# The effectiveness of green technology-based STEAM projects to improve scientific literacy

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Indonesian students' scientific literacy is classified as low in terms of international and regional research results. This research aims to increase students' scientific literacy through learning green technology-based STEAM (Science, Technology, Engineering, Art, Mathematics)-projects. This research is a quasi-experimental study using a nonequivalent pretest-posttest control-group design. The research sample consisted of 288 junior high school students in Yogyakarta. The details of sample involved in this study were 144 students from the experimental class and 144 students from the control class. The sampling technique is cluster random sampling because the population is divided into regions or clusters. The instrument is in the form of scientific literacy test questions. The test items were analyzed using the gain score test and the Independent Sample T-Test with SPSS 22. The results showed that green technology-based STEAM projects can increase scientific literacy in the high category. The increase in students' scientific literacy in the experimental class was higher than in the control class. The results of the study also showed that there were differences in scientific literacy between the experimental class and the control class. Green technology-based STEAM projects can be an alternative for teachers to develop student's scientific literacy.

*Keywords:* Green Technology; Scientific Literacy; Project-Based Learning; STEAM.

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## 1. Introduction

The development of the 21st century places demands on students to be able to follow developments in science and technology [1]. Learning must equip students to have various skills that are relevant to the pillars of 21st-century education in order to produce quality human resources [2,3]. The 21st-century skills framework suitable for integration into learning consists of four main domains, namely digital era literacy, inventive thinking, effective communication, and high productivity [4,5]. The digital era literacy domain is supported by several skills, namely basic literacy, economic literacy, technological literacy, visual literacy, information literacy, multicultural literacy, and scientific literacy [3,6,8].

Scientific literacy is needed by modern society to address various issues or problems related to science and technology [4]. Scientific literacy is a person's ability to use scientific knowledge and skills [5] based on empirical evidence, especially those that are relevant to careers and everyday life [7] to solve problems and make decisions [6]. The scientific literacy framework according to the 2015 Program for International Students Assessment (PISA) consists of four aspects, namely context, competence, knowledge, and attitude. Scientific literacy includes three competencies, namely explaining scientific phenomena, designing and evaluating scientific investigations, and interpreting data and scientific evidence [8]. The goal of scientific literacy education is to build a scientifically literate society, which means mastering science concepts and using their thinking skills in solving problems in life [9]. Therefore, optimal mastery of scientific literacy by students in the 21st century is important.

Indonesian students' scientific literacy results are based on international assessments by TIMSS (Trends International Mathematics and Science Study) and PISA (Program for International Student Assessment). TIMSS 2019 results show that Indonesia has obtained an average score of 396. TIMSS assessment information shows that students' scientific literacy in Indonesia is at the lowest level compared to the international average of 489 [10]. The 2018 PISA results show that students' scientific literacy in Indonesia is ranked 70 out of 78 countries. PISA assessment information shows that students' scientific literacy in Indonesia is still low [11-14], conducted research on scientific literacy in Makassar in four schools with a sample of 235 students showing that students' scientific literacy was still low, as many as 17.02% were able to understand inquiry methods on scientific knowledge and 36.23% were able to organize, analyze and interpret scientific data and information [15]. Researched the scientific literacy assessment of 428 students in Jambi which showed that the average value of scientific literacy was 33.7 in the low category. Research by [16] shows that students' scientific literacy is still low. As much as 45.73% were able to explain scientific phenomena, 62.77% were able to evaluate and design scientific investigations, and 61.46% were able to interpret scientific data and evidence. Overall, students only can explain the context in simple investigations but have not been able to explain scientific components in complex situations.

Low scientific literacy shows the perception that science as a subject is considered difficult, uninteresting, and boring [17-19]. Low scientific literature indicates that the context, content, and process of learning science have not been achieved [20-22]. This is because the learning process is still focused on memorizing material and students are not actively involved in learning [23]. The presentation of science material is not contextual, the teacher has not integrated the material with the student's environment [24]. In addition, there are internal and external factors that influence the success of learning science. Internal factors include intelligence, motivation, mental health, participation, and the relationship between students and teachers. External factors include media, school facilities, curriculum, learning methods, and models, learning resources, and teaching materials [25-27]. The results of scientific literacy illustrate that great attention is needed for the science learning process. This is reinforced by the statement of [28] that scientific literacy is the key to successful learning in education for 15-year-olds.

The development of scientific literacy can be done by applying a project-based learning model. Project-based learning (PjBL) is learning that is based on constructivist principles [29-31] which includes learning in a specific context, students are actively involved in constructing knowledge, and there is social interaction to share knowledge [32]. The projects provided can be in the form of cases, narratives, and real-world challenges [33]. The projects provided can be in the form of cases, narratives, and real-world challenges [34]. Learning is directed at meaningful learning experiences by providing authentic problems in the real world [35] with the unique construction of the final product [36]. The learning process begins with assignments that must be completed, and assignments are directed to the development of the final product [37]. Product development plays an important role in helping students construct knowledge [38], improve skills, and interest in disciplines [39], and collaborate with others [40]. PjBL is also effective in increasing scientific literacy [41]. Therefore, the final product expresses various competencies that students develop during learning activities [42].

Project-based learning was created to meet the need to adapt to a changing world. The main characteristic of PjBL which is a distinguishing feature is teaching content through skills. Students learn content by trying to complete projects. Teachers can design activities with technical elements in projects that integrate interdisciplinary learning such as STEAM [43]. Learning that integrates STEAM is suggested to encourage the development of learning attitudes in learning communities [44] by preparing students for higher education [45]. STEMPjBL engages students in effectively combining theory and practice [46] to produce a product [47]. Students can engage in learning projects to use STEAM knowledge and skills [48]. The application of STEAM trains students to plan, utilize, and construct technology properly so that they can improve affective, cognitive, and psychomotor skills [49]. The results of the STEM-PjBL research conducted by [50] show that PjBL is effective in increasing positive attitudes toward science, and collaboration between students and students and teachers.

Teachers can provide contextual problems such as environmental problems that can be solved by students. One of the environmental problems is the waste of eggshells and plastic bottles. Eggshell waste is easy to find in the surrounding environment. However, it is still rarely used. Used plastic bottles can be used to make simple rocket bodies to make products and technologies that are environmentally friendly (green technology). Green technology can contribute to solving societal problems [51]. Green technology is expected as an effort to reduce environmental pollution. In addition, green technology generates selling points, thereby increasing economic benefits [52]. Green technology is developed in the field of sustainable energy to produce the energy needed by humans without destroying the environment. One of the green technologies that students can make is a water rocket with an eggshell energy source. Eggshells can be used as a simple rocket fuel because they contain a chemical compound in the form of calcium carbonate ($CaCO_3$). The content of calcium carbonate in eggshells is around 96-97% [53]. The content of calcium carbonate is reacted with vinegar so that it can be used to make simple rocket fuel. Calcium carbonate can react with vinegar or acetic acid [54]. Acetic acid ($CH_3COOH$) is a liquid, colorless, with a pungent odor, and sour taste, soluble in water, alcohol, glycerol, and ether [55].

The results of PISA, TIMSS, and research from several regions in Indonesia show that scientific literacy is still low. Science learning is still focused on memorizing material, students are not actively involved in learning, and the presentation of science material is not yet contextual. Previous research related to learning models to increase scientific literacy conducted by [56] showed that science learning materials with guided inquiry were effective in increasing scientific literacy. The research results of Aiman *et al*., showed that there was a significant difference between scientific literacy and critical thinking of students who were taught with POGIL learning assisted by Realia media and students who used expository learning. The results of [57] showed that Edmodo-assisted guided inquiry learning was more effective in increasing cognitive aspects of scientific literacy compared to inquiry and conventional models.

The low achievement of scientific literacy can be caused by the presentation of material that is less contextual. In addition, this can also be caused by a low positive attitude toward science, so students do not enjoy the learning process [58]. Therefore, a solution is needed to overcome low scientific literacy. This research offers the integration of scientific literacy with project-based learning and green technology. It is hoped that students' scientific literacy can increase to increase the ranking of Indonesian students' scientific literacy. Based on this explanation, this study aims to determine the effect of green technology-based STEAM projects on students' scientific literacy in science learning.

- Research questions: Science learning in Indonesia should be integrated with green technology and project-based learning. Science learning that integrates the use of green technology and project-based learning is considered effective in developing students' scientific literacy. Therefore, the questions that will be answered in this research are 1) how to increase scientific literacy through green technology-based STEAM projects and 2) how is the effectiveness of scientific literacy through green technology-based STEAM projects.

- Research focus: This research focuses on the effect of green technology-based steam projects on scientific literacy with the aim of 1) increasing scientific literacy through green technology-based STEAM projects and 2) determining whether there are significant differences related to scientific literacy through green technology-based STEAM projects. The results of this study can be used as a reference for teachers, researchers, or supervisors in utilizing green technology in science learning in an effort to face the challenges of the 21st century and the industrial revolution 4.0. In addition, it can be used as a guide in improving students' abilities, especially scientific literacy.

- Methods research design: This research is quasi-experimental. This study was chosen because researchers cannot control external variables. Quasi-experimental research aims to investigate causal relationships or find the causes of an event. However, in this experiment, the control group and the treatment group were not randomly selected. Therefore, the research design used was the nonequivalent pretest-posttest control-group design. The research was started by giving a pretest to the experimental class (P1) and the control class (P2). The experimental class uses green technology-based STEAM projects (E1), while the control class uses direct instruction (E2). The research ended by giving a posttest to the experimental class (P3) and the control class (P4). The design is presented in Table I.

TABLE I. Nonequivalent pretest-posttest control-group design.

| Group | Pretest | Treatment | Posttest |
|---|---|---|---|
| Experiment Class | P1 | E1 | P3 |
| Control Class | P2 | E2 | P4 |

### 1.1. Research sample

Participants in this study were junior high school students in Yogyakarta, Indonesia. The sampling technique uses side random clusters. In this sampling technique, the population is divided into regions or clusters. If the cluster is selected, all members in the cluster are sampled. The sample consisted of 288 class VII students aged 12-13 years with 110 boys and 178 girls.

### 1.2. Instrument and procedures

Data collection in this quasi-experimental research was carried out using test techniques. The test technique is carried out by providing scientific literacy questions. Scientific literacy questions in the form of multiple choices [59]. Explained that multiple choice questions were chosen because scoring is easy, fast, objective, and can cover a wide scope of learning material. Indicators of scientific literacy questions according to the OECD (2015) are presented in Table II.

## 2. Validity and reliability of measurement instruments

All item items were analyzed for their validity and reliability. The validity and reliability of the questions were analyzed using quests. Validity is the accuracy or accuracy of an instrument in measurement. The measurement results are said to be valid if there are similarities between the data collected and the actual data on the object being measured, there are similarities between the test results and the actual conditions of the person being measured. Reliability is used to determine the consistency of the measuring instrument, whether the measuring device used is reliable, and remains consistent if the measurement is repeated. Reliability shows the consistency of a measuring device in measuring the same symptoms. The reliability value, based on the case or test estimates is called test reliability. The higher the value the more convincing that the measurement provides consistent results. These results are also determined by the characteristics of the sample.

The lower it means, the more samples for trials that do not provide the expected information [60].

TABLE II. Scientific literacy indicators.

| No. | Aspect | Indicator |
|---|---|---|
| Explain phenomena scientifically | a. Identify, use, and create simple models and descriptions to explain scientific phenomena encountered in everyday life. | b. Describe the potential involvement of scientific knowledge in society. |
| Evaluating and designing scientific investigations. Propose a way to investigate a scientific question (problem formulation). | | |
| Interpret scientific evidence and data. | a. Converting data from one form to another (charts, graphs, etc). | b. Analyze and interpret data to draw conclusions |

TABLE III. Criteria for increasing scientific literacy Gain Score Category.

| | |
|---|---|
| $g \geq 0.70$ | High |
| $0.30 \leq g \leq 0.70$ | Medium |
| $g < 0.30$ | Low |

## 3. Data analysis

The scientific literacy pretest questions are given before learning, while the posttest questions are given after the entire learning series has been completed. Learning in the experimental class, and control class was carried out for three meetings. The pretest and posttest data that have been obtained are analyzed to determine the increase in scientific literacy in the experimental class and the control class and to determine whether there are differences in scientific literacy skills between the experimental class and the control class. Analysis of increasing scientific literacy uses the gain score equation according to Hake (1999).

The data that has been calculated using the gain score equation is compared with the qualitative criteria presented in Table III.

Whether there is a difference in learning in students' scientific literacy skills is analyzed using the Independent Sample T-Test with SPSS 22. This test is used because it tests the significance or average difference between two independent groups. The hypothesis in this study is H1: there is no difference in the learning model for scientific literacy skills. H2: there are differences in learning models for scientific literacy abilities. The criteria for accepting and rejecting the hypothesis, namely H1 and H2, are accepted if Sig (2-tailed) $<$ (1/2)$\alpha$ with $\alpha$ (0.05). An Independent Sample T-test can be done if the data is normally distributed and homogeneous. The normality test was carried out using the Kolmogorov-Smirnov test, while the homogeneity test was carried out using the Levene Statistical test.

## 4. Results of validity and reliability of measurement instruments

The scientific literacy questions to be used were analyzed for their validity and reliability. The validity and reliability of the questions were analyzed using the quest program. The validity of scientific literacy questions is presented in Table IV.

Table IV shows that all of the items are declared fit. Determination of the fit test refers [61] based on the magnitude

TABLE IV. Validity of scientific literacy question items.

| No Item | INFIT MNSQ | Description | No Item | INFIT MNSQ | Description |
|---|---|---|---|---|---|
| Item 1 | 0.88 | Fit | Item 11 | 0.91 | Fit |
| Item 2 | 0.97 | Fit | Item 12 | 0.85 | Fit |
| Item 3 | 0.82 | Fit | Item 13 | 0.90 | Fit |
| Item 4 | 0.91 | Fit | Item 14 | 0.82 | Fit |
| Item 5 | 0.93 | Fit | Item 15 | 0.81 | Fit |
| Item 6 | 0.92 | Fit | Item 16 | 0.86 | Fit |
| Item 7 | 0.83 | Fit | Item 17 | 0.96 | Fit |
| Item 8 | 0.94 | Fit | Item 18 | 0.84 | Fit |
| Item 9 | 0.80 | Fit | Item 19 | 0.90 | Fit |
| Item 10 | 0.82 | Fit | Item 20 | 0.91 | Fit |

of the INFIT MNSQ average value in the range of 0.77 to 1.30. This shows that all item questions are valid. The validity of the question indicates that there is a similarity between the data collected and the actual data on the object being measured, and there is a similarity between the test results and the actual conditions of the person being measured. In addition, a reliability analysis was carried out. The reliability of the scientific literacy questions with an INFIT MNSQ means of 1.0 and an SD of 0.6 means that overall the items fit the Rash model. The reliability value based on item estimation [62] shows that the higher the value, the more convincing that the measurements provide consistent results.

## 5. Improving students' scientific literacy using green technology-based STEAM projects

The results of the scientific literacy assessment given before and after learning were analyzed to determine the increase in scientific literacy between the experimental class and the control class and to determine whether there was a significant difference between the experimental class and the control class. Increase in scientific literacy was analyzed using N-gain. The results of the analysis of increasing scientific literacy are presented in Table V.

Table V shows that the scientific literacy of the experimental and control class students has increased. However, the increase in the experimental class was higher than the control class. In the experimental class, the aspect of explaining phenomena scientifically obtained an N-gain of 0.86 (high category), the aspect of evaluating and designing scientific investigations obtained an N-gain of 0.75 (high category), and the aspect of interpreting scientific evidence and data obtained an N-gain of 0.71 (high category).

The Effect of Scientific Literacy Using Green Technology-Based STEAM Projects The prerequisite analysis before carrying out the Independent Sample T-Test is to carry out normality and homogeneity tests. The results of the normality test with the Kolmogorov-Smirnov test and the homogeneity test with the Levene Statistical test are presented in Table VI.

Table VI shows that the normality test obtained a value of Sig. $(0.200) \geq \alpha(0.05)$ so that the sample is normally distributed, while the homogeneity test obtains a Sig value.

TABLE V. Scores for each aspect of scientific literacy.

| Group | Explain phenomena scientifically |
|---|---|
| Evaluating and designing scientific investigations | |
| Interpret scientific evidence and data | |
| Experiment Class | |
| Control Class | |

TABLE VI. Normality and homogeneity test results statistic test.

| | |
|---|---|
| Normality | 0.200 |
| Homogeneity | 0.206 |

TABLE VII. Results of the scientific literacy difference test.

| Variable | F Value | Sig. | T value |
|---|---|---|---|
| Scientific Literacy | 16.272 | 0.000 | 19.012 |

$(0.206) > \alpha(0.05)$ so that the data variance of the two groups is the same/homogeneous. Therefore, the data meets the prerequisite test for different tests with the Independent Sample T-test presented in Table VII.

Table VII shows that scientific literacy is obtained Sig (2-tailed) $< (1/2)\alpha$ with $\alpha(0.05)$. So it can be explained that there are differences in scientific literacy between students who carry out learning with green technology-based STEAM projects and direct instruction.

## 6. Discussion

This experimental research involved an experimental class and a control class. Learning is carried out face-to-face in three meetings. The experimental class carries out learning with green technology-based STEAM projects, while the control class carries out learning with direct instruction. Data on scientific literacy skills were taken before and after learning activities were carried out. The data collected is calculated based on the scores obtained by students. The increase in scientific literacy skills is presented in Table V. The increase in scientific literacy in the experimental class with green technology-based STEAM projects is considered the result of learning activities that facilitate students' scientific literacy abilities. The aspect of explaining phenomena scientifically has increased the most compared to other aspects. This is because students have begun to be trained to connect knowledge with problems in everyday life.

Scientific literacy ability data were also analyzed to determine whether there were significant differences between the experimental class and the control class using the Independent Sample T-test. The results of the different tests are presented in Table VI. The results of hypothesis testing between the experimental class and the control class showed a significant difference in students' scientific literacy achievement with a significance of 5%. This difference is because each stage in learning based on green technology-based STEAM projects facilitates students' scientific literacy skills. The stages of activities in this learning are a) essential question; b) project design; c) creating a schedule; d) assessments; e) evaluation.

Learning activities are carried out in groups. The group carries out the project according to the instructions contained in the teaching materials. The teaching materials used have been validated by experts. Teaching materials contain learning resources accessed online such as YouTube, handouts, and student worksheets [65]. The first learning phase begins with an explanation of the problems obtained from online news about residents' anxiety about eggshell waste [66]. This problem is supported by the article that Indonesia is ranked second as a country that produces the most food waste in the world [67]. In addition, data from the Central Statistics Agency for 2022 shows that chicken egg production has increased 14.92 percent from the previous year, cumulatively until December it was recorded at 615.1 thousand tons [68]. The research results of [69-71] explained that the use of newspaper articles about science issues reported in the news is beneficial for students to promote scientific literacy.

Students ask essential questions such as the types of eggshells found in the surrounding environment, the impact of eggshell waste, and the content of eggshells that can be used as rocket fuel [72]. Said that asking essential questions would train to stimulate the mind, stimulate further inquiry, and raise new questions, including in-depth questions from students so that the answers obtained were not just basic. Another opinion is explained [73] that these essential questions can be generative or provocative, so it is hoped that students will be involved in rich and in-depth learning, not just learning facts and theories [74]. Explained that learning that presents problems and formulates problems is considered to be able to train the development of students' scientific literacy. Science learning that presents real problems to students can train scientific literacy [75,76]. Students are trained to become accustomed to recognizing and understanding problem patterns so they can plan, make solutions, and evaluate solutions to solve problems [77].

In the next lesson, students design a project to make an eggshell rocket. Students can dig up information on scientific aspects of the process of making rockets by utilizing bottle waste, the concept of physical and chemical changes in eggshell waste, and the concept of Newton's law on rocket launches. Students design a project activity plan that they will do by writing down the tools, materials, and work steps they will do. The activity of analyzing various aspects provides interdisciplinary knowledge such as science, technology, engineering, art, and mathematics [78]. Explained that integrating the five aspects of STEAM (Science, Technology, Engineering, Art, and Math) in learning will help students solve a contextual and conceptual problem in a much more comprehensive and meaningful way. Furthermore, [79] explain that project learning is more appropriately integrated with interdisciplinary learning because it involves a variety of different skills such as reading, writing, observing, and doing science as skills to solve problems in life related to STEAM.

Project planning that has been prepared is then made a schedule of activities in completing the project. The teacher is responsible for monitoring student activity while completing the project. The monitoring process can be done by using a rubric to record all important activities. The results of the projects that have been implemented are then assessed. Assessment is carried out to assist teachers in measuring standard achievement, provide feedback about the level of understanding students have achieved, and assist teachers in developing subsequent learning strategies. At the end of the learning process, teachers and students evaluate the activities and results of projects that have been carried out. The evaluation process is carried out both individually and in groups. Students test products, present their work in video form and make written reports. Teachers and students develop discussions to improve performance during the learning process so that in the end a new finding is found to answer the problems raised in the first stage of learning [80]. In addition, there is an assessment between groups to choose the best group. The best group will get a reward from the teacher and other groups. This is different from students in the direct instruction class, who only present knowledge to get feedback.

Students in the green technology-based STEAM projects class engage with activities to discover and explore knowledge in solving problems [81]. Explain that implementing STEAM projects enriches students' experiences of carrying out practical actions. Different treatment with direct instruction classes results in different activities, thereby affecting different scientific literacy abilities. Increased scientific literacy can occur because students are motivated to design eggshell rockets. Students get the opportunity to access information via the internet before designing a project [82]. Explain that STEAM learning has the advantage of making students confident, think logically, and literate in technology. In the green technology-based STEAM projects class, students can design their rockets with attractive sizes, designs, and decorations. Students also try to design so that the resulting rocket can glide at a certain height and hit the target precisely. This is in line with the opinion of that the application of techniques in project-STEAM classes can train students to be actively involved in learning and acquire in-depth scientific knowledge.

## 7. Conclusion and implications

The results of the study show that green technology-based STEAM projects can increase scientific literacy in the high category. The increase in students' scientific literacy in the experimental class was higher than in the control class. The results of the study also showed that there were differences in scientific literacy between the experimental class and the control class. This research implies that there is an evaluation in each stage of learning so that students can correct the deficiencies of the products made. In addition, the existence of rewards makes students excited to produce the best products. In general, green technology-based STEAM projects can contribute to increasing scientific literacy. However, this research still has limitations, namely learning does not pay attention to differences in children's learning styles or differentiated learning, and respondents are only limited to one city. This research can contribute thoughts that can be used by further researchers to increase scientific literacy. Teachers, practitioners, and researchers can use and modify green technology-based STEAM projects by adding learning media, differentiated learning, and blended learning.

**Limitations**

This study has limitations that can be overcome in future research. This research is limited to State Junior High School students in Yogyakarta, research in other provinces needs to be done. This study only focuses on students' scientific literacy, so it is necessary to explore other abilities in terms of cognitive, psychomotor, and effective.


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