Validity of teaching materials for environmentally friendly technology products using STEM-based guided inquiry to improve students' scientific literacy competence

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Abstract. Students' scientific literacy skills need to be improved because students in the 5.0 society era must have various skills. The availability of relevant student books has limitations in presenting the material. In overcoming this problem, science teaching materials that contain the scientific literacy referred to the 21st-century situation are needed. Therefore, research was conducted on developing integrated science teaching materials with STEM-based Guided Inquiry (STEM-based GI) to improve students' scientific literacy competence. This study aims to determine the validity of teaching materials (integrated science modules, lesson plans, and learning outcomes tests) for STEM-based GI on the topic of Environmentally Friendly Technology (EFT) products to improve students' scientific literacy competence. The research and development procedure used was the formative evaluation model. This research procedure was divided into three stages: self-evaluation, prototyping, and evaluation of field tests. However, this research only reached the stage of expert validation (prototyping). The results showed that the average value of the three validators was 94.33% which was included in the very valid category. The coefficient of agreement between validators was (R) 87.10%, included in the high category. Therefore, the resulting teaching material was valid and improved scientific literacy in junior high school science learning.

1. Introduction

Globalization has resulted in changes in the overall life of society, including the education sector. The 21st-century life skills are the answer to the Industrial Revolution 4.0 and the Society 5.0 challenges. Basic literacy skills and other competencies such as critical thinking, reasoning, creativity, communication, collaboration, and problem-solving abilities are essential.

Science education can be implemented in various ways, one of which is through science learning [1]. Science learning itself is a learning that can grow and instill scientific literacy in students through learning about science concepts, doing practical work, and solving problems scientifically. Based on the 2018 PISA tests and evaluations in mathematics, science, and reading, Indonesia was ranked 71st out of 77 countries with an average score of 382 [2].

This situation proves that students in Indonesia, compared to other countries, are still very low in scientific literacy skills. The factors that influence this are the education system and curriculum, the selection of learning models and methods, learning facilities, teaching materials, learning resources, and other factors.
Student learning resources are a factor that directly influences student learning activities that affect the low level of students' scientific literacy skills. Books are still the primary source of student learning in schools. The book used by the teacher in science learning does not contain complete scientific literacy. The material presented is also too broad, so students have difficulty understanding the science concepts presented in the book[3].

Teaching materials are one of the learning tools that help students understand the subject matter. Rizki [4] states that teaching materials categorized as good are attractive in terms of appearance and content and must adapt to students' needs. The teaching materials can be in the form of modules. Modules are teaching materials that are arranged systematically and made by using language that students easily understand. Modules are dynamic and self-contained. The module also has the advantages that can be adjusted to the students' age and knowledge level to learn independently through the instructions in the module. To be successful in the learning process, the teacher must be precise in choosing the approach used during the learning process.

Science, technology, engineering, and mathematics (STEM) education is crucial in today's educational trends. STEM is an alternative approach to education in the 21st century that realizes the fundamental goal of growing knowledge and expertise (IPTEK). Kelley [5] states that the STEM approach used during the learning process can train students to implement their knowledge to arrange something as a form of problem-solving related to their living environment by utilizing technology. The integrated STEM approach uses real-world contexts to investigate authentic problems using contextual and active learning approaches [6][7]. This approach helps students to be problem solvers, independents, innovators, inventors, creators, logical thinkers, science, and technology literate [8-12].

The approach enhances higher-order thinking skills, motivation, and achievement [13,14]. In addition, it improves students' cognitive skills, such as listening, thinking, problem-solving, and decision making, and also triggers the capability of self-expression, observation, cooperation, collaboration, and communication [15-18].

The STEM-based GI learning model can develop conceptual understanding[19], meta-cognitive knowledge, and skills [20,21]. It also improves student learning, achievement, motivation, and interest [22-24], as well as directs students to identify problems, find solutions, formulate questions, conduct experiments, analyze and draw conclusions [25]. Through inquiry, students engage in discovery, ask real questions about academic topics, and are interested in learning more and sharing with others[27]. A well-designed inquiry-based approach is effective in promoting positive learning outcomes such as deep thinking, application of knowledge, and logical reasoning [28,29].

One of the integrated science materials taken is Eco-Friendly Technology or Environmentally-Friendly Technology (EFT) products material for Junior High School class IX, based on the syllabus and basic competencies. EFT often involve some of the following: (a) recycled, recyclable, and/or biodegradable content, (b) plant-based materials, (c) reduction of polluting substances, (d) reduction of greenhouse gas emissions, (e) renewable energy, (f) energy-efficiency, (g) multi-functionality, (h) low-impact manufacturing. EFT is any technology that aims to make our lives and environment better [30]. This material can be related to STEM-based GI learning because it contains the four pillars of science and scientific literacy processes in everyday life. Water purification, composting, and biogases are examples of processes that involve the simplest scientific literacy and manufacture through a series of processes that use natural materials and simple tools. However, the existing textbooks do not contain elements of STEM-based GI, so there is still a need to develop teaching materials, especially on EFT product materials, to improve students' scientific literacy competence. Researchers hope that with the development of these teaching materials, they can make it easier for teachers and students in the learning process and easier to understand and master the material of EFT products.

2. Method
The research and development design was the formative evaluation model adapted from Plomp & Nieveen [31], which included the stages of self-evaluation, prototyping, and field test evaluation. The research object was an integrated science learning material for EFT using STEM-based GI, which is relevant to clean technology to produce environmentally friendly products [31]. The research was conducted from February to August 2020.
In the self-evaluation stage, the product developed went through the analysis and design stages related to relevant journal articles and STEM-based GI learning. The EFT module using STEM-based GI presented: (1) Determination and principles of EFT, (2) Application of EFT, and (3) Energy-saving behavior. The first meeting was about the lack of clean water as a problem, and the solution to this was manufacturing simple water filtration products. The filtration method in water treatment was simple by using bottles filled with gravel, fine sand, stones, fibers, zeolite, and activated carbon from coconut shells. These materials were arranged in bottles as dirty water filters to get clearer water. Students were assigned to find out how the composition and arrangement of these ingredients produced the clearest water. At the second meeting, the produced product was a simple technology for making biogas and organic fertilizer by solving the problem of animal manure or household organic waste. Then, the third meeting resolved the problem of the scarcity of fuel oil as an energy source. The EFT was produced in the form of bio-ethanol and bio-diesel. At the last meeting, the issue discussed was the lack of awareness in terms of energy saving. Then, a poster/mock-up of an energy-efficient home was made as a product.

Next is the prototyping stage, consisting of an expert review, one-to-one evaluation, and a small group. At the expert review stage, the product developed was validated by three experts and proceeded to the one-to-one evaluation stage, where product trials were conducted on a small scale of about three students. Then in the small group stage, the product was tested on a larger scale than the previous one. After that, the product was tested on a large scale at the last stage, named field test evaluation. However, this research was only carried out until the expert review stage. The following are the stages of development in this research:

![Figure 1. Stages of development module STEM-based GI in the topic EFT product](image)

Data was collected by the questionnaire method. Questionnaire forms were given to 3 validators. The score of the validators used a Likert scale of 1 – 4. The interpretation of the validity of the module, lesson plans and literacy tests were determined based on the following criteria: 85 < x 100 (very valid), 70 < x < 85 (valid), 50 < x < 70 (less valid), and x < 50 (invalid) [7]. The reliability of the validation results of the STEM-based GI learning tool was based on the statistical analysis of the percentage of agreement (R) [32], with $R = \left[1 - \frac{(A-B)}{(A+B)}\right] \times 100\%$. Description: A = the highest score, B = the lowest score, wherein the value of R is the percentage of agreement (consistency between validators). The consistency of the validation results is included in the reliable category if the R coefficient is above 75%. The criteria was adapted from Fraenkel et al. [33], which is: 90 < x 100 (very good reliability), 70 < x 90 (high reliability), 50 < x 70 (medium reliability), and x 50 (low reliability).

### 3. Result and Discussion

Teaching materials developed in this study were in the form of modules, lesson plans, and literacy test instruments. The feasibility of the developed teaching materials can be seen from the validation results at the stage expert review in Table 1.

| Aspect of Assessment | Validity Result | Coefficient of agreement between validators |
|----------------------|-----------------|-------------------------------------------|
|                      | Percentage      | Criteria        | R (%)      | Criteria      |
| Module               | 94.00           | Very Valid      | 86.00      | High consistency |
| Lesson plan          | 95.00           | Very Valid      | 86.00      | High consistency |
| Literacy test        | 94.00           | Very Valid      | 89.50      | High consistency |
| Average              | 94.33           | Very Valid      | 87.10      | High consistency |

![Table 1. Results of teaching materials validation](image)
3.1 Validation Module

The e-modules that have been compiled have various features to improve scientific literacy, namely: (1) Did you know, (2) Do it with STEM integration, and (3) Let’s practice. The features to improve scientific literacy competence are "STEM integration with EFT products" and "let's practice" because of the integration and interaction of STEM aspects in solving social-scientific societal issues. Validation results conducted by three experts were grouped into five reviews covering design aspects, format aspects, material aspects, linguistic aspects, and presentation aspects. Based on the five aspects of the validation assessment, the validation percentage of the module developed was 94%, classified as very valid; and the module reliability was 86% with very reliable criteria. So, the STEM-based GI module is feasible to be used as a support for science learning in schools. Students discover and explain natural phenomena and scientific concepts. This module also contains problem-solving and equips students with social skills through individual and group assignments, discussions, delegating responsibilities, and collaborating with their peers. This module also supports student-centered learning and the interdisciplinary nature of science, involving students in constructing their knowledge based on personal and meaningful experiences.

This developed module has advantages on the materials in KI and KD related to STEM. This developed module contains four pillars of STEM science using a guided inquiry model. Therefore, students can more quickly master the topic related to everyday life as a learning guide to independence. The module is designed with a more attractive appearance and equipped with pictures related to the subject. The module is attractive to foster curiosity and enthusiasm for learning in students. The weakness in this module is that the material developed is only limited to EFT products, so it needs to be developed more broadly in other materials. This module consists of study instructions, achievement competencies, subject materials, student worksheets, question sheets, answer keys, evaluation, and feedback on the evaluation results. The environmental problem and linkage of the material in the module are shown in Figure 2-5.

Figure 2. EFT module layout using STEM-based GI model

There are three problems for EFT using STEM-based GI learning presented below.

**Problem 1:**
"Consuming polluted water will cause various diseases such as typhoid, diarrhea, cholera, dysentery, tapeworm, hepatitis, polio, itching, diarrhea, and scaly skin [34,35], which can directly or indirectly undermine human health. Indeed, many people underestimate these diseases, but most are not aware that these diseases can also cause death. This water treatment aims to kill microorganisms in the water. How do you process this dirty water into clean and healthy drinking water?"
Several methods can be used to purify or treat raw water, such as coagulation, flocculation, sedimentation, filtration, adsorption, and chemical disinfection [36]. The adsorbent for decolorization and the removal of organic pollutants in wastewaters are activated carbon, alumina, chitin, chitosan [38, 39]. However, it is necessary to find and choose an effective and low-cost household water treatment method.

Problem 2:
"Energy is vital for human life because any form of human action or activity requires energy. We are now developing alternative energy other than fossil fuels, whose quantity is becoming increasingly limited. Waste from food production can be processed into biogas. This technology is useful for producing alternative energy sources, but it can also keep the environment clean. Organic waste from livestock and the food manufacturing industry is not simply thrown away, but used as biogas."

Biogas is a product of the anaerobic digestion of organic matter by methanogenic bacteria. Biogas technology utilizes organic agricultural waste and converts it into fuel and fertilizer. The direct impact of biogas is saving firewood and kerosene energy. Biogas technology also solves the problem of environmental pollution and improves household or communal sanitation.

Energy conservation is the first step to start the energy-saving movement to prevent an energy crisis. Current technological advances have created a variety of energy-efficient products that are much more environmentally friendly, such as bio-fuel technologies that can also reduce the use of fossil fuels for

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**Figure 3.** The relationship between water purification and STEM

**Figure 4.** The link between biogas and STEM
vehicles. Through a simple energy conservation movement, we can save the Earth from an energy crisis and save the environment from the damage caused by excessive energy use. Let us start the energy conservation movement!

Regarding the last issue, which discussed energy efficiency and energy-saving behavior.

**Problem 3:**
"Energy efficient homes are an important concern for current and future urban development. Housing contributes about 37.5% to significant energy consumption and carbon emissions [40]. What makes a home energy-efficient and energy-saving? The teacher instilled in students' awareness in terms of saving energy. Make a mock-up of an energy-efficient home made as a product. For example, designing a miniature house that saves electricity."

| SCIENCE                           | TECHNOLOGY                                      |
|----------------------------------|------------------------------------------------|
| **Factual:** the lamp will turn on if it is connected to a current source. | 1. Energy efficient homes.                      |
| **Conceptual:** with the same current, the voltage in the series circuit will be divided into several lamps, while in a parallel circuit, the voltage on each electrical load is the same as the source voltage. | 2. Electrical installation at home.             |
| **Procedural:** how to assemble open, closed, series, and parallel electrical circuits. | 3. Internet to find information related to energy-efficient homes and electrical circuits. |
| **Metacognitive:** save electricity consumption | 4. Computer for making reports.                  |

| ENGINEERING                      | MATHEMATICS                                    |
|----------------------------------|-----------------------------------------------|
| 1. Design a miniature energy-efficient house | 1. Using a scale, calculate the length, width, and height of the house. |
| 2. Make a miniature energy-efficient house | 2. Prove the Pythagorean theorem.             |
| 3. Design electrical installations in energy-efficient miniature houses. | 3. Determine the surface area and volume of the flat figure! |
| 4. Make electrical installations in energy-efficient miniature houses. | 4. Using social arithmetic, calculate the amount of electric power, the price, and the number of materials used. |
| 5. Evaluate the work.            |                                               |

![Figure 5. A miniature of energy-saving electricity house](image)

Figure 5 shows a description of the technical energy saving at home. Actions to be taken to increase energy efficiency at home include using compact fluorescent lamps (CFLs) or LED lamps. Turn off the lights, Air Conditioner, and heater when nobody is home. Using better insulation, high-performing or energy star windows, and equipment. Using photovoltaic (PV) solar panels at home is a good option if there is available electricity.
Based on research made by Islamyah [41], the implementation of learning with a STEM-based GI model can support students to find and explore a science concept more easily. It also motivates students to apply the knowledge they understand into their daily lives. Additionally, it can also improve students’ scientific literacy competence. The application of modules using the STEM approach for high school students has a positive effect [42].

3.2 Validation of Lesson Plan

The standard lesson plan elements consist of title, objectives, standards, explanation of the warm-up activity, assignments, materials, assessment, and questioning [43,44]. The results of the lesson plan analyzed by three validators include aspects of format, language, and content. Based on these three aspects, the percentage of lesson plan validation was 95%. Meanwhile, the result of the reliability analysis was 86%. From the assessment range determined, the value of 86% shows that the lesson plan is high consistency (reliability).

The lesson plan validation results with valid categories in each aspect indicate that the components building up the lesson plan were correctly fulfilled. Therefore, it can be concluded that the lesson plan developed is very valid and feasible to use in learning and can be used as a guide for teachers to improve students’ competence in the learning process following the teaching materials used. Instructional planning is a vital aspect of any teacher's work to give students meaningful learning experiences [45]. The advantage of developing this learning implementation plan is that it applies a guided inquiry model that makes students more proficient in the learning process. The learning implementation plan with the STEM approach with Engineering Design Process (EDP) is interrelated with the module, which is expected to make it easier for students to understand the learning provided by the teacher. The EDP has seven stages: define the problem, plan possible solutions, choose the possible solution, design, test, redesign, and communicate [46]. It is simplified into six stages for junior and senior high school, as presented in Table 2.

The STEM-based GI learning model is implemented to improve scientific literacy through scientific investigation or scientific methods because the three are related (Table 2).

| Table 2. The link between STEM-based GI and scientific literacy |
|---------------------------------------------------------------|
| **Guided inquiry syntax** [25][26] | **STEM (EDP stages)** [47] | **Scientific literacy indicator** [48] |
| **Initiation.** Formulate a well-formed investigation research question | Define the problem | Explain phenomena scientifically |
| **Invention.** Generate competitive alternative hypotheses and predictions | Plan | Design scientific investigations |
| **Investigation.** Design and carry out experiments for data collecting | Carry out investigations Design | Design scientific investigations |
| **Interpretation.** Analyze the data | Evaluate and Redesign | Interpret data and evidence scientifically |
| **Instruction.** Conclude, evaluate, and reflection | Evaluate scientific investigation |

The GI learning had five phases [25], and the STEM integration was done as follows. Two aspects of STEM: science and technology, were integrated into the first phase (Initiation) and the second phase (Invention). Three aspects of STEM: science, mathematics, and engineering, were integrated into the third phase (Investigation). All aspects of STEM: science, technology, engineering, and mathematics, were integrated into the fourth phase (Interpretation) and the fifth phase (Instruction). In STEM, students’ activities were primarily dominated in the engineering aspect. The EDP had six steps (define the problem, plan, carry out investigations, design, evaluate, and redesign). Through STEM-based GI learning, students can practice acquiring knowledge or concepts and conduct experiments. Therefore, they can learn to find various solutions to a particular task or problem. STEM education can help people practice their literacy skills in technology and science [5]. The integration of STEM aspects, especially engineering aspects in GI learning, is that applying mathematics and science concepts helps students understand certain phenomena.

The scientific processes, such as problem analysis, original investigation, communication with peers, formulation of solutions, and interpretation of results, with the help of mathematics, are essential in operating data [49]. In technology, students are given the skills to understand the tools used to simplify all existing
problems. Students are also be provided with how to make these tools and get ideas to find out a problem that can be done more efficiently. The engineering aspect helps transform understanding knowledge into practical technologies that can help to solve similar problems further [50]. The STEM-based GI learning can develop the skills and abilities necessary for work and daily life in the 21st century [51, 52], develop scientific literacy and problem-solving skills[53], processes, and student's academic success [54].

3.3 Validation of Literacy Test
The OECD Programme for International Student Assessment (PISA) [44] describes three competencies needed in scientific literacy, namely: (1) explain phenomena scientifically, (2) evaluate and design scientific inquiry, and (3) interpret data and evidence scientifically. Indicators of scientific literacy competency are presented in Table 3.

| Scientific Literacy Competency | Indicators                                                                 |
|-------------------------------|---------------------------------------------------------------------------|
| Explain Phenomena Scientifically | • recall and apply appropriate scientific knowledge                         |
|                                | • identify, use and generate explanatory models and representations         |
|                                | • make and justify appropriate predictions                                  |
|                                | • offer explanatory hypotheses                                              |
|                                | • explain the potential implications of scientific knowledge for society     |
| Evaluate and Design Scientific Enquiry | • identify the question explored in a given scientific study               |
|                                | • distinguish questions that could be investigated scientifically            |
|                                | • propose a way of exploring a given question scientifically                 |
|                                | • evaluate ways of exploring a given question scientifically                |
|                                | • describe and evaluate how scientists ensure the reliability of data, and the |
|                                |   objectivity and generalisability of explanations.                         |
| Interpret data and evidence scientifically | • transform data from one representation to another                         |
|                                | • analyse and interpret data and draw appropriate conclusions              |
|                                | • identify the assumptions, evidence and reasoning in science-related texts |
|                                | • distinguish between arguments that are based on scientific evidence and theory |
|                                |   and those based on other considerations                                   |
|                                | • evaluate scientific arguments and evidence from different sources (e.g.    |
|                                |   newspapers, the Internet, journals)                                      |

The learning outcomes test analyzed by three validators include several aspects: format, questions following scientific literacy indicators, clarity of questions' purposes, question sentences preventing multiple interpretations, questions using clear interrogative sentences or commands, clear and functioning images, using correct Indonesian rules, and using language that is easy to understand. In each aspect, various validation scores were obtained. The presentation of the test validation of learning outcomes was 94.00% with very valid criteria and a reliability value of 89.50% with very reliable criteria, showing that the questions for the learning outcomes test developed by the researcher are feasible to be used as learning tools. According to [19], learning tools are effective if they provide results following the goals that have been set. The guided inquiry learning model is very effective in managing various types of the learning atmosphere in the classroom and can facilitate the improvement of students' scientific literacy [55].

The advantages of the developed learning outcomes test questions refer to indicators of scientific literacy achievement. The increase in students' scientific literacy can be measured using questions that researchers have developed. The scientific literacy indicators used are for questions (1) Analyzing and assessing objective and reliable information relevant to energy issues (2) Applying appropriate and environmentally friendly alternative energy methods (3) Distinguishing scientific questions that enable scientific investigations in the manufacture of simple biogas; (4) Analyzing precise data on water pollution; (5) Identify, use and produce illustrative examples and illustrations; (6) Determining the correct order of ingredients in water purification; (7) Distinguishing scientific questions that allow for scientific investigation in the manufacture of simple water purifiers; (8) Explain the implications of energy-saving technology for
society; (9) Evaluating the lifestyle that contributes to solving global energy problems. (10) Interpreting the data and scientific evidence of energy efficiency and draw the appropriate conclusion. The learning outcomes test that has been developed has the advantage that there are ten valid and reliable items with indicators of scientific literacy and learning objectives. According to Turner [56], a literacy test is a handy tool in providing natural science. Therefore, this learning outcomes test provides multiple-choice questions that can measure scientific literacy levels and students' knowledge.

The EFT teaching materials using STEM-based GI provide students with a rich learning context in which students learn new knowledge and learn how to discover facts, concepts, and principles. If students are endeavored to think and act wisely towards the environment, the learning objectives oriented towards the environment will be achieved. Therefore, one thing that can be done to overcome the problem of environmental damage is through education [57].

4. Conclusion
Based on the results of expert validation, it was concluded that the EFT teaching materials using STEM-based GI in the form of modules, lesson plans, and literacy test instruments developed were very valid, with the coefficient of agreement between the validators (R) in the high category. Teaching materials are appropriate to be used as alternative learning resources and guidelines for teachers in EFT learning.

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