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Development of Green Chemistry Oriented Student Worksheets with Guided Inquiry Model to Improve Science Literacy Skills on Reaction Rate Material

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Abstract: Green chemistry plays a crucial role in minimizing the environmental impact of chemical processes, while science literacy equips students with the knowledge and skills to understand a sustainable future. This study aims to describe the feasibility of a Student Worksheet oriented toward green chemistry using a guided inquiry model, deemed suitable for enhancing students' scientific literacy skills in the reaction rate topic. The research method employed is the Research and Development (R&D) 4D model, which includes define, design, develop, and disseminate stages, limited in this study to the development stage to analyse needs, design, and test the conformity of the learning media. A limited trial was conducted with 30 eleventh-grade students who had previously received instruction on reaction rate and green chemistry at a senior high school in Nganjuk during the 2024/2025 academic year. Data were collected through questionnaires, observations, and tests, then analyzed quantitatively and descriptively using mode, percentage, Guttman scale, Likert scale, and N-Gain test. The results show that the worksheet is valid in terms of content and construct (mode 4, good category), practical based on student responses (97.5%, very good), student activities (96.86%, very good), and implementation (mode 5, very good). The worksheet was also effective in improving scientific literacy, as evidenced by 90% of students achieving a gain score ≥ 0.7 (high category). N-Gain by indicator: context 0.85, knowledge 0.85, and competence 0.88. Based on its validity, practicality, and effectiveness, the developed worksheet is feasible to use as a learning medium.

Keywords: Green Chemistry; Literacy Science; Reaction Rate Material; Student Worksheet; 4D.

Introduction

The 21st century is marked by rapid technological advancement, globalization, and social change, requiring individuals to possess globally competitive skills. In the context of education, this has driven the transformation of learning methods and the development of students' competencies to prepare them for future challenges [1]. The Indonesian government has responded to these demands by shifting from the 2013 Curriculum to the Merdeka Curriculum, which uses teaching modules as instructional guides. One of the main focuses of the Merdeka Curriculum is strengthening literacy skills through well-planned and continuous learning processes [2].

Scientific literacy, as one of the essential 21st-century skills, has become a major focus of educational reform because it equips students with logical and scientific thinking abilities to understand and respond to various social issues and modern life challenges. The importance of developing scientific literacy lies in: (a) providing personal satisfaction in understanding nature; (b) supporting scientifically informed daily decision-making; (c) enabling participation in public discussions related to science and technology issues; and (d) being necessary in the workforce, which demands high-level skills such as reasoning, creative thinking, decision-making, and problem-solving [3].

The 2018 PISA results show a decline in Indonesia's literacy scores compared to 2015, with a score of 396. In 2022, the reading literacy score dropped again to 359, marking the lowest score in Indonesia's participation history [4]. This decline reflects the low literacy abilities of students. At SMAN 1 Gedangan, 67% of students stated that scientific literacy in chemistry learning was still suboptimal [5].

The low level of students' scientific literacy in chemistry learning is caused by several factors: irrelevant teaching materials, conceptual misconceptions, a lack of contextual approaches, and limited ability to comprehend scientific texts. In some schools, learning resources are still limited, and teachers rely heavily on textbooks that emphasize definitions rather than problem-solving [6]. One solution is the development of Student Worksheets designed to foster critical thinking through structured activities. Worksheets help students understand chemical concepts more effectively and boost learning motivation through engaging and exploratory approaches.

To support this, it is necessary to provide high-quality and contextual learning materials relevant to the field of chemistry or science education, in order to make learning more meaningful and to develop students' scientific literacy [7]. Student Worksheets are learning activity guides that include theory-based steps, illustrations, and investigations to develop critical thinking skills and achieve learning objectives [8]. The use of worksheets can enhance learning motivation and effectiveness, as well as help students understand chemistry material optimally through interesting tasks aligned with the content being studied [9].

Chemistry is an exact science that studies facts, concepts, laws, and theories in everyday life and comprises

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various interrelated fields [10]. Preliminary research conducted by the researcher showed that 76.7% of students experienced difficulties in learning chemistry due to its complex nature. Chemistry learning involves three levels of representation: macroscopic, submicroscopic, and symbolic [11]. This indicates that chemistry is an abstract and complex science that requires deep understanding [12].

In chemistry learning, linking subject matter to everyday phenomena helps students understand concepts logically and meaningfully. Information that is understood is more effective than that which is merely memorized, making literacy a key to ideal learning [13]. Strong literacy skills enable students to find and process information efficiently [14]. Therefore, scientific literacy skills are essential to face the challenges of the 21st century [15].

The reaction rate topic demands mastery of procedural knowledge, which can be better understood through practical activities such as exploring the effects of surface area, concentration, temperature, and catalysts. However, chemistry experiments have the potential to produce chemical waste that may pollute the environment if not properly managed. The use of Student Worksheets in practical activities has been proven effective in enhancing students' understanding. Chemistry experiments also pose safety risks, thus requiring careful management based on safety principles. To minimize negative impacts, experiments should be conducted following the principles of green chemistry.

Preliminary interview data with chemistry teachers revealed that students perceive the reaction rate topic as difficult because of its abstract nature, the need for mathematical understanding, and the teacher-centered learning approach. Furthermore, 86.7% of students had never conducted or designed an experiment. Other studies have shown a high level of student misconceptions regarding various reaction rate concepts, such as surface area, temperature, and catalysts. Many students misunderstand or misinterpret the concepts in this topic [16]. Concepts related to the factors affecting reaction rate can be abstract and difficult to grasp if only delivered theoretically [17]. One solution to this problem is the implementation of inquiry-based learning.

The guided inquiry model is a teaching approach that incorporates scientific activities, such as encouraging students to express their thoughts before explaining a subject, investigating problems by observing phenomena, and deriving facts from scientific activities that can be explained using scientific theories. These scientific activities can be conducted through laboratory experiments [18].

Chemistry learning is inseparable from practical activities that pose risks and should be managed carefully to prevent accidents and minimize hazardous chemical waste [19]. In the context of green chemistry, school laboratories are seen as potential sources of hazardous waste and environments with a high risk of accidents. Therefore, sustainable and safety-based management is required to minimize negative impacts on both the environment and health [20]. To avoid the use of harmful chemical waste, practical activities should be aligned with the principles of green chemistry [21].

Green chemistry is an innovative approach in chemistry education that aims to reduce the use of hazardous substances and promote environmentally friendly practices. Implementing this principle is essential for addressing environmental issues and preparing students for 21st-century challenges. Chemistry education in schools can integrate green chemistry principles, particularly in laboratory practices.

From the above description, it can be concluded that chemistry learning has never specifically trained students' scientific literacy skills. This issue is further exacerbated by the use of teacher-centered learning models, which result in suboptimal student engagement during the learning process. Additionally, some students report that the topic of reaction rates is particularly challenging and requires more in-depth conceptual understanding compared to other topics. However, there is currently no available learning media that effectively supports this process, especially one that can foster scientific literacy and actively engage students in classroom activities. One effort to support this integration is through research titled The Development of Student Worksheets Oriented toward Green Chemistry Using the Guided Inquiry Model to Improve Students' Scientific Literacy on Reaction Rate Topics. This study aims to determine the feasibility of worksheet in enhancing students' scientific literacy in the reaction rate material.

Research Methods

This study is a Research and Development (R&D) study aimed at developing Student Worksheets oriented toward green chemistry to improve students' scientific literacy skills on the topic of reaction rates. R&D is used to create or refine products to make them more effective and relevant. The development model used is the 4D model by Thiagarajan (limited to 3D stages), which is adapted from Ibrahim (2014). It consists of three main stages: (1) Define, which focuses on needs analysis; (2) Design, which involves designing the conceptual framework and learning tools; and (3) Develop, which includes validation and feasibility testing of the learning media, as illustrated in the following figure.

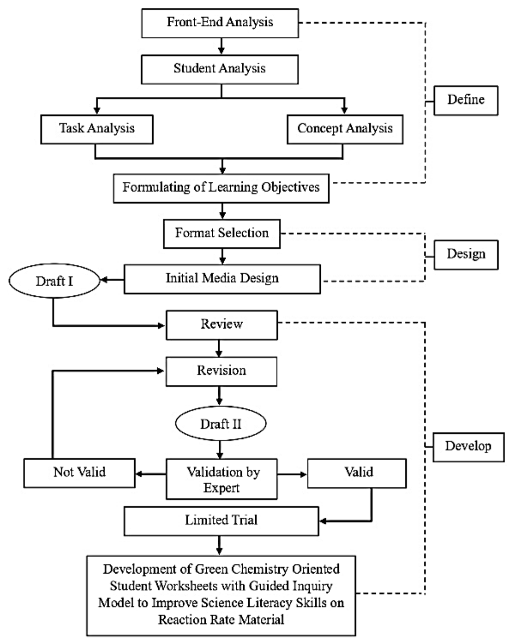

Figure 1. Research Design

This research was conducted through a limited trial involving 30 Grade XI science students at a senior high school in Nganjuk during the 2024/2025 academic year. The students who served as research subjects were those with homogeneous abilities and skills, based on the recommendation of the chemistry teacher. There were two sources of data in this study: primary and secondary sources. Primary data were obtained directly from the research subjects, while secondary data came from books, articles, journals, and previous research relevant to this study. The research instruments included review sheets, validation sheets, response questionnaires, observation sheets, and tests (pretest and posttest), which were used to evaluate the quality and effectiveness of the worksheet.

The data collection methods used in this research included three techniques:

1. Questionnaire Method
   Response questionnaires were distributed to 30 Grade XI science students to gather their responses to the developed worksheet. The results of these questionnaires were used to assess the practicality of the worksheet and were supported by observation results of student activities and the implementation of learning.
2. Observation Method
   Observations were conducted to monitor students' activities and the implementation of learning, carried out by five observers. The observation results served as supporting data to assess the practicality of the worksheet used in the learning process.
3. Test Method (Pretest and Posttest)
   Pretests and posttests were conducted to measure students' scientific literacy skills before and after using the worksheet. These results were used to determine the effectiveness of the green chemistry–oriented worksheet developed in this study.

The collected data were analyzed using the following methods:

1. Review Data Analysis

The review data obtained from chemistry expert lecturers were analyzed using descriptive quantitative methods.

2. Validity Data Analysis

The validation data from the validators were ordinal data analyzed using the mode. Ordinal data are non-comparable and cannot be processed using mathematical operations [22]. Since the validation data were ordinal, they were analyzed using the mode. The results were then categorized using the Likert scale criteria, as shown in Table 1.

Table 1. Likert Scale Criteria

Score	Category
1	Not good
2	Less good
3	Fair
4	Good
5	Very good

[1]

The validation data were analyzed using the mode method, with the provision that an aspect is considered valid if it receives the most frequent score (mode) ≥ 3. If the mode score is < 3, the aspect is considered invalid and must be revised and reassessed until it meets the minimum score criterion of 3.

3. Practicality Data Analysis

Data from student response questionnaires and observations were used to analyze the practicality of the developed worksheet. The student questionnaire data were analyzed using the Guttman scale criteria and then calculated using a percentage formula. The results were categorized using practicality criteria, as shown in Table 2.

Table 2. Guttman Scale Criteria

Answers	Score	
	Positive Statement	Negative Statement
Yes	1	0
No	0	1

The scores obtained were then used to calculate the practicality percentage using the following formula.

$$P\,(\%) = \frac{\text{Total score obtained}}{\text{Max possible score}} \text{ x } 100\%$$

The percentage results of the practicality from the students' response questionnaires can be interpreted according to the practicality criteria presented in Table 3.

Table 3. Practical Categories

Percentage (%)	Category
0-20	Not practical
21-40	Less practical
41-60	Fairly practical
61-80	Practical
81-100	Very practical

Based on Table 3, the green chemistry–oriented worksheet is considered practical for improving students' scientific literacy skills on the reaction rate topic if it achieves a practicality percentage of ≥ 61%. The observational data of students' activities will be scored based on the Guttman scale scoring guide, as shown in Table 2. The obtained scores are then used to calculate the practicality percentage using the following percentage formula.

$$P\,(\%) = \frac{\text{Total score obtained}}{\text{Max score possible}} \text{ x } 100\%$$

The percentage of practicality from the observation of student activities is then interpreted according to the practicality criteria presented in Table 3. The data from the observation of lesson implementation will be scored using the mode of the data, with score categories as shown in Table 1. The worksheet can be considered practical if it meets a minimum score criterion of 3.

4. Effectiveness Data Analysis

The data obtained from the pretest and posttest are analyzed using the N-Gain Score formula and categorized according to the N-Gain value categories presented in the following table.

$$< g >= \frac{\text{Spost} - \text{Spre}}{\text{Smaks} - \text{Spre}}$$

Caption:
Spost: Posttest score Smaks: Maximum score
Spre: Pretest score
The obtained values are interpreted based on the score criteria in the table below:

Table 4. N-Gain Score Categories

N-Gain Score	Categories
$g \geq 0.7$	High
$0.7 > g \geq 0.3$	Medium
$g < 0.3$	Low

[2].

The worksheet is considered effective if it achieves at least a medium category N-Gain score.

Results and Discussion

This section presents the results of the research on the development of a Student Worksheet oriented toward green chemistry to enhance students' scientific literacy skills on the topic of reaction rates, using the Guided Inquiry Learning model through the stages of define, design, and develop. The first stage, define, aims to identify the learning needs in preparing the worksheet to improve students' scientific literacy. Based on preliminary data collected at SMA in Nganjuk, 77% of students stated that the reaction rate topic was quite difficult to understand, so the research focused on this topic, particularly on the influencing factors. This stage involved several steps: 1) Preliminary and final analysis, aimed at identifying key issues to be addressed in the worksheet. The analysis revealed that chemistry learning was still dominated by lectures and conventional worksheets that had not integrated scientific approaches or green chemistry principles. Laboratory work still used hazardous chemicals and generated significant waste, resulting in low student scientific literacy, especially in using scientific evidence and applying chemistry concepts; 2) Student analysis, conducted to understand the type of learners and adapt the worksheet accordingly. Preliminary questionnaires and interviews showed that most 11th-grade students had moderate interest in chemistry but struggled to understand abstract concepts such as reaction rates. They tended to be passive in laboratory work and were not familiar with inquiry-based approaches. Their scientific literacy was still low, especially in interpreting data, explaining phenomena, and evaluating scientific information; 3) Task analysis, aimed at identifying the main tasks students will perform during learning activities. Students were expected to complete assigned tasks to demonstrate their competencies. The tasks were aligned with the Independent Curriculum (Kurikulum Merdeka) and the learning objectives of the chemistry subject; 4) Concept analysis, intended to classify the key concepts students would learn through the worksheet. This stage involved examining learning resources adjusted to the learning indicators. The reaction rate topic was chosen because it is an essential part of the curriculum, containing fundamental concepts such as the factors affecting reaction rate, collision theory, and measurements. This topic is well-suited for guided inquiry approaches and is relevant to green chemistry principles, such as energy efficiency and waste reduction; 5) Formulating learning objectives, in which the intended learning goals and flow were outlined. These include: students being able to formulate problems and hypotheses based on presented phenomena, explain factors affecting reaction rate through scientific phenomena, evaluate and design experiments through literacy activities, interpret experimental data, and implement green chemistry principles in daily life.

The second stage, design, involved planning the worksheet to improve students' scientific literacy skills based on the data and problems identified in the define stage. This stage consisted of two main steps: 1) Format selection, ensuring that the worksheet structure matched the needs. The format was adjusted to learning resources and included materials, content, and visual design (layout, graphics, and text). The worksheet combined experimental guidance with concept discovery activities, divided into three parts: introduction (general information), core activities (following guided inquiry syntax, scientific literacy, and green chemistry principles), and closing (reflection and references); 2) Initial worksheet design, which involved creating a complete draft before the limited trial and further development. The worksheet design emphasized guided inquiry syntax, green chemistry principles, and scientific literacy skills.

The third stage is develop. The objective of this stage is to create an updated worksheet based on input from expert lecturers, which is then tested on a limited group of students. This stage consists of three steps: 1) Review and revision, which involves examining the worksheet before it is validated by expert reviewers. The review results consist of suggestions and feedback that are used for improvement; 2) Expert validation, which aims to test the validity of the developed worksheet as a learning medium. The worksheet is considered valid if it receives a mode score of ≥3 [22]. In this stage, the overall worksheet received a mode score of 4, categorized as valid. In addition to the worksheet, other learning tools and instruments used in this study also underwent validation by expert validators. Other tools used in this study include a teaching module, while the instruments include pretest-posttest questions, student response questionnaires on the worksheet and the learning process, observations of student activities and learning implementation, and a scientific literacy skills test given before and after the implementation of the developed worksheet. The following table presents a summary of the validation results for the tools and instruments evaluated by the three validators.

Table 5. Validation Result

No.	Perangkat/Instrumen	Modus	Kategori
1.	WORKSHEET	4	Good
2.	Teach Module	4	Good
3.	WORKSHEET Response Questionnaire Sheet	4	Good
4.	Learning Response Questionnaire Sheet	4	Good
5.	Observation Sheet Activity	4	Good
6.	Observation Sheet Implementation	4	Good
7.	Pretest-posttest Question	4	Good

The limited trial was conducted after completing the review and validation stages of the developed worksheet. The result of the validation showed that the developed worksheet falls into the valid category.

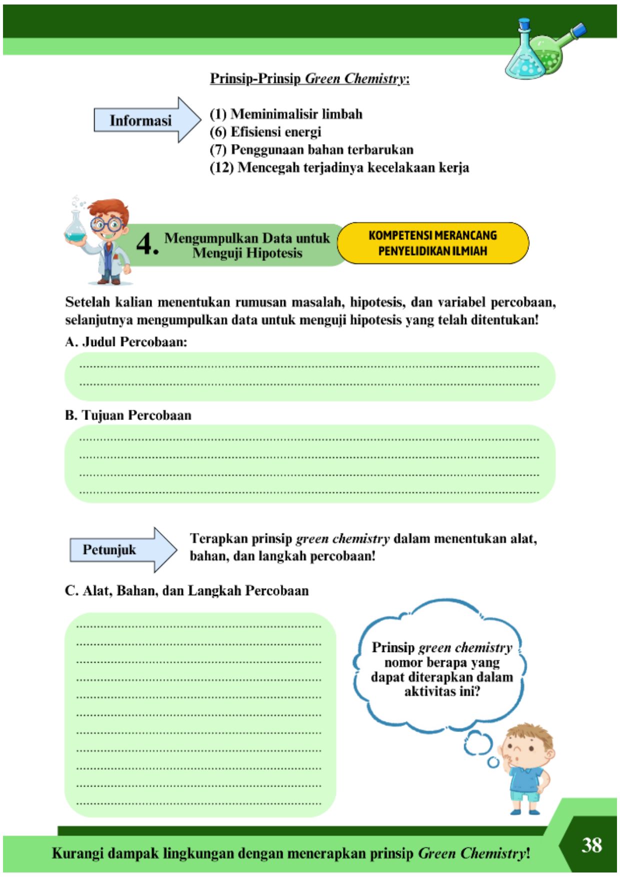

Figure 2. The Worksheet Includes Design, Science Literacy Aspect, Guided Inquiry, and Green Chemistry

Next is the limited trial stage. This stage was conducted to determine the practicality and effectiveness of the developed worksheet. The learning process during the limited trial applied the Guided Inquiry model as reflected in the worksheet. This study used a one-group pretest-posttest Design. The outcomes of this stage include: student responses to the worksheet and the learning process, student activity and learning implementation observed by observers, and pretest-posttest results of scientific literacy skills. The following is a description of the limited trial results of the developed product.

Practicality of the Worksheet

Student Responses to the Worksheet

The student response questionnaire was given after students participated in learning activities using the developed worksheet as a learning medium, with the expectation that they would answer honestly without external influence. The data from the questionnaire was used to assess the practicality of the worksheet, particularly in terms of content clarity, student comprehension, literacy skill development, understanding of green chemistry principles in daily life, interest in the worksheet, language clarity, and ease of use. Results showed that 5.9% of students noted a mismatch between the content, and 13.7% identified ambiguous sentences, attributed to heterogeneous student abilities and comprehension levels. Overall, 98% of students responded positively; thus, the worksheet is categorized as highly practical.

Student Responses to the Learning Process

The student response questionnaire regarding the learning process aimed to determine their understanding and perceptions related to the implementation of the learning and their appreciation of the green chemistry-based practicum embedded in the lesson. Results showed that 12.9% of students felt that green chemistry principles did not help in solving real-life problems, likely because they had never applied these principles before. Additionally, 10.9% of students expressed disinterest in conducting experiments using green chemistry due to their unfamiliarity with eco-friendly materials. However, in general, 97% of students gave positive responses, indicating that the worksheet with guided inquiry model is highly practical.

Observation of Student Activities

Student activity observation was conducted to evaluate the practicality of the green chemistry-oriented worksheet as a learning medium. Observations were carried out by five observers, based on 16 statements aligned with the guided inquiry phases and scientific literacy components. The analysis showed that student activity during the two learning sessions was high: First session, 96.86% positive activity; Second session, 93.48% positive activity. Positive activity percentage was calculated by subtracting the negative activity percentage from 100%. The decrease in the second session was due to time constraints, which made students rush when drawing conclusions, leading some to open their phones (a negative activity). The worksheet is considered practical if it achieves at least 61%. Based on these percentages, the developed worksheet is considered practical and suitable for use as a learning medium.

Results of Learning Implementation Observation

Observations on the implementation of learning were conducted to assess the practicality of using the green chemistry–oriented worksheet as a learning medium. Five observers evaluated 15 statements aligned with the inquiry phases. They rated the implementation on a scale from 1 to 5 according to the level of learning execution. The scores were analyzed using the mode. The analysis showed that across two sessions, the inquiry phases consistently received a mode score of 5, indicating a very good category. This demonstrates that learning using the developed worksheet was carried out excellently, confirming that the worksheet is practical and suitable to be used as a learning medium.

Effectiveness of the Worksheet

Effectiveness was measured using pretest and posttest assessments to evaluate the impact of the green chemistry–oriented worksheet on students' scientific literacy in the reaction rate topic. The tests were aligned with reaction rate concepts and scientific literacy components, including context, knowledge, and skills. The context domain scored an n-gain of 0.851 (high category). The knowledge domain was divided into content, procedural, and epistemic aspects: content knowledge scored 0.864 (high), procedural knowledge 0.817 (high), and epistemic knowledge 0.867 (high). The lower score in procedural knowledge was attributed to limited lab experience, as students rarely conducted chemistry practicum activities. The competency domain included explaining scientific phenomena, designing experiments, and interpreting data. Scores were 0.813 (high) for explaining phenomena, 0.873 (high) for designing experiments, and 0.955 (high) for interpreting data. The lowest score in explaining phenomena was due to students' limited practice in connecting concepts to real-life situations. Overall, 90% of students achieved an n-gain ≥ 0.7 (high category). This indicates that the posttest scores increased compared to the pretest scores, which means that the students' scientific literacy skills showed improvement. This finding is consistent with the results of a study, which stated that the use of contextual teaching materials such as student worksheets oriented toward green chemistry can provide meaningful learning experiences and enhance students' scientific literacy [23-25]. Thus, the developed worksheet can be considered effective, as evidenced by an n-gain score of ≥0.7 in the high category. Here is the diagram of the pretest and posttest scores obtained by the students.

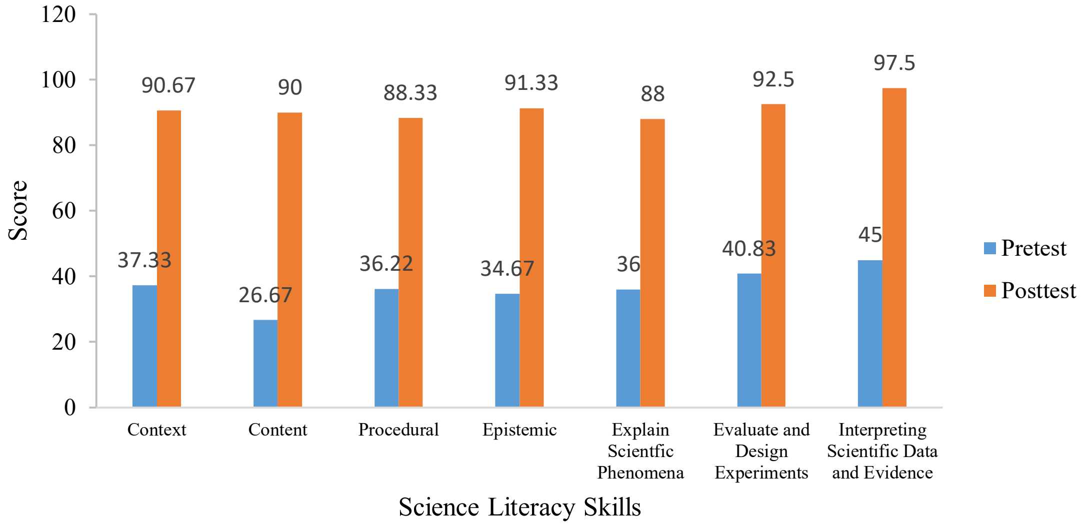

Figure 3. Graphic of Pretest-Posttest Score

Conclusion

Based on the results of this study, several implications can be drawn for other researchers interested in conducting similar research. First, the findings can serve as a foundation for further studies and as a reference for future research on guided inquiry learning models that implement green chemistry principles to enhance students' scientific literacy skills. Second, the results are expected to be used as an alternative learning medium that aligns with students' needs, particularly in learning chemical reaction rate material and subtopics related to the factors affecting reaction rates, in order to support the improvement of students' scientific literacy**.**

Author's Contribution

Karina Rike Pratiwi: conceptualizing the study, developing the student worksheets, conducting classroom implementation, and analyzing the data. Mitarlis: contributed to manuscript revision and final approval.

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