



The effectiveness of science encyclopedia-assisted project-based learning integrated with the STEM approach in enhancing pre-service elementary teachers' scientific literacy

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Abstract

Scientific literacy plays a crucial role for elementary teachers in developing the strategies of science learning and implementing them in the classroom. Nevertheless, the scientific literacy of college students in elementary education has not been optimal. Science encyclopedia-assisted project-based learning (PjBL) integrated into the science, technology, engineering and mathematics (STEM) approach is hypothesized to enhance scientific literacy. The present study describes and examines the effectiveness of science encyclopedia-assisted STEM-PjBL in enhancing pre-service elementary teachers' scientific literacy. Quasi-experimental research using a pre- and post-tests control group design was applied to this study. 56 pre-service elementary teachers at the University of Halu Oleo were involved in this study whereby they were equally distributed to two groups. A test of scientific literacy was adapted and used to measure scientific literacy. Descriptive and inferential statistics were used to describe and analyse the data of scientific literacy. Results revealed that science encyclopedia-assisted STEM-PjBL had a positive modest effect on the achievement of scientific literacy. The scientific literacy of college students in elementary education who received science encyclopedia-assisted STEM-PjBL had moderate enhancement. Additionally, a science encyclopedia-assisted STEM-PjBL significantly enhanced scientific literacy. Educational practitioners can implement a science encyclopedia-assisted PjBL integrated STEM approach to enhance scientific literacy resulting in high achievement in science education.

Keywords: Pre-service elementary teachers, Project-based learning, Science encyclopedia, Scientific literacy, STEM approach.

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Contribution of this paper to the literature

Studies on the use of project-based learning and an integrated STEM approach to enhance pre-service elementary teachers' scientific literacy have been conducted widely in recent years. However, the present study uses the science encyclopedia as an assistant tool in the implementation of project-based learning integrated into the STEM approach to enhance pre-service elementary teachers' scientific literacy.

1. Introduction

The advances in technology and science in the current era are infiltrating a variety of life aspects including the educational sector (Meyer & Norman, 2020). The incoming process of sciences and technologies in the educational system must be followed by the sustainable enhancement of literacy abilities (Ariani, Suparman, Helsa, Zainil, & Rahmatina, 2024; Rifai, Setiadi, Renaldo, & Andreani, 2021). Moreover, teachers and students are extremely required to possess some essential literacies such as technology, mathematics, science, digital and reading in dealing with challenges in the current era (Fuad, Suyanto, Muhammad, & Suparman, 2023; Storksdieck, 2016). Therefore, scientific literacy is one of the literacy abilities that is needed to be cultivated in science education especially science learning. The assertions relate to the viewpoint of Burnett and Merchant (2015) who emphasize that scientific literacy is a crucial factor in students' science achievements due to the challenges posed by the fast development of sciences in the educational system.

Scientific literacy refers to the ability to analyse scientific laws, theories, phenomena and use scientific knowledge that has proof and data in making decisions regarding the world and its changes because of human activities (Dragoş & Mih, 2015; Roberts & Bybee, 2014). This ability has a fundamental role for science teachers in developing the strategies of science learning and implementing them (Juandi, Tamur, & Suparman, 2023; Kim, Raza, & Seidman, 2019; Retnawati, Djidu, Kartianom, & Anazifa, 2018; Tawaldi, Nurlaelah, Juandi, & Suparman, 2023). Nevertheless, a few empirical studies revealed that science teachers in biology and physics have relatively low scientific literacy (Sanchez-Martin & Dávila-Acedo, 2018). Moreover, a few empirical studies also showed that college students in elementary education do not have sufficiently scientific literacy (Fazilla, 2016; Winata, Cacik, & RW, 2016). These reports provide strong evidence that the scientific literacy of college students in elementary education has not been optimal. Consequently, their scientific literacy has to be enhanced in the supported environments of science education.

Improving the scientific literacy of pre-service elementary teachers can be predicted by the integration of PjBL with a STEM approach. STEM-PjBL refers to a learning model integrating mathematics, science, engineering and technology in interdisciplinary form involving students to solve real-life problems and work in technology-based groups (Sunyoung Han, Capraro, & Capraro, 2015; Lou, Chou, Shih, & Chung, 2017). Several empirical studies showed that the intervention of STEM-PjBL can enhance students' achievement, interest, motivation, creativity, attention and scientific literacy in science learning. Moreover, it can also enhance teachers' critical thinking and creativity (Han et al., 2015; Lou et al., 2017; Putra et al., 2024; Siew, Amir, & Chong, 2015; Suparman, Marasabessy, & Helsa, 2024; Tati, Firman, & Riandi, 2017). Additionally, the science encyclopedia developed is used as a learning media to promote STEM-PjBL implementation in science learning. This media refers to reference materials presenting basically scientific information but it is complete regarding a variety of scientific problems usually arranged alphabetically equipped with an index (Schopflin, 2014). Thus, science encyclopedia-assisted PjBL integrated into the STEM approach can be hypothesized to be able to enhance the scientific literacy of college elementary students.

PjBL integrated into the STEM approach has often been implemented in science learning to optimize students' critical thinking, motivation, communication, creativity, problem-solving and science achievement (Furi, Handayani, & Maharani, 2018; Han et al., 2015; Hanif, Wijaya, & Winarno, 2019; Lou et al., 2017; Oktavia & Ridlo, 2020; Purwaningsih et al., 2020; Sarwi, Baihaqi, & Ellianawati, 2021; Siew et al., 2015). Additionally, PjBL integrated into the STEM approach also has positive effect on enhancing the scientific literacy of students (Afriana, Permanasari, & Fitriani, 2016; Tati et al., 2017). Moreover, Ubaidillah (2017) studied PjBL to develop pre-service teachers' ability in creating biological educational entrepreneurship-based encyclopedia. In addition, Han, Yalvac, Capraro, and Capraro (2015) studied in-service teachers' understanding of the implementation of the PjBL integrated STEM approach. However, the present study focuses on the implementation of a science encyclopedia-assisted PjBL integrated STEM approach on the enhancement of scientific literacy of college elementary students.

The present study describes and examines the effect of a science encyclopedia-assisted PjBL integrated STEM approach on the enhancement of scientific literacy among college students in elementary education. This study contributes in improving and enhancing pre-service elementary teachers' competencies in Indonesia, including scientific literacy ability. So, this study has a strategic position in implementing PjBL integrated STEM approach which can be a prevalent issue in the world and its crucial role in enhancing the scientific literacy of college students in elementary education. The subsequent research questions are directed to serve the purpose of the present study such as

1. How is the achievement of scientific literacy among college students in elementary education both experimental and control classes?
2. How much of an effect does the science encyclopedia-assisted PjBL integrated STEM approach have on scientific literacy among college students in elementary education?
3. Is there any significantly different achievement of scientific literacy between those who receive PjBL and those who receive a science encyclopedia-assisted PjBL integrated STEM approach?
4. How is the enhancement of scientific literacy among college students in elementary education both experimental and control classes?
5. Does the intervention of a science encyclopedia-assisted PjBL integrated STEM approach significantly enhance scientific literacy among college students in elementary education?
6. Does the intervention of PjBL significantly enhance scientific literacy among college students in elementary education?

7. Is there any significantly different enhancement of scientific literacy between they who receive PjBL and they who receive science encyclopedia-assisted PjBL integrated STEM approach?

2. Literature Review

2.1. Scientific Literacy

Literacy is a comprehensive ability including the ability to process, analyse and communicate information through writing and reading both for individuals and societies (Kirsch & Jungeblut, 2016). Literacy is related to several kinds of skills in science, mathematics, technology, digital media, economics and other areas of advancements in science and technology in the contemporary era. Scientific literacy is an important attention that can be a focus in the current era. Several studies stated that it is the ability to analyse scientific laws, theories and phenomena and use scientific knowledge that has proof and data in generating decisions regarding the world and its changes because of human actions (Dragoş & Mih, 2015; Roberts & Bybee, 2014).

Scientific literacy assessment is basically developed by the OECD referring to four aspects such as knowledge, competence, context and scientific attitude (OECD, 2021). Additionally, Gormally, Brickman, and Lutz (2012) explained that there are nine indicators to measure teachers' scientific literacy such as (1) evaluating the use and misuse of scientific information including probability and statistics. (2) Evaluating the validity of library sources. (3) Solving problems using quantitative skills. (4) Understanding the elements of research methods and their effect on scientific findings. (5) Justifying conclusions and predictions based on quantitative data. (6) Reading and interpreting graphs that depict the data. (7) Understanding and interpreting basic statistics. (8) Identifying valid scientific argument and (9) determining a graph that depicts the data. The indicators of scientific literacy proposed by Gormally et al. (2012) are used to measure the scientific literacy of college students in elementary education in this study.

2.2. Project-Based Learning

PjBL is a learning model that has widely been implemented in advanced educational institutions. Some study defines PjBL as a learning model organizing students in the classroom to work on projects in a group atmosphere in solving a real-world problem and preparing themselves for real life (Kokotsaki, Menzies, & Wiggins, 2016; Tasci, 2015). In a literature, Kokotsaki et al. (2016) particularly stated that PjBL aims to get new knowledge and skill in the learning and construct students to be more active in solving intricate project problems. Additionally, Tasci (2015) revealed that PjBL has some advantages such as solving real problems through project activity, being more active in learning, being more independent in solving the project, being motivated to compete in producing a good product and having responsibility for the projects. PjBL also has a few weaknesses such as needing a relatively long time in solving the project and requiring self-regulated learning and responsibility to solve the project. Furthermore, Kapila and Iskander (2014) stated that there are six phases in implementing the PjBL, namely: (1) identifying the real problem. (2) Formulating strategy or alternative problem-solving. (3) Designing the product. (4) Production process. (5) Evaluation and (6) presentation. The syntaxes of PjBL mentioned by Kapila and Iskander (2014) are applied as the intervention of the control class in this study.

2.3. Project-based Learning Integrated with the STEM Approach

The current era's global society has several kinds of challenges that require multidisciplinary approaches integrated with a range of knowledge concepts, including STEM. Some studies explained that STEM is a learning approach viewing mathematics, technology, science and mathematics as an inseparable unit in discussing and developing learning, oriented to real-world problems with investigations and project activities (Breiner, Harkness, Johnson, & Koehler, 2012; Kapila & Iskander, 2014; Moore & Smith, 2014). The difference between the STEM approach and other science learning models lies in how students can solve real-life problems by applying scientific methods. Moreover, several studies defined PjBL integrated into STEM as a learning model integrating mathematics, technology, engineering and science in interdisciplinary form involving students to solve real-life problems and work in technology-based groups (Han et al., 2015; Lou et al., 2017).

STEM-PjBL aims to systematically solve complex problems, cultivate critical thinking, creative and analytic skills and also enhance higher-order thinking skills (Afriana et al., 2016). PjBL integrated into STEM education provides the freedom of students to discuss, examine and create solutions and also constructs students to be responsible but it is less structured than other learning approaches because each team has to organize their own time and work (Tseng, Chang, Lou, & Chen, 2013). Moreover, stated that there are five phases in performing STEM-PjBL in the learning environment, namely: (1) reflection, (2) research, (3) discovery, (4) application, and (5) communication. The syntaxes of PjBL integrated with the STEM approach mentioned by are applied as the intervention of the experimental class in this study.

2.4. Science Encyclopedia

A science encyclopedia refers to materials presenting scientific information but it is complete regarding a variety of scientific problems usually arranged alphabetically and equipped with an index (Schopflin, 2014). A science encyclopedia becomes a learning medium promoting the implementation of PjBL integrated into STEM approach in this study. Generally, this media consists of an introductory part (e.g., cover, title, redaction, preface, instruction, content list and conceptual map), science contents (e.g., material and its properties and changes, simple planes, sound energy, simple electricity, plants and their environment and the anatomy and physiology of the human body), and a closing part (e.g., glossary, bibliography and author biography).

Scientific literacy which is required of pre-service elementary teachers will improve with both the implementation of STEM-PjBL and the capacity to create science encyclopedias in the process of science learning (Capraro, Capraro, & Morgan, 2013). Therefore, they must be able to enhance the scientific literacy of prospective elementary teachers. There are some reasons for combining STEM-PjBL and the developmental ability of the science encyclopedia in this study such as (1) the need for learning materials connected to real-world contexts and

ensuring meaningful learning experiences and (3) the relation between assertions of 21st century learning and assessing development.

3. Method

3.1. Research Design and Approach

A quantitative approach was used to achieve the aim of the present study. Creswell and Creswell (2018) stated that this approach can facilitate providing a description and examining hypothetical questions through a series of inferential statistics tests. Moreover, quasi-experiment was the research type used in this study. The limitation in conducting random assignment in the educational field, including elementary education was the reason that this research type was selected (Fuad & Suyanto, 2022; Helsa, Juandi, & Ghazali, 2023; Sulistiawati et al., 2022; Suyanto, Fuad, & Antrakusuma, 2023). Additionally, the design of the pre-post-tests control group without randomization was used to analyze the difference in the intervention effect of science encyclopedia-assisted STEM-PjBL on the enhancement of scientific literacy of college students in elementary education.

3.2. Participant

This study involved 56 seventh-semester college students in the department of elementary education, the University Of Halu Oleo Indonesia. They were selected by using purposive sampling because access to involve the participants in those classes was available (Cohen, Manion, & Morrison, 2018). The participants were grouped into two classrooms whereby one classroom is an experimental class (28 pre-service elementary teachers) and another classroom is a control class (28 pre-service elementary teachers). Additionally, the experimental classroom was intervened by science encyclopedia-assisted PjBL integrated into the STEM approach while the control classroom was intervened by only PjBL.

3.3. Instrument

This study used the test of scientific literacy proposed by Gormally et al. (2012) as an instrument to measure the scientific literacy of college students in elementary education. The test consisted of 24 multiple-choice problems and 14 essay problems. The test in this study has a minimum score of 0 and a maximum score of 80. This test was valid ($r = 0.79$) and reliable ($\alpha = 0.87$). Kennedy (2022) stated that the coefficient of correlation r was classified as high validity and the Cronbach alpha score was categorized as high reliability. Consequently, the test has been eligible to be used to measure the scientific literacy of college students in elementary education in this study.

3.4. Procedure

We had to go through a few procedures to conduct this study. Firstly, we observed the actual problem in elementary education, including in science learning whereby there was low scientific literacy among college students in elementary education and we tried to give a solution for this problem by implementing science encyclopedia-assisted STEM-PjBL in elementary education. Secondly, we adapted and rearranged the test to measure pre-service elementary teachers' scientific literacy. Thirdly, we administered a few letters to get permission from the higher educational authorities to do an experiment at the public university. Fourthly, we organized the research participants into two groups such as the experimental classroom and the control classroom. Fifthly, we administered the pre-test to pre-service elementary teachers about the scientific literacy for 120 minutes. Sixthly, we implemented science encyclopedia-assisted STEM-PjBL in experimental class and PjBL in control class during four months (14 meetings) for each classroom. Seventhly, we administered the post-test to pre-service elementary teachers about scientific literacy for 120 minutes. Eighthly, we analyzed the data and interpreted it.

3.5. Data Analysis

Descriptive statistics such as mean, standard deviation, minimum, maximum and sample size were used to describe the scientific literacy of college students in elementary education. The Hedges' equation was selected to compute the intervention effect of science encyclopedia-assisted STEM-PjBL on the achievement of scientific literacy among college students in elementary education. The effect size in g unit was classified as $0 \leq g \leq 0.20$ (weak), $0.21 \leq g \leq 0.50$ (modest), $0.51 \leq g \leq 1.00$ (moderate), and $g > 1.00$ (strong) (Juandi, Tamur, Martadiputra, Suparman, & Kurnila, 2022; Suparman & Juandi, 2022; Susiyanti, Juandi, & Suparman, 2022; Yunita, Juandi, Hasanah, & Suparman, 2022). Additionally, N-gain value was used to describe the enhancement of scientific literacy of college students in elementary education whereby a few literatures classified N-gain value as $Ng < 0.30$ (low), $0.30 \leq Ng < 0.70$ (moderate), and $Ng > 0.70$ (high) (Bao, 2006; Hake, 1998). Moreover, a paired Wilcoxon test was used to examine the effect of PjBL or science encyclopedia-assisted STEM PjBL on the enhancement of scientific literacy of college students in elementary education whereas a Mann-Whitney test was used to examine the difference in achievement and enhancement of scientific literacy skills who received PjBL and those who received a science encyclopaedia-assisted PjBL integrated STEM approach. These non-parametric statistical tests were applied to examine the hypotheses in that the data was not normally distributed (Rutherford, 2011). All calculations of descriptive and inferential statistics were supported by Comprehensive Meta-Analysis (CMA) version 4 and SPSS version 26.

4. Results

4.1. The Intervention Effect of Science Encyclopedia-assisted STEM-PjBL on the Achievement of Scientific Literacy of College Students in Elementary Education (RQ1 and RQ2)

The achievement of scientific literacy among college elementary students who received only PjBL and science encyclopedia-assisted PjBL integrated into STEM is presented in Table 1.

Table 1. Scientific literacy of pre-service elementary teachers.

Test	Intervention	Mean	Deviation standard	Min.	Max.	Sample size
Pre-test	Science encyclopedia-assisted STEM-PjBL	47.89	11.93	29.00	65.00	28
	PjBL	48.00	11.97	28.00	65.00	28
Post-test	Science encyclopedia-assisted STEM-PjBL	63.21	15.21	69.00	78.00	28
	PjBL	58.32	5.55	45.00	70.00	28

According to Table 1, it can be stated that before the intervention of PjBL and science encyclopedia-assisted STEM-PjBL was conducted, the scientific literacy of college elementary students in the experimental class was lower than scientific literacy of college elementary students in the control class. Meanwhile, scientific literacy of those who received science encyclopedia-assisted PjBL integrated into the STEM approach was higher than scientific literacy of those who received PjBL.

The Hedges' equation was used to measure the intervention effect of science encyclopedia-assisted PjBL integrated into the STEM approach on the achievement of scientific literacy of college elementary students (see Table 2).

Table 2. The intervention effect in the g unit.

Intervention	Effect size	Deviation standard	Min.	Max.
Science encyclopedia-assisted STEM-PjBL	0.427	0.267	-0.101	0.944

Table 2 showed that the effect size of science encyclopedia-assisted PjBL integrated into the STEM approach on the achievement of scientific literacy among college elementary students was 0.427 in which Cohen et al. (2018) categorized the intervention effect as a moderate effect. This indicates that science encyclopedia-assisted STEM-PjBL has a positive moderate effect on the achievement of scientific literacy among college elementary students.

4.2. The Difference in the Achievement of Scientific Literacy of College Students in Elementary Education (RQ3)

The Kolmogorov-Smirnov test was used to examine the data normality of scientific literacy of college elementary students in both experimental and control classes (see Table 3).

Table 3. The results of the Kolmogorov Smirnov test for the achievement of scientific literacy.

Data	Group	Statistic	Degree of freedom	Sig. value
Pre-test	Experimental class	0.224	28	0.001
	Control class	0.221	28	0.001
Post-test	Experimental class	0.220	28	0.001
	Control class	0.166	28	0.048

According to Table 3, it can be stated that the scientific literacy in two groups before and after the intervention conducted was not normally distributed. Consequently, the difference in the achievement of scientific literacy of college students in elementary education who received PjBL and science encyclopedia-assisted STEM-PjBL was examined using a non-parametric Mann-Whitney test (see Table 4).

Table 4. The results of the Mann-Whitney test for the achievement of scientific literacy.

Achievement difference of scientific literacy	Mann-Whitney U	Z-value	Asymp. sig. value
Pre-test experimental & control class	392.00	0.000	1.000
Post-test experimental & control class	221.50	-2.799	0.005

Table 4 showed that the significance value of the Mann-Whitney test for pre-test experimental and control classes was more than 0.05 which indicates that there is no significant difference in scientific literacy achievement between pre-service elementary teachers who will receive PjBL and pre-service elementary teachers who will receive a science encyclopedia-assisted PjBL integrated STEM approach. Additionally, the significance value of the Mann-Whitney test for pre-test experimental and control classes was less than 0.05 which indicates that there is a significant difference in scientific literacy achievement between those who receive PjBL and those who receive science encyclopedia-assisted STEM-PjBL.

Using Table 1, this interprets that the intervention of science encyclopedia-assisted STEM-PjBL on the achievement of scientific literacy of college elementary students is more effective than the intervention of PjBL on the achievement of scientific literacy of college elementary students.

4.3. The Enhancement of Scientific Literacy of College Students in Elementary Education Using PjBL and Science Encyclopedia-Assisted STEM-PjBL (RQ4, RQ5 and RQ6)

The N-gain value was applied to describe the enhancement of scientific literacy among college students in elementary education using PjBL and science encyclopedia-assisted PjBL integrated into the STEM approach (see Table 5).

Table 5. The enhancement of scientific literacy among college students in elementary education.

Intervention	Mean	Deviation standard	Min.	Max.	Sample size	Category
Science encyclopedia-assisted STEM-PjBL	0.56	0.26	-0.02	0.87	28	Moderate
PjBL	0.29	0.14	0.05	0.47	28	Low

Table 5 revealed that the scientific literacy of college elementary students in the experimental class had moderate enhancement while the scientific literacy of college elementary students in the control class had low enhancement. Additionally, the enhancement of the scientific literacy who received science encyclopedia-assisted STEM-PjBL was higher than the enhancement of scientific literacy in those who received PjBL.

Using Table 3, the enhancement of scientific literacy of those who received PjBL and science encyclopedia-assisted STEM-PjBL was examined using a non-parametric paired Wilcoxon test (see Table 6).

Table 6. The results of the paired Wilcoxon test.

Enhancement of scientific literacy	Z-value	Asymp. sig. value
Pre-post-test experimental class	-4.523	0.000
Pre-post-test control class	-4.631	0.000

Table 4 showed that the significance value of the paired Wilcoxon test for the pre-and post-tests experimental class was less than 0.05 indicating that the intervention of science encyclopedia-assisted STEM-PjBL significantly enhanced pre-service elementary teachers' scientific literacy. Additionally, the significance value of the paired Wilcoxon test for the pre-and post-tests control class was less than 0.05 indicating that PjBL significantly enhanced scientific literacy of college elementary students. This indicates that the intervention of PjBL or science encyclopedia-assisted STEM-PjBL is effective in enhancing the scientific literacy of college elementary students.

4.4. The Difference of the Enhancement of Scientific Literacy of College Students in Elementary Education (RQ7)

The Kolmogorov-Smirnov test was used to examine the normality of enhancement data of scientific literacy of college elementary students in two groups (see Table 7).

Table 7. The results of the Kolmogorov-Smirnov test for the enhancement of scientific literacy.

Groups	Statistic	Degree of freedom	Sig. value
Experimental class	0.191	28	0.010
Control class	0.229	28	0.001

According to Table 7, it can be stated that the enhancement data on the scientific literacy of college elementary students in two groups was not normally distributed. Consequently, the difference between the enhancement who received PjBL and science encyclopedia-assisted STEM-PjBL was examined using a non-parametric Mann-Whitney test (see Table 8).

Table 8. The results of the Mann-Whitney test for the enhancement of scientific literacy.

Enhancement and difference in scientific literacy	Mann-Whitney U	Z-value	Asymp. sig. value
PjBL and science encyclopedia-assisted STEM-PjBL	131.50	-4.277	0.000

Table 8 showed that the significance value of the Mann-Whitney test for the N-gain value of two groups was less than 0.05 which indicates that there is a significant difference in scientific literacy enhancement between those who receive PjBL and who receive science encyclopedia-assisted STEM-PjBL. Using Table 5, this interprets that the intervention of science encyclopedia-assisted STEM-PjBL in enhancing scientific literacy of college elementary students is more effective than the intervention of PjBL in enhancing scientific literacy of college elementary students.

5. Discussion

5.1. The Achievement and Enhancement of Pre-Service Elementary Teachers' Scientific Literacy Using a Science Encyclopedia-Assisted PjBL-integrated STEM Approach

This study reveals that the intervention of science encyclopedia-assisted STEM-PjBL on the achievement of scientific literacy of college elementary students is more effective than the intervention of PjBL on the achievement of scientific literacy of college elementary students. This statement is strengthened by another finding of this study which shows that pre-service elementary teachers' scientific literacy who received science encyclopedia-assisted PjBL integrated into the STEM approach was higher than pre-service elementary teachers' scientific literacy who received PjBL. Moreover, science encyclopedia-assisted STEM-PjBL had a positive moderate effect on the achievement of scientific literacy among college students in elementary education. Some previous empirical studies also revealed that PjBL integrated into the STEM approach has a positive effect on science teachers' perceptions about scientific literacy (Chistyakov et al., 2023). Additionally, Tuong et al. (2023) also showed that the implementation of STEM-PjBL can significantly affect college students' curiosity about exploring knowledge related to scientific topics. Particularly, few empirical studies revealed that PjBL integrated into the STEM approach has a significant and positive effect on the acquisition of elementary teachers' scientific literacy (Lou et al., 2017; Siew et al., 2015). These reports provide strong evidence that the implementation of PjBL integrated into the STEM approach significantly and positively affects the scientific literacy achievement among college elementary students.

Furthermore, the present study also shows that the scientific literacy who received the intervention of science encyclopedia-assisted STEM-PjBL had a moderate enhancement. Additionally, the intervention of science encyclopedia-assisted STEM-PjBL significantly enhanced the scientific literacy of college elementary students. Consequently, the intervention of science encyclopedia-assisted STEM-PjBL in enhancing the scientific literacy of college elementary students is more effective than the intervention of PjBL in enhancing the scientific literacy of college elementary students. Several previous empirical studies also revealed that PjBL integrated into the STEM approach has a positive effect on strengthening the science content knowledge of pre-service science teachers (Karademir & Ulucinar, 2017; Kim & Kim, 2021). In addition, Tuong et al. (2023) also showed that STEM-PjBL significantly enhances science teachers' curiosity in exploring knowledge related to scientific topics. Empirical studies have revealed that PjBL integrated into the STEM approach has a significant positive effect on the enhancement of elementary teachers' scientific literacy (Lou et al., 2017; Siew et al., 2015). These reports strengthen the finding of the present study that the implementation of PjBL integrated into the STEM approach significantly enhances pre-service elementary teachers' scientific literacy.

PjBL integrated into STEM as a learning model integrating mathematics, technology, engineering, and science in interdisciplinary form involves students solving real-life problems and working in technology-based groups (Han et al., 2015; Lou et al., 2017). Additionally, STEM-PjBL systematically solves complex problems, cultivates critical thinking, creative and analytic skills and also enhances higher-order thinking skills (Afriana et al., 2016). Moreover, PjBL integrated into the STEM education provides the freedom for students to discuss, examine and create solutions and it also constructs students to be responsible but it is less structured than other learning approaches in that every team has to set their work and time (Tseng et al., 2013). The science encyclopedia becomes a learning medium promoting the implementation of PjBL integrated into the STEM approach in this study. It refers to materials presenting basically scientific information but it is complete regarding a variety of scientific problems usually arranged alphabetically equipped with an index (Schopflin, 2014). The ability to read and write enables college students to comprehend various concepts and interrelationships, automatically enhancing scientific literacy. Lou et al. (2017) explained that engaging with well-written scientific texts and attempting to write the words helps pre-service science teachers get familiar with conceptual relationships, forming the foundation for enhanced scientific expertise and understanding. Moreover, Ritchie (2014) stated that a series of stories helps college students become more acquainted with scientific topics cultivating a deeper understanding of scientific concepts and fostering scientific interest. All the explanations above present logical reasons that a science encyclopedia-assisted PjBL integrated STEM approach can enhance the scientific literacy of college students in elementary education.

5.2. Limitation and Suggestion

There are some limitations in the present study and several suggestions are expected to minimize the limitations in future research. Firstly, the sample size involved in this study tends to be small which means it is not so strong in estimating the population. Consequently, the relevant future research should involve a large sample size so it can precisely describe and estimate the generalization regarding the population. Secondly, it is difficult to apply random assignment in this quasi-experimental research. It is related to the regulation of each higher educational institution. As a consequence, the researchers in the relevant future studies have to find the solution to this gap and discuss it with the educational authorities. Thirdly, it is also difficult to ensure that there are no other variables that indirectly have a significant effect on the enhancement of scientific literacy among college elementary students besides the intervention of science encyclopedia-assisted STEM-PjBL. Therefore, the researchers in the relevant future research can make sure of some other factors that also have an indirect potential impact on the enhancement of scientific literacy among college elementary students in science education.

6. Conclusion and Implications

6.1. Conclusion

The present study reports that the scientific literacy of those who receive science encyclopedia-assisted PjBL integrated into the STEM approach is higher than scientific literacy of those who receive PjBL. Science encyclopedia-assisted STEM-PjBL has a positive moderate effect on the achievement of scientific literacy of college elementary students. There is a significant difference in scientific literacy achievement between those who receive PjBL and those who receive science encyclopedia-assisted STEM-PjBL. Consequently, the intervention of science encyclopedia-assisted STEM-PjBL on the achievement of scientific literacy of college elementary students is more effective than the intervention of PjBL on the achievement of scientific literacy of college elementary students.

Furthermore, the intervention of PjBL or science encyclopedia-assisted STEM-PjBL is effective in enhancing the scientific literacy of college elementary students. However, the scientific literacy enhancement for those who receive science encyclopedia-assisted STEM-PjBL is higher than the scientific literacy enhancement for those who receive PjBL. Additionally, there is a significant difference in scientific literacy enhancement between those who receive PjBL and those who receive science encyclopedia-assisted STEM-PjBL. As a consequence, the intervention of science encyclopedia-assisted STEM-PjBL in enhancing the scientific literacy of college elementary students is more effective than the intervention of PjBL in enhancing the scientific literacy of college elementary students.

6.2. Implications

This recent study has justified that science encyclopedia-assisted STEM-PjBL is one of the alternative interventions to enhance the scientific literacy of college students in elementary education. Consequently, educational practitioners in the field of elementary science education such as lecturers and teachers can use the science encyclopedia-assisted PjBL integrated STEM approach to optimize scientific literacy in which they can enhance their scientific literacy to get high achievement in science subjects. Additionally, science literacy plays a crucial role in cultivating students' multi-intelligence abilities, specifically college students. Moreover, Siew et al. (2015) stated that it enables students not only to apply scientific principles in personal decision-making but also to participate in discussions about scientific issues affecting society. The implementation of effective science learning models, including science encyclopedia-assisted STEM-PjBL helps promote the enhancement of students' scientific literacy specifically college students or pre-service elementary teachers.

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