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THE EFFECT OF VIRTUAL REALITY GAME-BASED LEARNING TO ENHANCE STEM LITERACY IN ENERGY CONCEPTS

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ABSTRACT

STEM literacy is a skill students must possess in the 21st century. The purpose of this study is to measure the effectiveness of Virtual Reality Game-based Learning (VRGBL) in improving STEM literacy among junior high school students. The research employed a quasi-experimental design. This study's sample consisted of eighth-grade students from a public junior high school who were divided into two groups: the control class and the experimental class. The data analysis for this study focuses on the influence of VRGBL on students' STEM literacy in energy concepts. The study discovers that STEM literacy for eighth-grade students is made up of four components: science literacy, technology literacy, engineering literacy, and mathematical literacy. The results show a significant difference between the control and experimental groups: Mexp = 83.59, SDexp = 7.54, Mcon = 65.48, SDcon = 7.89, t = 0.00, sig < 0.05. The results of this research suggest that VRGBL improves students' STEM literacy in energy concepts in the experimental class, with an N-gain of 0.57 in the medium category, compared to the control class, which has an N-gain of 0.28 in the low category.

Keywords: energy concepts; game-based learning; STEM literacy; virtual reality

INTRODUCTION

The present era is marked by an increased demand for a new set of skills, known as generic skills or 21st-century skills (Silber-Varod et al., 2019; Dishon & Gilead, 2021; Lavi et al., 2021). Knowledge merely is insufficient. Students require 21st-century skills to live in the modern world, specifically the current era of Industrial Revolution 4.0 and Society 5.0 (Rahman, 2019). 21st-century skills are comprised of four domains: traditional core subjects and skills (TCS), learning and innovation skills (LIS), career and life skills (CLS), and digital literacy skills (DLS) (Sulam et al., 2019). Students need to be taught the 4C skills, namely critical thinking, creative, communicative, and collaborative (Bedir, 2019; Erdoğan, 2019; Khoiri et al., 2021).

Skills that can support students' 4C skills in the 21st Century are Science, Technology, Engineering, and Mathematics (STEM) literacy (Abdurrahman et al., 2019; Tang & Williams, 2019; Triana et al., 2020; Jackson et al., 2021; Falloon et al., 2022). Widya et al. (2019), in their research, state that STEM can improve students' 4C skills. STEM is a component that can make learning more meaningful (King & Pringle, 2019; Li & Schoenfeld, 2019). However, students' STEM literacy is still low (van Laar et al., 2020). STEM literacy is fundamental to many professions, especially science, technology, and engineering (van Laar et al., 2020).

STEM literacy is defined as the capacity to utilize conceptual knowledge to solve issues

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in science, technology, engineering, and mathematics. The essence of each discipline must be emphasized (Huang et al., 2023). Students' STEM literacy growth will be correlated to improved communication and literacy skills (Joyner & Parks, 2023; Tenney et al., 2023). However, according to Nugroho et al. (2019), Rochman et al. (2019), and van Laar et al. (2020), STEM is frequently perceived as difficult, and many students leave science, technology, engineering, and mathematics (STEM) courses.

STEM is a great program that should be supported in the curriculum, particularly in secondary education. The inclusion of STEM content in the school curriculum ensures that students will develop a variety of abilities, including scientific literacy, technology literacy, engineering literacy, and mathematics literacy (Rochman et al., 2019). STEM-based learning will enable students to not only memorize concepts but also understand and comprehend scientific concepts through applications in everyday life. However, in many nations, including Indonesia, literacy levels in science, mathematics, and technology remain poor, and other impediments exist. Several factors contribute to this low capacity, including a lack of creativity and innovation in using learning media (Stehle & Peters-Burton, 2019).

Along with the development of ICT, learning media is developing very rapidly, including augmented reality and virtual reality. However, virtual reality media in Indonesia is currently not widely used by educators to teach material in class (Liu et al., 2020), especially science subjects. In fact, employing virtual reality in the classroom will broaden the range of learning media available to students, preventing boredom and monotony (Rebollo et al., 2022), and is consistent with technology improvements in the Industrial Revolution 4.0 and Society 5.0.

Numerous countries are now adopting STEM as an educational innovation, resulting in a global movement to bridge the gap between the need and availability of skills required in the 21st century (Atabey & Topcu, 2020; Zhan et al., 2021). STEM applications are also linked with a variety of learning mediums, including virtual reality. The innovation in this research will integrate educational games into learning media that will be developed, especially in energy concepts. The concept of energy in science subjects is essential because it can give students an attitude of saving energy and increasing conservation. Therefore, the development of Virtual Reality Game-Based Learning (VRGBL) learning media is critical to increasing students' STEM literacy in energy concepts.

The Industrial Revolution 4.0 is marked by technological changes that significantly impact education (Kowang et al., 2020), namely the existence of learning media in the form of virtual reality. This research aims to develop virtual reality game-based learning to increase students' STEM literacy in energy concepts. Recent studies show that virtual reality can be used for the learning process (Durukan et al., 2020; Gungor et al., 2022). Research has shown that VR technology can benefit students if implemented appropriately in the classroom (Zhou et al., 2018). The use of VR in the classroom increases students' active engagement (Zhou et al., 2018), increases students' motivation to learn (Kwon & Morrill, 2022), and increases students' technological literacy (Yildirim et al., 2020). There has been no research examining the use of VR to increase STEM literacy. Apart from that, virtual reality in Indonesia is currently not widely used by educators for the learning process in the classroom (Liu et al., 2020).

A particular kind of technology-based learning media is game-based learning (GBL), sometimes known as digital game-based learning. The growing popularity of gamification in the learning process has demonstrated that GBL will become an integral aspect of both offline and online learning at all levels of education (Lengyel, 2020). The world of education needs to implement virtual and digital media in the form of virtual reality. So, it is essential to integrate virtual reality learning media and game-based learning in one application called Virtual Reality Game-Based Learning (VRGBL). The aim of this research is to analyze the effectiveness of Virtual Reality Game-based Learning (VRGBL) in increasing junior high school students' STEM literacy in energy concepts.

METHODS

The research type used was quasi-experimental design. A pretest was carried out to determine students' STEM literacy. After carrying out the pretest, the experimental class was given treatment by applying VRGBL. Meanwhile, the control class was given learning using PowerPoint learning media assisted by student textbooks. After the learning process, a posttest was carried out for both classes. The research implementation process can be seen in Figure 1.

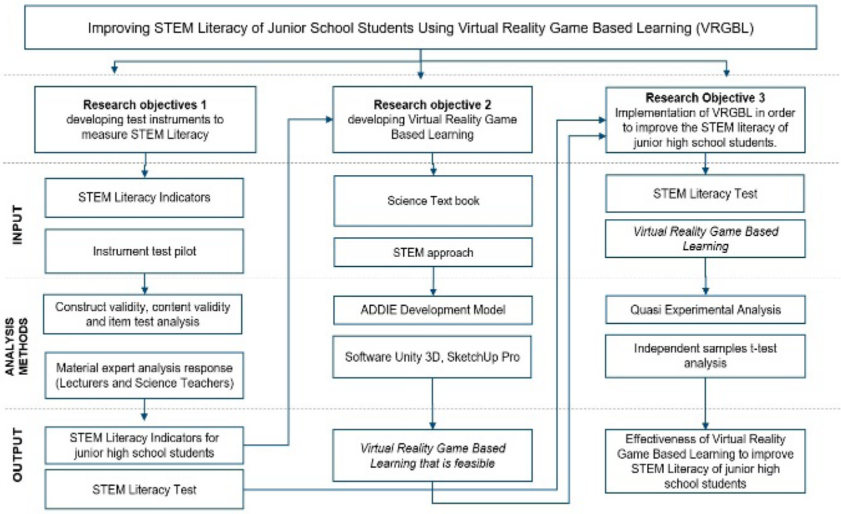

Figure 1. Research Stages

Figure 1 shows the details of the research stages to enhance students' STEM literacy in energy concepts using VRGBL. This study consisted of three stages, namely (1) developing a test instrument to measure student's STEM literacy, (2) developing VRGBL, and (3) implementing VRGBL to improve students' STEM literacy.

This research sample consisted of eighth-grade students from a public junior high school during the odd semester of 2023/2024. Students were placed into two groups: the control group and the experimental group. The experimental group began with a pretest, VRGBL implementation, and posttest. The control group started with a pretest, then implemented presentation learning media and completed a posttest.

The data collection instrument employed a questionnaire to examine the adequacy of science learning material utilizing "Virtual Reality Game-Based Learning". A feasibility test was conducted through expert and specialist assessments consisting of material experts, media and technology experts, and students.

The instrument contained 20 multiple-choice questions with STEM literacy indicators consisting of science literacy, technology literacy, engineering literacy, and mathematics literacy (Utami et al., 2020). The question numbers for each STEM literacy indicator and their explanations are presented in Table 1.

Table 1. STEM Literacy Indicators (Utami et al., 2020)

STEM Literacy Indicator	Details	Number of Questions
Science literacy	Interpret scientific data and evidence; explain scientific phenomena	1, 2, 3, 6, 10
Technology literacy	Develop solutions and achieve goals; understand the principles of technology	7, 11, 17, 18, 19
Engineering literacy	Understand how students think about applied scientific and technological phenomena	4, 5, 8, 9, 20
Mathematic literacy	Formulate the situation mathematically	12, 13, 14, 15, 16

The questions were assessed on a sample to determine the outcome of students' STEM literacy scores using the formula:

$$Score = \frac{\sum obtained\ score}{\sum max.score} \times 100$$

Descriptive statistics were used to determine the mean, standard deviation, maximum, and minimum scores. Descriptive statistical analysis was also performed on each of the students' STEM literacy components, namely science, technology, engineering, and mathematics literacy.

The analysis of quantitative data obtained from the VRGBL and STEM literacy was done by the IBM SPSS 25.00 statistical program. The normality test was performed with descriptive statistics, the homogeneity test with one-way ANOVA, and the t-test with the independent sample t-test. The normality and homogeneity tests yielded a significance level of more than 0.05 (sig. > 0.05), indicating normal and homogenous data. The t-test results are less than 0.05 (sig. 2 tailed < 0.05), indicating a significant difference in STEM literacy results between control and experimental classes.

RESULTS AND DISCUSSION

VRGBL, or Virtual Reality Game-Based Learning, is an Android-based learning media that teachers can use in STEM-based science learning in the classroom, especially energy material, with a learning outcome of 7.8. Students are able to understand the concepts of work and energy and the learning goal flow such as: 1) Students are able to identify various forms of energy; 2) Students determine various uses of energy in everyday life; 3) Students are able to plan projects for utilizing energy for life; 4) Students are able to analyze data and information for project needs; 5) Students are able to present the project plan, and 6) Students are able to present the designed project model. VRGBL features include: 1) Home, to open the VRGBL, users simply download and install the application. The initial page of the application displays several menus: (1) introduction, (2) materials, (3) virtual reality, (4) quizzes, (5) games, and (6) developer. The main page of VRGBL is shown in Figure 2.

Figure 2. VRGBL Main Page

The introduction menu contains an explanation of VRGBL and learning objectives of energy concepts. This is intended to make users, both students and teachers, understand VRGBL in general and the learning objectives that will be studied in energy concepts.

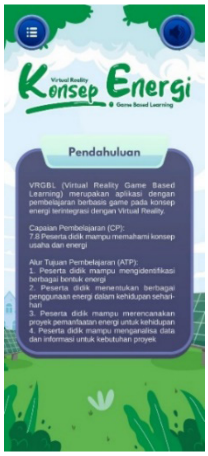

Figure 3. Introduction Features

The material menu contains energy concepts consisting of Go-Science, Go-Technology, Go-Engineering, and Go-Mathematics features. The material presented is an implementation of STEM-based science learning equipped with pictures and videos to support students' learning. Go-Science contains knowledge about the meaning of energy, the law of energy conservation, and forms of energy such as kinetic energy, potential energy, mechanical energy, heat energy, electrical energy, chemical energy, and nuclear energy. Go-Science also contains scientific facts that explain Hydroelectric Power Plants. The Go-Technology feature contains energy-saving and environmentally friendly technologies that play an important role in managing and using energy efficiently, such as LED lights, solar panels, electric cars, and biogas. Go-Engineering contains inspiration for creating effective solutions to solve energy problems. Meanwhile, Go-Mathematic contains mathematical formulas for kinetic energy, gravitational potential energy, elastic potential energy, and mechanical energy.

Figure 4. STEM-based Material

The virtual reality menu contains an explanation of the processes that occur at the hydropower plant in three dimensions. Students will be able to see the hydropower process more realistically. This allows students to learn contextually energy transformation from mechanical energy into electrical energy.

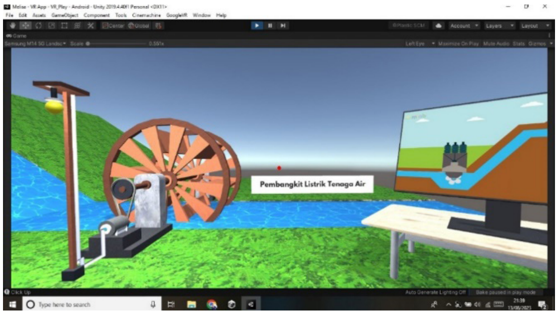

Figure 5. Virtual Reality

The next feature is Quiz (Figure 6). The quiz menu contains questions about energy concepts according to learning objectives. Students will answer ten multiple-choice questions. Each question has a correction in the form of right or wrong so that it can be used as a student evaluation in the future. At the end of the quiz, students will receive the final score.

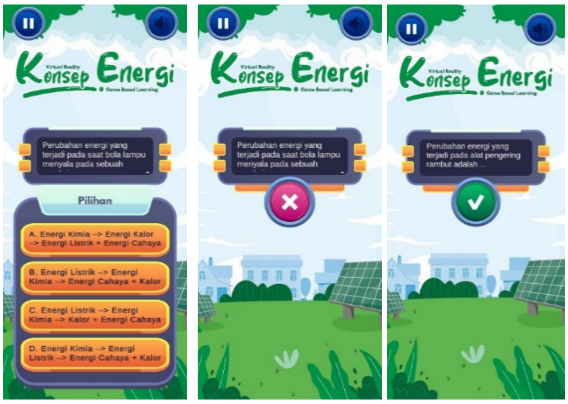

Figure 6. Quiz

The next feature is a game (Figure 7). There are two games which contain: 1) Virtual reality game, which contains a quiz. This quiz is done by correctly grouping energy sources into renewable energy sources/non-renewable energy sources using VR technology. Each question has a correction in the form of right or wrong so that it can be used as a student evaluation in the future. At the end of the quiz, students will receive their final score. 2) Energy conversion; this game contains objects in a room around users. Students are asked to name the correct energy conversion by pressing the object. If the answer is correct, the object will also perform its conversion function correctly.

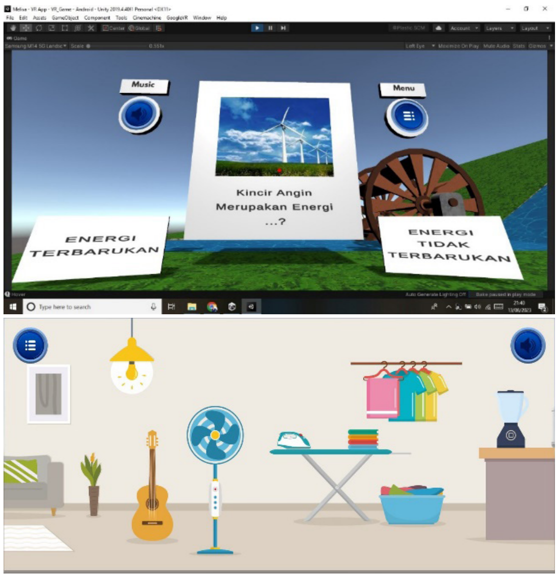

Figure 7. Game Features

The effectiveness of students' STEM literacy was assessed using pretest and posttest questions with 20 multiple-choice questions. The improvement in STEM literacy among students in the experimental and control classrooms is calculated using N-gain, as shown in Table 2.

Table 2. Data on Increasing STEM Literacy of Students in the Experimental and Control Classes

Participant	The average of pretest	The average of posttest	N-Gain	Category
Experimental class	61.41	83.59	0.57	Medium
Control class	52.26	65.48	0.28	Low

Table 2 displays data on the increase in STEM literacy among students in the experimental and control classes. In the experimental class, the pretest average is 61.41, while the posttest average is 83.59. So, the N-gain is 0.57 in the medium category. Meanwhile, in the control class, the pretest average is 52.26 and the posttest average is 65.48. Thus, the N-gain is 0.28 in the low category. The pretest and posttest questions are based on STEM Literacy indicators developed by Utami et al. (2020). The STEM Literacy indicator has multiple components: (1) scientific literacy, (2) technological literacy, (3) engineering literacy, and (4) mathematical literacy. Table 3 provides detailed information on N-Gain for each indicator.

Table 3. N-Gain for Each Aspect of the STEM Literacy Indicator

Aspect of STEM literacy	The average of pretest	The average of posttest	N-Gain	Category
Experiment class				
Science literacy	55.62	88.12	0.73	High
Technology literacy	60	76.87	0.42	Medium
Engineering literacy	53.75	85	0.68	Medium
Mathematic literacy	76.25	84.37	0.34	Medium
Control class				
Science literacy	59.35	75.48	0.40	Medium
Technology literacy	47.10	56.13	0.17	Low
Engineering literacy	54.19	67.10	0.28	Low
Mathematic literacy	48.39	63.22	0.29	Low

Table 3 displays the N-Gain for each aspect of the STEM literacy indicator, which includes scientific literacy, technological literacy, engineering literacy, and mathematics literacy. Each aspect of STEM literacy includes five multiple-choice questions about energy concepts. Figure 8 depicts the increase in students' STEM literacy indicators in the form of a diagram.

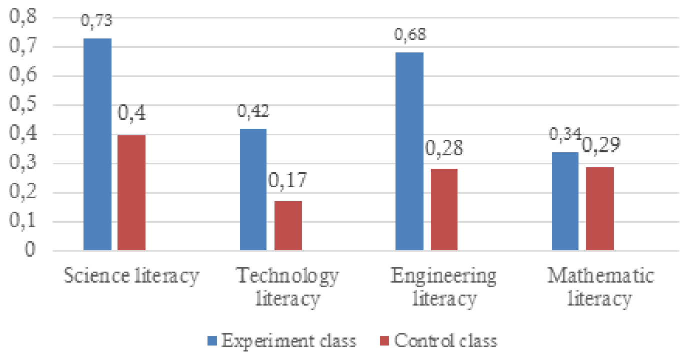

Figure 8. Diagram of N-Gain Test Results for Questions per Aspect of STEM Literacy

Figure 8 shows a diagram of the N-Gain test results per STEM literacy aspect. In the experimental class, the N-Gain result for the scientific literacy aspect is 0.73, technological literacy is 0.42, engineering literacy is 0.68, and mathematics literacy is 0.34. The N-Gain results in the experimental class show that scientific literacy has a higher increase than other aspects, followed by engineering, technology, and mathematics aspects. Meanwhile, in the control class, the N-Gain result in the scientific literacy aspect is 0.4, technological literacy 0.17, engineering literacy 0.28, and mathematics literacy 0.29. The N-Gain results in the control class show that scientific literacy has a higher increase than other aspects, followed by mathematics, engineering, and technology aspects. Aspects of each STEM literacy indicator in the experimental class are higher than in the control class. This is caused by implementing VRGBL in science learning energy concepts in the experimental class. The effect of VRGBL in increasing STEM literacy is then analyzed using the t-test presented in Table 4.

Table 4. T-test on Experimental and Control Classes

Participant	Pretest						Posttest					
	N	df	M	SD	t	p	N	df	M	SD	T	p
Experiment class	32	31	61.41	12.65	0.03	<0.05	32	31	83.59	7.54	0.00	<0.05
Control class	31	30	52.26	10.86			31	30	65.48	7.89		

Table 4 shows the t-tests in the experimental class (32 students) and control class (31 students). The results of the analysis show that the t-test in the pretest is 0.03 ($p<0.05$) and in the posttest is 0.00 ($p<0.05$). The t-test results are less than 0.05, proving a significant difference between the STEM literacy results in the control and experimental classes. The pretest average in the control class is 52.26 (SD=10.86), and the experimental class is 61.41 (SD=12.65), while the posttest average in the control class is 65.48 (SD=7, 89) and the experimental class is 83.59 (SD=7.54). These results show that the posttest average in the experimental class is greater than that of the control class. This is due to differences in treatment between the experiment and control classes.

The control class uses PPT in energy concepts as the media, as usual, while the experimental class uses VRGBL as the media. VRGBL provides features that attract students to learn energy concepts. These features include STEM-based energy material in Go-Science, Go-Technology, Go-Engineering, and Go-Mathematic, VR, which contains an exploration of technology related to energy, namely hydropower in three dimensions, games that contain exciting games in VR form, and quizzes related to energy material. Students' STEM literacy is then measured using pretest and posttest questions in multiple-choice form.

STEM indicators, such as science literacy, technology literacy, engineering literacy, and mathematics literacy, are used to design the pretest and posttest questions (Utami et al., 2020). Pretest questions were presented at the first meeting before the energy material learning activity, which was followed by energy material delivery via PPT (in the control class) and VRGBL implementation (in the experimental class). This pretest activity is intended to provide an overview of students' basic material concepts and serve as a bridge for teachers to introduce students to initial knowledge concepts (Bybee et al., 2009). Based on the average pretest and posttest scores, N-gain on each STEM literacy indicator, and t-test results, VRGBL implementation has been shown to be effective in enhancing students' STEM literacy. STEM literacy indicators encompass numerous dimensions, including scientific literacy, technology literacy, engineering literacy, and mathematical literacy (Utami et al., 2020).

According to Fogarty et al. (2018), scientific literacy relates to students' scientific knowledge. This knowledge is applied to identify problems, acquire new knowledge, demonstrate scientific phenomena, generate conclusions based on evidence about science-related issues, comprehend the characteristics of science as a form of knowledge and inquiry, and boost awareness of how science and technology shape the environment. Increasing scientific literacy in the experimental and control classes yielded better results than other features, with an N-Gain of 0.73 (high) in the experimental group and 0.4 (medium) in the control group. The experimental class has a greater N-gain than the control class, by 0.33. This proves that VRGBL provides students with a better understanding of scientific knowledge on energy material than those who do not apply VRGBL. This aligns with research by Hatimah and Khery (2021), showing that scientific literacy can support conceptual understanding by implementing Android-based learning.

Similar research by Susilowati and Saputra (2022), which implements PBL-based educational games, results in increased scientific literacy, which can be seen in the changes in students' cognitive levels from knowing to understanding and analyzing. Using digital technology in implementing VRGBL can also increase students' scientific literacy. This aligns with Handayani (2021), who developed digital comic media that can increase students' scientific literacy. Integrating a STEM approach into VRGBL is also an effective strategy for enhancing junior high school students' STEM literacy. This is similar to the research results of Widayoko et al. (2018), who report that incorporating STEM into teaching materials generated using impulse and momentum materials results in higher scientific literacy competence. Other research suggests that involving virtual reality (Rustono et al., 2023) and a STEM approach to learning may promote students' scientific literacy (Listiana et al., 2019; Wahyu et al., 2020; Prasetyo et al., 2021).

The second aspect of the STEM literacy indicator is technological literacy (Utami et al., 2020). This indicator shows that someone technologically literate will understand that technology is becoming more sophisticated over time (Maritsa et al., 2021). Students will know what technology is, how it is created, and how technology can shape society. The Go-Technology feature on VRGBL includes material regarding any technologies related to energy concepts. Additionally, integrating YouTube into this feature allows students to learn by accessing the technology. The implementation of VRGBL has proven effective in increasing technological literacy because the N-Gain test result in the experimental class is 0.42 in the medium category, which is greater than the control class, namely 0.17 in the low category.

A significant advancement has been achieved because adopting VRGBL to produce learning media technology helps improve students' technological literacy. This is corroborated by prior research by Setiawan et al. (2023), which identify that virtual reality (VRGBL) has a good influence on students' technological literacy. Other research suggests that incorporating STEM into education can improve students' technological literacy (Prima et al., 2018; Utami & Wilujeng, 2020; Dier & Asrizal, 2022; Ahzari & Asrizal, 2023).

The third aspect of the STEM literacy indicator is engineering literacy (Utami et al., 2020). Students' engineering literacy in the experimental class obtained an N-Gain result of 0.68 in the medium category. There is a significant difference in the N-Gain result of the control class, which only gets an N-Gain of 0.28 in the low category. This proves that VRGBL helps students' way of thinking about scientific phenomena and technological principles so that students gain an understanding of scientific concepts. The Go-Engineering feature in VRGBL is related to students' thinking about applied scientific and technological phenomena, namely the processes that occur in energy concept technology. This is confirmed by prior research, which demonstrates that STEM integration can strengthen students' technological literacy (Harpian et al., 2023; Prima et al., 2018).

The last aspect of the STEM indicator is mathematical literacy. Mathematical literacy is described as an individual's ability to formulate, apply, and interpret mathematics in various scientific concepts (Dinni, 2018; Nurlaili et al., 2022). Students in the experimental class achieve an N-Gain of 0.34, which place them in the medium category for mathematical literacy. This result is greater than the control class, at 0.29 in the low category. This demonstrates that VRGBL media has a positive impact on students' mathematical literacy compared to those who do not utilize VRGBL. This aligns with research by Çakıroğlu et al. (2023), which states that virtual reality can enhance students' mathematical literacy. Other research suggests that incorporating STEM concepts into learning can help students improve their mathematical literacy (Kelana et al., 2020; Hadiyanti et al., 2021).

CONCLUSION

The results reveal a significant discrepancy in students' STEM literacy between the control and experimental groups, Mexp = 83.59, SDexp = 7.54, Mcon = 65.48, SDcon = 7.89, t = 0.00, sig < 0.05. The research results indicate that VRGBL effectively enhances students' STEM literacy in energy concepts with an N-gain in the experimental class of 0.57 in the medium category compared to the control class of 0.28 in the low category.

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