students. In this regard, it can be concluded that the literacy and numeracy skills of tenth and eleventh graders can be developed through the use of new technologies that mix virtual and real objects in a game-based learning environment.

The study is important because it contributes to the existing body of knowledge that ARGBL positively impacts better literacy and numeracy. Hence, it provides educators and researchers with insight into the effectiveness of ARGBL. Therefore, ARGBL can be recommended for teachers and educators as an effective interactive learning method in secondary education. It is further suggested that future studies should explore twelfth-grade students' literacy and numeracy using GBL with AR effectively. Lastly, a recommendation for future scholars is that the impacts of ARGBL on high school students' academic achievement, attitudes, and perceptions of different fields of study should be investigated and compared.

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