

Development of STEAM-ESD-oriented Renewable Energy Learning Tools to improve creative thinking and environmental literacy

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Abstract. Renewable energy education empowers students to become creative and innovative agents of change in efforts to protect the environment. This study aims to determine the characteristics, validity, practicality, and effectiveness of learning tools on the topic of renewable energy oriented towards Science, Technology, Engineering, Art, and Mathematics (STEAM) - Education for Sustainable Development (ESD) to improve creative thinking and environmental literacy skills. The research was conducted in two different classes using a research and development (R&D) approach. The ADDIE model (Analyze, Design, Development, Implementation, and Evaluation) was used with stages of needs analysis and mini-research, device design and evaluation, as well as development, implementation, and results. The data collection methods used were interviews, tests, and questionnaires. Based on expert validation results, the category obtained was very feasible to use with an average validation of ATP 89%, Teaching Module 88%, Teaching Materials 87.10%, LKPD 94%, and Creative Thinking Instruments 85.25%. The research results showed an average practicality score of 96% in the very practical category. Meanwhile, the improvement in creative thinking skills and environmental literacy was quite effective.

Keywords: learning tools, creative thinking skills, environmental literacy

1. Introduction

The Sciences, Technology, Engineering, Art, and Mathematics (STEAM) approach and education for Sustainable Development (ESD) have several fundamental similarities, including an emphasis on holistic and interdisciplinary learning, the development of critical and creative thinking skills, the promotion of collaboration and communication, and the instilling of values and responsibility [1]. The Sciences, Technology, Engineering, Art, and Mathematics (STEAM) and Education for Sustainable Development (ESD) approaches are a powerful combination for equipping students with the knowledge, skills, and values necessary to become agents of positive change and contribute to sustainable development. Physics is one area where PPB-focused learning can be applied. The integration of the Engineering Design Process (EDP) into renewable energy education has proven effective in improving students' critical thinking, problem-solving, and scientific concept comprehension skills. This approach emphasizes a sustainability-oriented investigation and design process, in line with the principles of Education for Sustainable Development (ESD) and the interdisciplinary STEAM approach [2].

Physics is both a process and a product. Process means the procedure for discovering physics products (facts, concepts, principles, theories, or laws) carried out through scientific steps [3]. Physics learning is generally theoretical and informative in nature, resulting in a lack of support and instruction in developing students' skills, values, and attitudes that reflect concern and responsibility for the environment, making it difficult to achieve learning objectives. STEAM is learning content that uses five sciences, namely science, technology, engineering, art, and mathematics, which are interrelated as

a problem-solving pattern [4]. STEAM learning fosters students' creativity in creating enjoyable learning experiences [5].

Science education is no longer limited to a single discipline, but must be linked to other disciplines. The use of monotonous learning models makes the learning atmosphere monotonous and sometimes boring. This limits students' ability to discover and try new things. In response to this problem, a project-based learning model is offered that can improve student learning outcomes [6]. Creative thinking is a process used to generate ideas or concepts for problem solving [7]. This study was conducted using an integrated STEAM-ESD PjBL model to improve creative thinking and environmental literacy skills. This is in line with other studies showing that STEAM-based PjBL significantly affects creative and critical thinking skills in secondary school students [8].

Environmental literacy is a person's understanding of everything related to the environment, including knowing existing problems and being able to find solutions to overcome problems in the surrounding environment [9]. Improving environmental literacy is important for building awareness and the ability to make sustainable decisions, as well as encouraging actions to preserve nature [10]. In line with UNESCO's 2030 Sustainable Development Goals (SDGs) number 7 on Clean and Affordable Energy, one of the cognitive learning objectives is for students to learn about various renewable and non-renewable energy sources, along with their advantages, disadvantages, and impacts on the environment, health, usage, safety, and energy security, as well as their role in the energy mix at the local, national, and global levels. Environmental literacy encompasses not only knowledge and understanding of the environment, but also attitudes and behaviors that care for the environment. The results of the study show that the environmental literacy score at SMA N 1 Gemuh is 48.76, which is considered sufficient. Therefore, efforts are needed to further improve environmental literacy skills [11].

Other studies show that ESD-based learning tools are effective in improving students' science literacy, critical thinking skills, and environmental awareness [12]. In addition, ESD-oriented learning has been proven effective in improving creative thinking skills among secondary school students [13]. This is reinforced by other studies showing that STEAM-ESD learning has the potential to improve students' creativity and problem-solving skills while promoting environmental awareness [14]. Sustainable technology integration innovations in education have been proven to improve environmental literacy and student awareness of clean energy issues and global sustainability. Sustainable technology-based learning creates contextual, project-centered learning experiences that connect science with socio-environmental impacts [15]. Therefore, STEAM-ESD oriented learning tools on renewable energy topics that are valid, practical, and effective are needed in order to improve students' creative thinking and environmental literacy skills.

2. Method

This study used a research and development (R&D) approach with the ADDIE model. It began with analysis and research, followed by development, design, and evaluation, and finally implementation and evaluation of results. The research was conducted on 71 tenth-grade students at SMA N 1 Gemuh Kendal, with 36 students in class X1 as the experimental class and 35 students in class X6 as the control class. This research was a quasi-experimental study using the Project-Based Learning model with a STEAM-ESD approach. The instrument in this study consisted of 8 essay questions to test creative thinking skills. Before the test instruments were administered to students, expert validation and practitioner validation tests were conducted. The physics concepts studied were limited to the topic of renewable energy, which is one of the subjects taught in 10th grade high school.

The environmental literacy instrument used is the standardized Middle School Environmental Literacy Survey (MSELS) assessment instrument. This instrument has been used in national literacy assessments conducted in the United States, known as the National Environmental Literacy Assessment Project (NELA) [16]. There are four components measured, namely (1) ecological knowledge component, (2) affective component consisting of environmental sensitivity, attitude towards the environment, motivation and intention to act, (3) the competency component (cognitive skills), namely

identifying environmental issues, analyzing environmental issues, making plans to investigate environmental issues, and (4) the responsible behavior component, namely committed action.

Project-based learning has the potential to make learning experiences more engaging and meaningful, as well as improve scientific performance [17]. In addition, students are required to understand renewable energy by observing phenomena that occur in the surrounding environment using developing technology so that students can discover concepts and present their project results with consideration for ethical and aesthetic values as art and displaying other forms (material forms with mathematical manifestations).

2.1. *Data Collection Process*

Data collection was conducted in several ways, such as through unstructured interviews. Interview techniques were used to collect data on practitioners' opinions regarding the learning tools developed. Questionnaires were used as a data collection technique by providing respondents with a set of written questions or statements to answer [18]. The questionnaire method was used to collect data on the practicality of the learning tools developed. The questionnaire was completed by two experts and six fellow physics teachers as education practitioners. The questionnaire was used to obtain data on the assessment of the learning tools developed, including ATP, teaching modules, teaching materials, student worksheets, and creative thinking instruments. The questionnaire was in the form of a validation sheet covering 4 validations, namely content validity, construction validity, present validity, and predictive validity [19]. With an assessment checklist on a scale of 1-5 for the learning tools developed.

Next is the test instrument, which consists of a creative thinking test instrument and an environmental literacy test instrument. The creative thinking instrument takes the form of essay questions covering four creative thinking skills, namely fluent thinking, flexible thinking, originality, and detailed thinking [20]. The creative thinking instrument developed consists of 8 questions, 2 questions on fluent thinking, 2 questions on flexible thinking, 2 questions on originality thinking, and 2 questions on elaborative thinking. Meanwhile, the environmental literacy instrument consists of 4 areas of environmental literacy, including ecological knowledge (17 multiple-choice questions), cognitive skills (10 multiple-choice questions), affective (25 Likert scale items), and responsible behavior towards the environment (12 Likert scale items) [21]. Through pre-tests and post-tests, this instrument measures improvements in creative thinking and environmental literacy.

2.2. *Data Analysis Techniques*

The data analysis technique used to measure the validity of the tools developed in this study was based on percentage calculations and quantitative descriptive analysis techniques according to (Akbar, 2013). The use and decision-making regarding the analysis results referred to the validity criteria for learning tools according to (Akbar, 2013). The validity test criteria for learning tools are shown in Table 1.

Table 1. Criteria for testing the validity of learning tools.

Validity Criteria (%)	Level of Validity	Category
85-100	Very valid, or can be used without revision/with minor revision	Highly recommended
70-85	Valid, or usable but needs minor revision	Worthy
50-70	Not valid, not recommended for use as major revisions are needed	Unsuitable
1-50	Invalid, or cannot be used	Unfit

2.3. *Effectiveness*

Data on the effectiveness of the developed tool was obtained from the results of tests on students' creative thinking abilities and environmental literacy. To determine the effectiveness of the developed tool, normality, homogeneity, and N-gain tests were conducted. The interpretation of the calculation results is based on Table 2 according to the criteria.

Table 2. N-gain acquisition category [22].

Value	Interpretation
< 40	Ineffective
40 – 55	Less effective
56 – 75	Quite effective
≥ 76	Effective

3. Results and Discussion

Development of STEAM-ESD-oriented renewable energy learning tools in the form of ATP, Teaching Materials, Teaching Modules, Student Worksheets, and Creative Thinking Instruments. The ATP is designed with consideration of the intended learning outcomes, namely the learning outcomes of the Physics Phase E subject in the Merdeka Curriculum, which focuses on developing students' abilities to become individuals who are responsive to global issues and capable of actively contributing creative and innovative solutions to achieve sustainable development goals [23].

3.1. Validity of STEAM-ESD-Oriented Learning Tools.

The average validation results obtained by practitioners are shown in Table 3.

Table 3. Average practitioner validation results.

Product	Presentation	Category
Learning Objective Flow	92.33	Highly Recommended
Teaching Module	93.18	Highly Recommended
Teaching Materials	96.39	Highly Recommended
Student Worksheets	94.50	Highly Recommended
Creative Thinking Instruments	91.38	Highly Recommended

The results show the average validation score given by practitioners for the learning tools developed. ATP in the validation stage had a percentage of 92.33. The teaching module had a validation percentage of 93.18. Teaching materials had a percentage of 96.39. LKPD had a validation percentage of 94.50, while creative thinking instruments had a percentage of 91.38.

The expert validation results were obtained from two questionnaire data filled out using a Likert scale for the developed learning tools. The total score of the validation results was divided by the total maximum score and then converted into a percentage. The following table shows the average percentage of expert validation for the developed learning tools in Table 4.

Table 4. Average results of learning device expert validation.

Product	Presentation	Category
Learning Objective Flow	89.00	Highly Recommended
Teaching Module	88.00	Highly Recommended
Teaching Materials	87.10	Highly Recommended
Student Worksheets	94.00	Highly Recommended
Creative Thinking Instruments	85.25	Highly Recommended

The results obtained show the average percentage of learning tool validation by experts for five learning tools consisting of ATP, teaching modules, LKPD, and creative thinking instruments. ATP in the validation stage is 89.00. The teaching module has a percentage of 88.00. The LKPD has a percentage of 94.00. And the creative thinking instrument has a percentage of 85.25. The five products developed have an average validation score percentage above 85%, so all are categorized as very feasible.

3.2. Practicality of STEAM-ESD-Oriented Learning Tools

The level of practicality can be seen from the level of learning implementation in accordance with the independent curriculum. The assessment of the practicality of STEAM-ESD-oriented learning tools on the topic of renewable energy was carried out by observing the implementation of learning using teaching modules and STEAM-ESD-oriented LKPD in experimental classes. The data from observations of the implementation of the learning process using STEAM-ESD-oriented learning tools with the PjBL learning model showed an average of 96%, placing it in the excellent category. These STEAM-ESD-oriented LKPDs are practical because they contain learning evaluations related to ESD aspects and how students carry out activities related to STEAM aspects. This is in line with the opinion [14] which states that LKPD is a learning resource in the form of assignment sheets, task implementation instructions, and learning evaluations that must be completed by students and created in accordance with the basic competencies that must be achieved.

3.3. *Effectiveness of STEAM-ESD-oriented renewable energy learning tools*

The effectiveness of the STEAM-ESD-oriented renewable energy learning tools developed can improve students' creative thinking and environmental literacy skills. The improvement in creative thinking skills was obtained from the N-Gain calculation of the pre-test and post-test scores of the control and experimental classes in Figure 1.

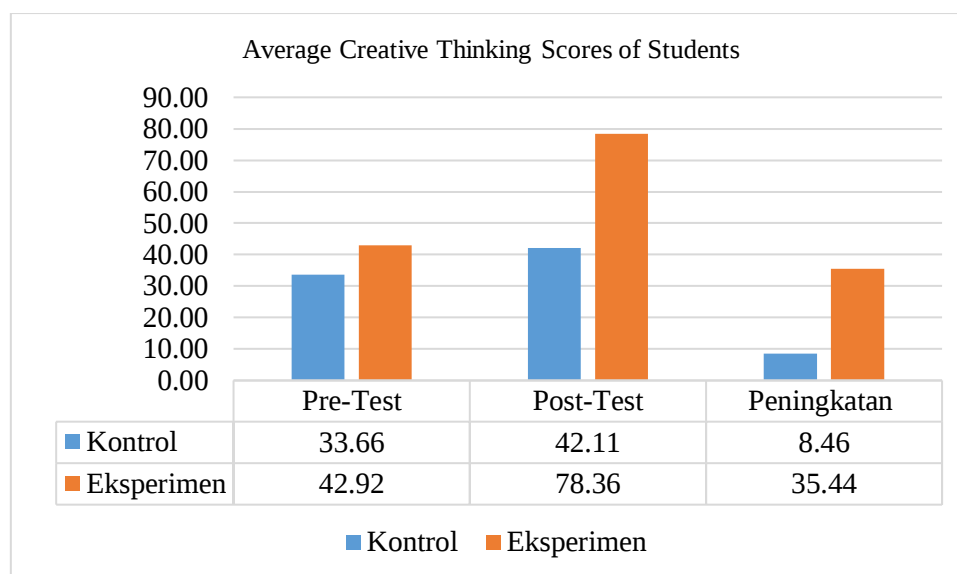


Figure 1. Diagram of creative thinking abilities in the control and experimental classes.

The results in the diagram above show that the improvement in the experimental class that was given the STEAM (Science, Technology, Engineering, Art, and Mathematics) - Education for Sustainable Development (ESD) renewable energy learning tools was higher than that of the control class. The environmental literacy data for the control and experimental classes are shown in Figure 2.

Figure 2 illustrates the respondents' level of environmental literacy using a negative Likert scale (5-1). In this scale, the answer options are ranked from the most negative, which is 5 (not willing), 4 (less willing), 3 (somewhat willing), 2 (willing), and 1 (very willing). Therefore, a higher value on the diagram indicates a lower level of environmental literacy, and a lower value indicates a higher level of environmental literacy. Thus, it can be seen that the results of the improvement in the experimental class that was given the STEAM (Science, Technology, Engineering, Art, and Mathematics) - Education for Sustainable Development (ESD) renewable energy topic learning tools were higher than those in the control class.

This STEAM-ESD-oriented renewable energy learning tool offers advantages in improving students' creative thinking and environmental literacy skills. Through an integrated STEAM (Science, Technology, Engineering, Art, and Mathematics) interdisciplinary approach combined with ESD (Education for Sustainable Development) principles, this tool encourages students to explore innovative

and sustainable solutions to renewable energy challenges through projects, experimentation, and collaboration. Additionally, students gain a deep understanding of environmental issues related to energy, their impact on ecosystems, and the importance of renewable energy for sustainability. This aligns with research findings that the use of ESD-based learning tools significantly improves students' creative thinking skills, particularly in terms of originality [24]. Another study found that ESD-oriented STEAM-based science learning can improve students' ability to understand complex scientific concepts by linking learning materials to real-world environmental issues [25].

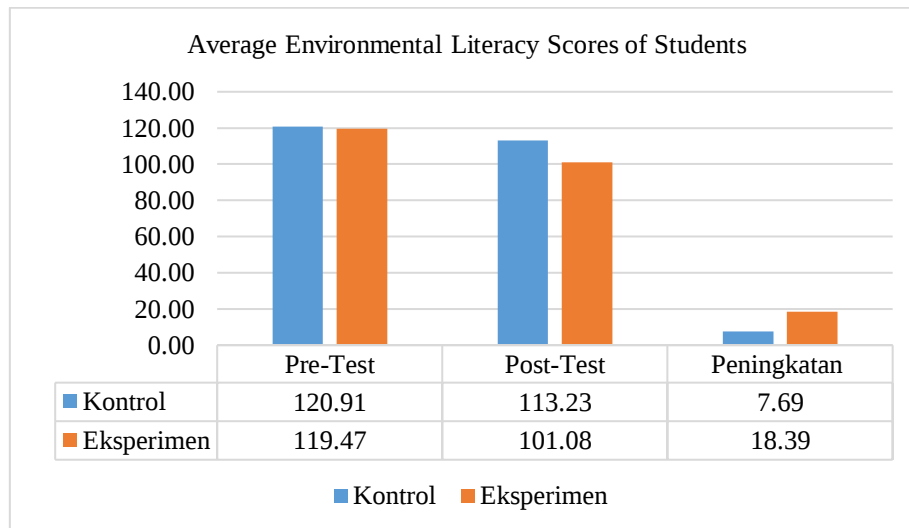


Figure 2. Diagram of environmental literacy in the control and experimental classes.

Despite its advantages, this learning tool also has limitations that need to be addressed, including resource constraints such as laboratory equipment, and experimental materials. Another important factor is the readiness of teachers to facilitate learning effectively. Context adaptation is also necessary, in this case adapting to the local context and student characteristics to ensure relevance and effectiveness.

4. Conclusion

STEAM-ESD oriented learning tools are highly valid, practical, and effective in improving students' creative thinking skills in renewable energy concepts and environmental literacy. The implication of this research is to make physics learning more interesting for students. In addition, the results of this study can provide suggestions to curriculum developers to incorporate this approach into physics learning in the classroom. The limitation of this study is that this learning tool has only been tried and tested in physics lessons. Therefore, it needs to be tried and tested in other subjects such as chemistry and biology or other science subjects.

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