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Designing a Green Chemistry-Based Practical Guide: Enhancing Learning on Reaction Rates and Chemical Equilibrium

Hana Nazelia Afriani[1], and Agus Widodo[2]
Chemistry Education, Walisongo State Islamic University, Central Java, Indonesia
State Senior High School 1 Kaliwungu, Central Java, Indonesia

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ABSTRACT

Purpose of the study: This study aims to determine the characteristics and quality of the green chemistry-based chemical reaction rate and equilibrium laboratory manual.

Methodology: The research employed a modified 4-D development model (define, design, develop) to create a green chemistry-based practical manual. Initial stages involved analyzing student needs and curriculum compatibility. The manual was validated by experts and refined through student trials. Data were gathered via questionnaires assessing feasibility and quality, yielding a manual designed to enhance learning and environmental consciousness.

Main Findings: The validation results by material experts showed that the developed practical manual was in the very good category with a percentage of 84.38%. While the validation results by media experts obtained a very good category with a percentage of 91% and students gave responses to the practical manual showing a very good category with a percentage of 88.2%.

Novelty/Originality of this study: This study introduces a green chemistry-based practical guidebook for reaction rates and chemical equilibrium, emphasizing environmentally friendly practices. Unlike conventional manuals, it integrates sustainable materials and safety-focused procedures. By addressing gaps in practical resources and promoting ecological awareness, this research advances chemistry education by aligning hands-on learning with principles of sustainability, benefiting educators and students alike.

Corresponding Author:
Hana Nazelia Afriani,
Chemistry Education, Walisongo State Islamic University, Jl. Walisongo No. 3-5, Tambakaji, Ngaliyan, Tambakaji, Ngaliyan, Kota Semarang, Jawa Tengah, Indonesia.
Email: afhana@gmail.com

1. INTRODUCTION

Chemistry is one of the subjects taught at the high school level and has the characteristics of an experimental-based science [1], [2]. Most concepts in chemistry are obtained through observation and laboratory experiments [3], [4]. Chemistry is the science that studies matter and its changes. Chemistry is applicable because theoretical information is proven through experiments [5], [6]. Therefore, practical activities are an important part of chemistry learning.

Practical work plays a major role in fostering students' curiosity and providing direct experience in understanding chemical concepts [7], [8]. Practical work is an effective medium in the learning process [9], [10]. In addition, practical work can strengthen science process skills and improve understanding of abstract concepts [11], [12]. However, practical work is not free from various challenges that accompany it. One of the main challenges that is often faced is chemical waste management.

The use of hazardous chemicals in practical work is often not accompanied by awareness of the impact of the waste produced. Many schools do not yet have a good laboratory waste management system [13], [14]. This can cause environmental pollution and pose health risks. In addition, many students still do not understand basic laboratory techniques and work safety principles [15], [16]. The absence of personal protective equipment and strict supervision are factors that increase the potential for accidents [17], [18].

This condition was also found in Kaliwungu 1 State Senior High School, where chemistry practicum activities still do not pay attention to safety and environmental aspects. Based on the results of interviews with chemistry teachers, it was found that protective equipment such as lab coats, gloves, and masks were not used routinely. Students also often use chemicals excessively and dispose of waste into water channels. This shows the need for more responsible and environmentally friendly laboratory practices. For this reason, a new approach to practicums needs to be developed.

One relevant approach is the application of the principle of green chemistry in chemistry practicum activities in schools [19], [20]. Green chemistry is a chemical technology concept that aims to reduce or avoid the use of hazardous materials and harmful waste [21], [22]. This principle also emphasizes resource efficiency and environmentally safe process design. The principles of green chemistry include waste prevention, energy efficiency, and the use of non-hazardous chemicals [23], [24]. The application of this principle is very suitable for overcoming the problems of chemistry practicums in schools.

State Senior High School 1 Kaliwungu is an Adiwiyata school that is committed to environmental conservation. This school has natural potential such as school gardens and green houses that can be utilized in practicum activities. For example, in the material on reaction rates, students can test the effect of catalysts using natural materials available in the school environment [25], [26]. By utilizing this potential, practicums can be carried out more safely and sustainably [27], [28]. This approach is in line with the principles of green chemistry which emphasize the use of local resources [29], [30].

To support the application of green chemistry in learning, it is necessary to develop supporting media such as practicum manuals. The practicum manual functions as a guide in implementing safe and environmentally friendly practicum activities [31], [32]. Currently, State Senior High School 1 Kaliwungu only uses worksheets from Student Worksheets or textbooks without a special manual. Therefore, the development of a practicum manual based on green chemistry is urgently needed [33], [34]. This book will focus on the material on reaction rates and chemical equilibrium because both materials often use hazardous chemicals and produce large amounts of waste.

Research conducted by Qulub et al., [35] focuses on the development of environmental chemistry practicum guidelines integrated with green chemistry principles, contributing to efforts to reduce environmental impacts through the use of environmentally friendly materials and methods. Meanwhile, research by Chamidah & Mulyanti [36] evaluated the implementation of green chemistry-based reaction rate practicums through online media, with an emphasis on teacher and student responses to the effectiveness of virtual learning. This study is different because it develops green chemistry-based practicum guidelines that are specifically designed for reaction rates and chemical equilibria, with a direct approach to the use of local materials and practicum methods that support environmental sustainability. In addition, this study integrates expert validation and student trials to ensure that the resulting practicum guidelines are of high quality and relevant to classroom learning needs.

This study offers novelty by developing a green chemistry-based laboratory guide specifically designed for the material of reaction rates and chemical equilibrium. This guide not only emphasizes the use of environmentally friendly materials and safe procedures, but also utilizes local resources to support sustainability. The urgency of this study lies in the need for solutions to the challenges of chemistry laboratory experiments in schools, such as poor laboratory waste management and low student awareness of work safety principles [37], [38]. By integrating green chemistry principles into laboratory learning, this study contributes to improving the quality of chemistry education while supporting environmental awareness among students. This study aims to determine the characteristics and quality of the green chemistry-based chemical reaction rate and equilibrium laboratory manual.

2. RESEARCH METHOD

2.1. Development Model

The development model used in this study is the 4-D (Four D) development model, which is a learning device development model developed by Thiagarajan, Semmel, and Semmel (1974) [39], [40]. The stages of this 4-D development model include define, design, develop, and disseminate [41], [42]. However, in this study the author only limits it to the develop stage due to the author's limitations.

2.2. Development Procedures

The development procedure is carried out in accordance with the steps of the 4-D (Four D) development model which is modified into 3-D (Three D), namely define, design, and develop. The first stage is the define

stage, which begins with a front-end analysis. This activity aims to explore and identify problems faced by students in learning chemistry at Kaliwungu 1 State Senior High School. The method used includes distributing questionnaires to students. The results of the analysis show that students prefer practical activities, but there is no adequate practical manual and there is no good laboratory waste management. This shows the urgency of developing safe and environmentally friendly practical products. Furthermore, an analysis of students is carried out to determine the characteristics, initial abilities, and experiences of students in the school environment. This analysis is important for adjusting the content and level of difficulty of the manual to be developed. Then continued with a task analysis to determine the contents of learning resources and identify the main skills that students need to have.

At this stage, a Basic Competency analysis is also carried out so that the contents of the book are in accordance with the curriculum [43], [44]. After that, learning objectives are compiled to determine the achievement indicators that will be measured in the book development process. The second stage is the design stage, which is the initial part of the product prototype development process. At this stage, references are collected to compile experiments that are relevant to the material on reaction rates and chemical equilibrium. After that, the format of the practical manual is determined, including the design of the layout, cover, contents, and characteristics of the green chemistry-based book. Then, an initial draft of the guidebook format was prepared containing learning achievement indicators, learning objectives, and practicum procedures using safer and more environmentally friendly materials.

This trial involved nine students selected based on their level of understanding, consisting of three high-ability students, three medium-ability students, and three low-ability students based on their Final Semester Exam scores [45], [46]. Students carried out the practicum using the guidebook that had been developed, then were asked to fill out an assessment questionnaire. Data from this trial was used as a basis for revising the final product if deficiencies were found. Thus, the resulting guidebook is expected to be effective, feasible, and in accordance with the principles of green chemistry.

2.3. Research Subjects

The subject of research is an important aspect in research, where the subject of research must be prepared before the researcher collects data, the subject of research can be an object, thing or person [47], [48]. The subject of this study was the students of class XI majoring in natural sciences at State Senior High School 1 Kaliwungu.

2.4. Data Collection Techniques

The data in this study were obtained from distributing questionnaires. A questionnaire is an indirect data collection technique [49], [50]. The data collection instrument is in the form of several questions or statements that must be answered by the respondents. The questionnaire must have a focus, namely containing questions about facts that are considered to be mastered by the respondents. The questionnaire is also used to find out students' responses regarding the level of quality and validity of the green chemistry-based chemistry practicum manual that was developed. The questionnaire used is in the form of a checklist. The questionnaire is given to the validator as a test of the feasibility of the green chemistry-based chemistry practicum manual. The questionnaire is also used to obtain student and teacher responses to the product of the development of the green chemistry-based chemistry practicum manual. The indicators of the quality of the chemistry practicum manual in this study can be seen in table 1.

Table 1. Quality Indicators of Chemistry Practical Manuals

No.	Aspects assessed
1.	Writing and organization of the book
2.	Conceptual truth
3.	Depth of material
4.	Green chemistry
5.	Clarity of sentences
6.	Level of practical implementation
7.	Practical report
8.	Physical appearance of the practical manual

2.5. Data Analysis Techniques

Validation data is obtained from the results of product validation and instrument validation, in the form of descriptive data in accordance with the product development procedure which includes the stages of definition, design, and development [51], [52]. Validation is carried out by media experts and chemical material experts. The existing validation data is collected and then examined to be used as a reference for product improvement. The results of the student assessment (response) in the form of qualitative values are changed into quantitative values,

then calculated and changed back into qualitative values so that the quality value of the chemistry practicum manual is obtained in the form of an overall ideal percentage with the formula:

$$\%\,The\ ideality\ of\ every\ aspect = \frac{Average\ score\ for\ each\ aspect}{Overall\ ideal\ maximum\ score}\ x\ 100\%$$

The ideality percentage shows the level of ideality of the practical manual produced based on the assessment (response) of students at Kaliwungu 1 State Senior High School.

3. RESULTS AND DISCUSSION

After product development, product validation tests and field tests are carried out.

3.1. Expert Validation

The validation results were obtained from the validation of the initial product by two expert lecturers, one media expert lecturer, and one chemistry teacher to determine the feasibility of the laboratory manual product that had been developed on a limited basis. The assessment by the expert and media validators used a validation sheet instrument containing several assessment aspects so that quantitative data and development process data were obtained in the form of suggestions or input in each assessment indicator. Suggestions or input from the validator were used as a reference for improving the manual so that the final product was obtained. The results of the validation of the quality of the laboratory manual for reaction rates and chemical equilibrium based on green chemistry by the expert validator can be seen in. The validation results can be seen in the table below:

Table 2. Results of the Expert Validator Assessment of Material

No.	Assessment Aspect	Number of Indicators	Average Score	Maximum Score	Ideality (%)	Category
1.	Apperception Constructivism	1	4.3	5	86%	Very Good
2.	Conceptual Truth	2	9	10	90%	Very Good
3.	In Material	1	4	5	80%	Good
4.	Green Chemistry Content	7	30	35	85.7%	Very Good
5.	Level of Practical Implementation	2	8.6	10	86%	Very Good
6.	Practical Report Assessment	2	8.3	10	83%	Good
7.	Psychomotor Assessment Sheet	1	4	5	80%	Good
	Amount	16	68.2	80	84.38%	Very good

Based on Table 2. above, the assessment of the material validator has a very good category with an ideal percentage of 84.38%.

Table 3. Results of Media Expert Validator Assessment

No.	Assessment Aspects	Number of Indicators	Average Score	Maximum Score	Ideality (%)	Category
1.	Physical appearance of the book	3	13.5	15	90%	Very good
2.	Writing and organization of the book	3	14	15	93%	Very good
3.	Clarity of sentences and Readability	3	13	15	90%	Very good
	Amount	9	40.5	45	91%	Very good

Based on Table 3. above, the media validator's assessment has a very good category with an ideal percentage of 91%.

3.2. Student Response Questionnaire for Green Chemistry-Based Practical Manual

After the practicum, students were asked to provide responses to the chemical reaction rate and equilibrium practicum manual based on green chemistry by filling out a response questionnaire that was distributed to students. The results of the student response questionnaire can be seen in table 4.

Table 4. Student Response Questionnaire Regarding the Green Chemistry-Based Practical Instructions Book

No.	Criteria	Total Score	Ideality (%)	Quality
1.	Physical appearance of the book	24	89%	Very Good
2	Clarity and readability of sentences	27	100%	Good
3.	Apperception Constructivism	9	100%	Very Good
4.	Green Chemistry Aspects	63	100%	Very Good
5.	Practical implementation	17	94.5%	Good
6.	Practical report assessment	9	100%	Very Good
	Overall Percentage		88.2%	Very Good

Based on the table above, it can be seen that the percentage of aspects of sentence clarity and readability, apperception constructivism, green chemistry content and assessment of practical reports is 100%, while the physical appearance of the book and the level of practical implementation have a percentage of 89% and 94.5%.

This study supports the integration of green chemistry principles in chemistry practicum learning in schools. With a sustainability-based approach, students are introduced to environmentally friendly laboratory practices. This helps reduce the negative impact of chemical waste, while increasing students' awareness of environmental issues. This guide also provides innovative solutions to support safe and responsible chemistry learning. Thus, this study contributes to global efforts to integrate sustainability principles in education.

This guide is designed by considering the applicable curriculum and the needs of students in the classroom. The green chemistry-based approach bridges the gap between theory and practice through meaningful laboratory activities. Students are invited to better understand the concepts of reaction rates and chemical equilibrium in a relevant and contextual way. In addition, this guide supports the formation of students' character to be more concerned with safety and the environment. This is in line with the national education goal of developing 21st century skills that are oriented towards sustainability.

This guide introduces innovation by integrating local materials and environmentally friendly methods in chemistry practicums. This is different from conventional guides that often use hazardous and environmentally unfriendly chemicals. This innovation also creates a more interactive and relevant learning experience for students. Thus, this study encourages the use of local resources to improve the quality of learning. This is a model for developing laboratory materials that can be applied in various educational contexts.

This laboratory guide provides opportunities for students to develop laboratory and problem-solving skills. By following a systematic procedure, students can effectively train their psychomotor skills. In addition, this guide encourages students to think critically in applying green chemistry principles. This approach also increases students' awareness of the implications of laboratory work on the environment and safety. Thus, this guide is an important tool in supporting skills-based learning.

This guide has the potential to be applied in various schools, especially those facing similar challenges related to laboratory waste management. With some improvements, this guide can be adapted to other chemistry materials at various levels of education. This will expand the positive impact of this research in encouraging sustainable chemistry learning. In addition, this guide can be used as a reference for the development of more environmentally friendly education policies. This opens up opportunities for collaboration between educational institutions and the government to create sustainability-oriented learning programs.

This research paves the way for further development in the context of green chemistry-based laboratory work. Future research can evaluate the effectiveness of this guide through trials in various schools with a wider student population. In addition, the development of similar guides for other chemistry materials can provide greater contributions to sustainability-based education. Long-term research is also needed to assess the impact of this guide on changing students' attitudes towards the environment. With further research, this guide can be continuously refined to provide broader benefits.

The limitation of this study lies in its focus which only covers the material of reaction rates and chemical equilibrium. Nevertheless, the approach used in this study can be a reference for the development of other materials in the future. The practical implication of this guide is its ability to teach students about the principles of sustainability through laboratory activities. By promoting safety and responsible management of materials, this guide adds value to chemistry learning. This limitation also provides an opportunity to expand the scope of future research.

4. CONCLUSION

The quality of the chemical experiment manual for reaction rates and chemical equilibrium based on green chemistry based on the assessment of material experts has a very good category with a percentage of 84.38% and based on media experts it has a very good category with a percentage of 91%. While based on student

responses, the experiment manual gets a percentage of 88.2%. This shows that the experiment manual for reaction rates and chemical equilibrium based on green chemistry is suitable for use in implementing laboratory experiments. Further research can develop green chemistry-based lab guides for other chemistry materials, such as electrochemistry or organic synthesis, to expand the implementation of sustainability in chemistry learning. In addition, research is needed that evaluates the long-term impact of using these guides on changing students' attitudes and awareness of environmental issues.

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