HYDROGEN
JURNAL KEPENDIDIKAN KIMIA
https://e-journal.undikma.ac.id/index.php/hydrogen/index

December 2025. 13(6)
e-ISSN: 2656-3061
p-ISSN: 2338-6487
pp. 1264-1279

Trial of Green Chemistry-Based Chemistry Laboratory Manual on Acid-Base Indicators

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Article History
Received: 24-08-2025
Revised: 25-12-2025
Published: 31-12-2025

Keywords: Practicality; Effectiveness; Green Chemistry-Based Chemistry Practicum Guidelines; Acid-Base Indicators; Borg and Gall R&D Model

Abstract
Chemistry laboratory experiments often use hazardous chemicals that can pose health risks and cause environmental damage. Green chemistry-based chemistry experiments are important because they use materials that are safe for students and the environment. Unlike previous laboratory manuals, this manual integrates green chemistry principles and digital features to enhance student independence. The purpose of this study was to examine the practicality and effectiveness of the green chemistry-based chemistry practicum guide on acid-base indicator material. This study was a Research and Development (R&D) study using the Borg and Gall model. This study focused only on the limited trial stage, initial product revision, and field trials to test the practicality and effectiveness of the Practicum Guide. Data collection techniques used questionnaires to determine practicality scores and N-Gain tests for effectiveness. The results of the practicality score analysis of the green chemistry-based chemistry practicum guide for teachers were in the very practical category, while students were in the practical category, reinforced by the results of observations of teacher and student activities in the very good category. The results of the analysis of the effectiveness of the green chemistry-based chemistry Practicum Guide using N-Gain were in the moderate category. Thus, this chemistry Practicum Guide is practical and effective for use in simple acid-base indicator practicums.

How to Cite: Aldiansyah, Febry, M., Nurlaili, Hartati, Y., & Usman. (2025). Trial of Green Chemistry-Based Chemistry Laboratory Manual on Acid-Base Indicators. Hydrogen: Jurnal Kependidikan Kimia, 13(6), 1264–1279. https://doi.org/10.33394/hjkk.v13i6.17322

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INTRODUCTION

Practical work is a form of learning that aims to improve students' understanding of theory and practice (Nisa, 2017). According to Zainuddin (1996) in Nisa (2017), practical work can teach students new skills and give them the opportunity to apply their knowledge and skills in the real world. Practical work activities will improve students' scientific process skills, both those they already have and those they do not yet have. Practical activities will run smoothly if there is a practical guide (Ningsi et al., 2021).

A laboratory manual is a guide for laboratory work that covers procedures for preparation, implementation, data analysis, and reporting. This guide is created by instructors who handle laboratory work in accordance with scientific writing standards (Ningsi et al., 2021). The function of a laboratory manual is as teaching material that can reduce the role of teachers and encourage students to be more active and acquire useful knowledge. They can also assist students in applying laboratory instruction through their own hands-on skills and creative thinking. The laboratory manual required by students is one that is easy to understand and easy to use during the laboratory activity (Ningsi et al., 2021).

Practical guides in school learning activities are synonymous with the use of chemicals, one example being acid-base practicals. In a laboratory practical, the indicators commonly used are synthetic indicators such as litmus paper, methyl red, and bromothymol blue (Minarni et al., 2023). These chemical substances can pose health risks to teachers and students. Additionally, the laboratory process generates waste. If not properly managed, this waste can harm living organisms and the environment (Rizkiana et al., 2020). To address this issue, teachers can apply green chemistry principles to each laboratory experiment. Thus, teachers will ensure that experiments conducted using green chemistry follow safe processes and utilize non-hazardous materials, thereby preventing the generation of waste that could harm the environment and human health (Wahyuningsih & Rohmah, 2017).

Research (Utami et al., 2020) shows that according to observations at SMA Negeri 2 Surakarta, students still have difficulty learning acid-base material because the average chemistry test scores for the acid-base chapter are below the minimum passing grade. Acid-base material is considered one of the most difficult subjects because it contains complex, interrelated material and calculations that are necessary to understand the concepts gradually and deeply. In 2020, Fajrin et al. interviewed teachers at Wolowa High School 1 and found that students found it most difficult to understand acid-base theory, acid-base indicators, and pH calculations. This was evident in the time it took students to understand acid-base theory, acid-base solution indicators, and pH of acid-base solutions when the teacher explained them.

Febry (2024) has developed a green chemistry-based chemistry laboratory guide using Android media on the subject of acid-base indicators, which has been declared valid. The effectiveness and practicality of this laboratory guide have not yet been tested, so this study focuses on testing the effectiveness and practicality of the chemistry laboratory guide as part of its development. The model used in Febry's (2024) research is the Research and Development (R&D) method by Borg and Gall. Febry (2024) has conducted the research and information gathering stage, planning, and developing the initial product form, so this study will focus on limited testing, revising the initial product, and field testing to determine whether this green chemistry-based chemistry laboratory guide is effective and practical to use as a guide in laboratory activities. Based on the above, the researcher aims to test the practicality and effectiveness of the green chemistry-based chemistry laboratory manual using acid-base indicator metrics.

This study is not the first to develop a learning medium in the form of a green chemistry-based chemistry practicum guidebook. Compared to guidebooks developed by other researchers, the work procedures and tools and materials in those guidebooks are only described in writing, the content of the guidebooks focuses only on work procedures, and most of the tools and materials must be available in the laboratory. Meanwhile, the guide developed in this study provides two work procedures, namely video and written, and the tools and materials include pictures and are easy to find so that the practicum does not have to be carried out in a laboratory. This is because this guidebook is intended for schools in 3T (Underdeveloped, Frontier, and Outermost) areas that do not have or cannot access laboratories. In addition, this guide is in the form of an e-book containing videos of procedures and observation results linked to Google forms, not just a regular e-book containing text.

This study differs from previous studies in that it focuses not only on validation but also on empirical testing of feasibility and effectiveness. This study aims to examine the practicality and effectiveness of the green chemistry-based chemistry practicum guide on acid-base indicator material. This study is a Research and Development (R&D) study using the Borg and Gall model. This study only reached the stage of limited testing, initial product revision, and field testing to examine the practicality and effectiveness of the Practicum Guide.

METHOD

The type of research used is research and development (R&D). According to Borg and Gall (Sugiyono, 2008), the R&D process consists of ten steps: (1) research and information gathering; (2) planning; (3) developing the initial form of the product; (4) limited testing; (5) revision of the initial product; (6) field or large-scale testing; (7) revision of the operational product; (8) feasibility testing; (9) revision of the prototype product; and (10) implementation. In the study (Febry., 2024), the stages of research and information gathering, planning, and developing the initial product form have been carried out, so the focus of this study is on the stages of limited testing, initial product testing, and field testing. The following are the R&D steps according to Borg and Gall

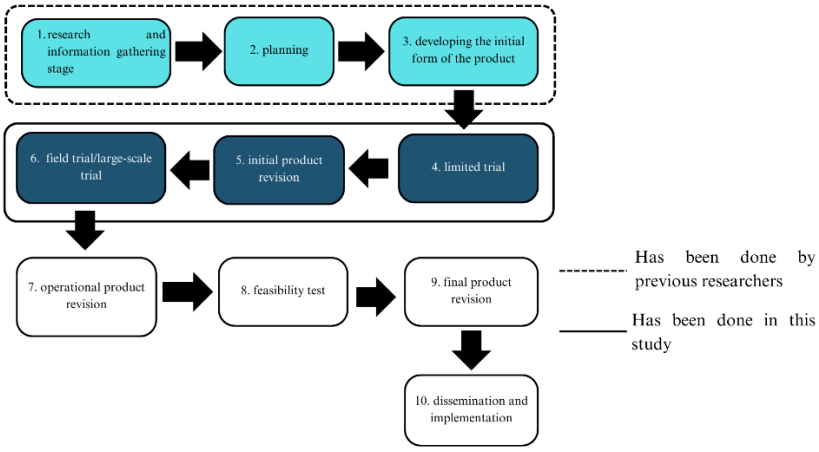

Figure 1. R&D steps according to Borg and Gall

The population of this study consisted of all 12th grade students at SMA Negeri 16 Samarinda in the 2024/2025 academic year, divided into five groups or five classes. The sample in this study consisted of students in class XII-1 as the limited pilot class and class XII-2 as the field pilot class. The sampling technique used in this study was cluster random sampling. The data in this study is quantitative, used to measure the effectiveness and practicality of the green chemistry-based chemistry practicum guide. The techniques used in data collection were tests and non-tests. The indicators used in the pre-test and post-test are as follows:

Table 1. Pre-test and Post-test Question Indicators

Indicators	Number of Questions
Students are able to correctly identify the acid-base properties of a solution.	6
Students are able to correctly name examples of acids and bases.	1
Students are able to analyze information and data related to acid-base indicators based on the color of the indicator.	3

This study conducted two tests, namely before (pre-test) and after (post-test) students were given lessons using the green chemistry-based chemistry practicum guide. The questions consisted of 10 multiple-choice questions and were completed individually. Before the treatment was administered, the pre-test measured students' initial understanding of acids and bases. After the treatment was administered, the post-test measured students' understanding of the Green Chemistry-Based Chemistry Laboratory Manual. Observations and questionnaires were used as non-test techniques. Observation sheets were used for research data. This study used observation sheets to directly observe student and teacher activities during the learning process. The observation sheets were created based on the STAD learning model, and the student activity observation sheets used a Likert scale with five categories, while the teacher

observation sheets used a Guttman scale. The questionnaire instrument was used to test the practicality of using the Green Chemistry-Based Chemistry Laboratory Manual by teachers and students. For teachers, the questionnaire focused on the ease of use and usefulness of the Practical Guide. For students, the questionnaire assessed the ease of use, independence, and usefulness of the Practical Guide. The scale used in this questionnaire was a Likert scale, with a rating range from 1 to 5.

Data processing in written tests, namely final scores, can be calculated by adding up the scores obtained by students according to the assessment rubric. To find out the results of the test, students can use the following formula:

$$\text{Value} = \frac{\text{Total Score}}{\text{Maximum Score}} \times 100$$

After calculating each individual score using the formula, the scores were averaged and then read based on the criteria in Table 2. Test scores can be measured based on the following test result criteria:

Table 2. Test Result Criteria according to Emilya (2010) in Risman et al., (2020)

Value	Criteria
$80 \leq N < 100$	Very good
$60 \leq N < 80$	good
$40 \leq N < 60$	Enough
$20 \leq N < 40$	Not enough
$0 \leq N < 20$	Not enough at all

The observation sheet used for students is the Likert scale, and the assessment criteria for the Likert scale observation sheet consist of 5 scores, namely score 1 for very poor (SK), score 2 for poor (K), score 3 for fair (C), score 4 for good (B), and score 5 for very good (SB). The assessment categories for the observation sheet are as follows:

Table 3. Likert Scale Assessment Categories according to Widastuti (2022)

Score	value interval	Description
5	81 – 100	Very good
4	61 – 80	good
3	31 – 60	Enough
2	21 – 40	Not enough
1	1 – 20	Not enough at all

The observation sheet used by teachers is the Guttman Scale. Assessments on the Guttman Scale can be seen in Table 4.

Table 4. Guttman Scale Assessment according to Yanto et al., (2021)

Score	Answer
1	Yes
0	No

The questionnaire was used to measure students' opinions on the effectiveness, level of understanding of the material, ease of learning the lessons, and use of the green chemistry-based practical guide during the learning process. The questionnaire was given to students and teachers, and a Likert scale was used for both students and teachers.

Practicality analysis will be obtained from data collected from questionnaires distributed to teachers and students. The data obtained will be analyzed by calculating the percentage of responses using the following formula:

$$\text{Value} = \frac{\text{Total Score}}{\text{Maximum Score}} \times 100$$

All respondents will be averaged and considered practical if the average score indicates a minimum category of 61%, because the researcher assesses practicality by referring to a minimum average score of 61%. Then adjusted to the practicality criteria in Table 5.

Table 5. Practicality Criteria

Average value	Categories
81% - 100%	Very practical
61% - 80%	Practical
41% - 60%	Quite practical
21% - 40%	Not very practical
1% - 20%	Not practical

The indicators used to measure teachers' and students' opinions on the implementation of learning using the green chemistry-based chemistry practicum guide are as follows:

Table 6. Questionnaire Indicators

No.	Indicators
1.	Usefulness of learning media
2.	Ease of use of learning media
3.	Independence in learning
4.	Readability of learning media

Individual observation data analysis can be calculated using the following formula:

$$\text{Value} = \frac{\text{Total Score}}{\text{Maximum Score}} \times 100$$

The calculation data was then averaged and categorized based on the following table:

Table 7. Criteria for Student Learning Activities

Score Range	Criteria
81% - 100%	Very Active
61% - 80%	Active
41% - 60%	Moderately Active
21% - 40%	Less Active
1% - 20%	Inactive

The effectiveness analysis in this study, in other words, used student response questionnaires, normality tests, homogeneity tests, t-tests, and N-Gain tests. The normality test determines whether the data is normal. In this study, SPSS was used to test normality. The data were tested using the Shapiro-Wilk test, where a sig value greater than 0.05 indicates that the data distribution is normal, while a sig value below 0.05 indicates that the data distribution is not normal (Ismail, 2024). If the data are normally distributed, the homogeneity test can be used, and if not, the Wilcoxon test can be used.

Homogeneity testing was conducted using SPSS to evaluate whether the data distribution in this study was homogeneous or not. The criterion was that the significance value (sig) based on the mean was greater than 0.05, and the data distribution was not homogeneous if the significance value (sig) was less than 0.05 (Ismail, 2022).

In this study, a t-test was used to determine significant differences before and after the trial of the green chemistry-based chemistry practicum guide. The t-test used was a paired sample t-test ($\alpha = 5\%$), which was used to determine the differences before and after the treatment. The decision criteria in this test are as follows: if the significance level (sig) is greater than 0.05,

then H0 is accepted; if the significance level (sig) is less than 0.05, then H0 is rejected (Amelia et al., 2021).

The normality test of gain (N-Gain) is used to determine the effectiveness of a treatment in research (Madjid, 2019). N-Gain is averaged and then calculated using the following formula:

$$\text{N } Gain = \frac{\text{Skor } Post\ Test - \text{Skor } Pre\ Test}{\text{Skor Maksimal} - \text{Skor } Pre\ test}$$

The N-Gain calculation results are categorized using the following classification table:

Table 8. Classification of N-Gain Values

N-Gain Value	Criteria
$0{,}70 \leq n \leq 1{,}00$	High
$0{,}30 \leq n < 0{,}70$	Medium
$0{,}00 \leq n < 0{,}30$	Low

The student response data obtained can be analyzed descriptively using percentages. The percentage of individual student responses in this study was calculated using Microsoft Excel with the following formula:

$$\text{Value} = \frac{\text{Total Score}}{\text{Maximum Score}} \times 100$$

After obtaining the student response percentage data, it will be averaged and categorized using the response percentage table in Table 9.

Table 9. Response Percentage Categories

Response Percentage	Categories
$85\% \leq NR$	Very good
$70\% \leq NR \leq 85\%$	Good
$50\% \leq NR \leq 70\%$	Enough
$NR < 50\%$	Not enough

RESULTS AND DISCUSSION

Limited Trial of Green Chemistry-based Chemistry Laboratory Manual

A limited study was conducted to evaluate the practicality and effectiveness of the media developed by previous researchers. This study was conducted using the Practicum Guide during the learning process. At this stage, the study was conducted on a limited basis, involving 18 students and 1 chemistry teacher as respondents.

Practicality of Green Chemistry-Based Chemistry Laboratory Manual by Teachers

In an effort to improve the effectiveness of learning in the laboratory, clear and easy-to-use laboratory manuals are essential. One approach that is increasingly being applied in chemistry education is Green Chemistry, which emphasizes environmentally friendly and efficient practices. Therefore, an evaluation of the practicality of Green Chemistry-based laboratory manuals was conducted to ensure that the instructions meet standards of readability, ease of use, and usefulness for students.

The results of this evaluation were obtained through an assessment of several key indicators, namely readability, ease of use, and usefulness of the Practical Guide. The following table summarizes the results of the analysis, showing that the developed Practical Guide has a very high level of practicality.

Table 10. Results of the Questionnaire on the Practicality of the Practicum Guide According to Teachers

No	Practicality Indicator	Value (%)	Category
1.	Readability of green chemistry-based chemistry lab manual	96	Very Practical
2.	Ease of Use of green chemistry-based chemistry lab manual	88	Very Practical
3.	Usefulness of the Green Chemistry-Based Chemistry Laboratory Manual	100	Very Practical
	Average	95	Very Practical

Based on Table 10, the indicators of readability, ease of use, and usefulness of the green chemistry-based chemistry practicum guide are in the very practical category. All indicators in the teacher practicality questionnaire averaged 95% in the very practical category. These results show that the green chemistry-based chemistry practicum guide is very practical for use in the chemistry learning process.

Practicality of Green Chemistry-Based Chemistry Laboratory Manual by Students

The survey was conducted using a questionnaire to assess the practicality of the green chemistry-based chemistry practicum guide from the students' perspective. This assessment covered several key indicators, namely readability, ease of use, independent learning, and the usefulness of the practicum guide. The results of this questionnaire provide an overview of the extent to which the practicum guide developed can be effectively applied by students in practicum activities. The following table presents the results of the practicality questionnaire based on student assessments.

Table 11. Results of the Questionnaire on the Practicality of the Practicum Guide According to Students

No	Practicality Indicator	value (%)	Category
1.	Readability of green chemistry-based chemistry lab manual	80	Practical
2.	Ease of Use of Green Chemistry-Based Chemistry Laboratory Manual	73	Practical
3.	Independence in Learning	79	Practical
4.	Usefulness of Green Chemistry-Based Chemistry Laboratory Manual	82	Very practical
	Average	79	Practical

The data in Table 10 is reinforced by the results of a questionnaire on the practicality of the green chemistry-based chemistry practicum guide by students. The four indicators, after being averaged, obtained a practical category with an average of 79%. Based on these results, it can be concluded that students also consider the green chemistry-based chemistry practicum guide to be practical in the learning process.

Revision of the Initial Product of the Green Chemistry-Based Chemistry Practicum Guide

The initial product revision stage is a stage to improve the quality and effectiveness of the Practical Guide that has been developed, and limited trials have been conducted. These trials aim to identify the strengths and weaknesses of the initial product, as well as to obtain constructive feedback from users. Based on the results of these trials, revisions were made to the initial product to refine the Practical Guide so that it better aligns with the needs and expectations of users. In the following section, the revisions made to the initial product will be outlined.

Table 12. Revision of green chemistry-based chemistry laboratory guidelines

Before Revision	After Revision
	

Table 12 was revised based on suggestions and input provided by teachers. These suggestions and input were used as a basis for researchers to improve the media to make it more perfect. The suggestion was to add the practical objectives in the Practical Guide so that they could be more visible to students using the Practical Guide.

Field Trials of Green Chemistry-Based Chemistry Practicum Guidelines

Results of Data Analysis from Observations of Teachers and Students in Class XII-2

The data on teacher and student activities in class XII-2 is as follows.

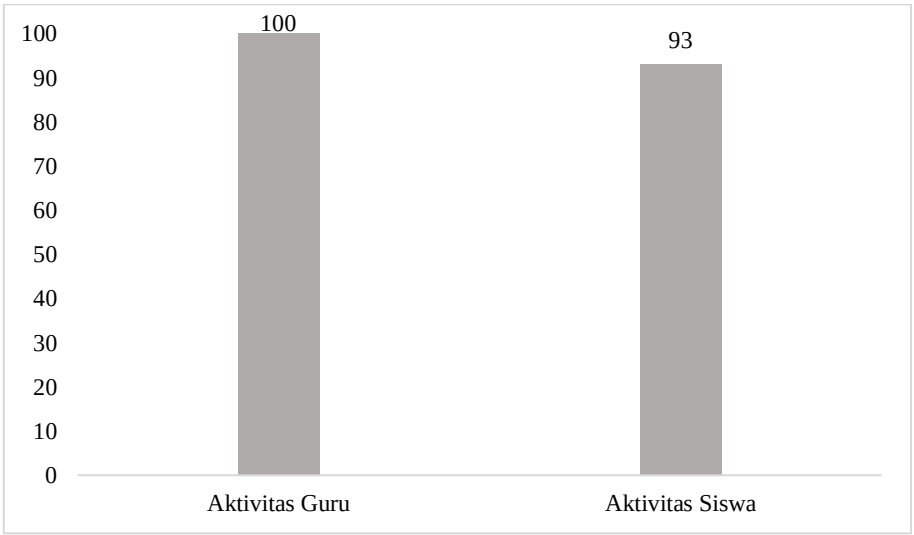

Figure 2. Observation of Teacher and Student Activities in Class XII-2

Figure 2 shows the average percentage of teacher activity in learning with the green chemistry-based chemistry practicum guide at 100% in the excellent category. The average percentage of student activity in learning using the green chemistry-based chemistry practicum guide was 93% in the excellent category.

Data on Student Learning Achievement Improvement

Measurements of students' understanding improvement were conducted through written tests consisting of pre-tests and post-tests. The scores obtained reflect the effectiveness of the learning that has been implemented. A comparison of the pre-test and post-test results shows the extent to which students have improved their understanding of the material. The average scores of the written tests for grade XII-2 students are presented in the following table.

Table 13. Average Written Test Scores of Grade XII-2 Students

Written test	Value	Category
Pre-test	49	Enough
Post-test	61	Good

Table 13 shows that students' learning outcomes improved after using the green chemistry-based chemistry practicum guide, from poor to good. To assess the effectiveness of this Practical Guide in improving student learning outcomes, an N-Gain test was conducted. Prior to the N-Gain test, a prerequisite test was performed, starting with a normality test to determine whether the pre-test and post-test mean scores were normally distributed or not, using the Shapiro-Wilk test in SPSS, as shown in Table 14.

Table 14. Normality Test

Class	Data	Sig	Description
XII-2	Pre-test	0,037	Abnormally Distributed
	Post-test	0,00	Abnormally Distributed

Table 14 shows a pre-test value of 0.037 and a post-test value of 0.00. Both significance values are less than 0.05, so it can be concluded that the data is not normally distributed. Therefore, a non-parametric test, namely the Wilcoxon test, was conducted to determine whether there was a difference between the pre-test and post-test results.

Table 15. Nonparametric Test

Wilcoxon W	528,000
Z	-4,953
Asymp.Sig.(2-Tailed)	0,000

The Wilcoxon W value is 528,000, with a Z value of -4.953, and a significance value (Asymptotic Sign 2-Tailed) of 0.000, according to the analysis results shown in Table 15. It is possible that the pre-test and post-test results for class XII-2 are significantly different, because this value is less than 0.05. In other words, it can be concluded that the improvement has led to a significant increase. The N-Gain test can be conducted after the results are known.

Table 16. N-Gain Test

Class	$\bar{x}$*pre-test*	$\bar{x}$*post-test*	N-Gain	Category
XII-2	23	68	0,59	Medium

Based on the results of Table 16, the average pre-test score was 23, while the average post-test score was 68. The N-Gain calculation resulted in a value of 0.59, which falls into the moderate category. This indicates that the improvement in learning outcomes after the treatment was moderate.

Results of Data Analysis of Student Response Questionnaire for Class XII-2

The data supporting the effectiveness of this study are the results of a student response questionnaire on learning using green chemistry-based chemistry laboratory manuals to improve student learning outcomes on acid-base indicator material. The results of the student response questionnaire for class XII-2 are shown in Figure 2.

Based on the results of the student response questionnaire regarding learning with the green chemistry-based chemistry practicum guide that has been conducted, all indicators measured fall into the practical category, with an average ease of understanding the material of 77%, activity in learning of 78%, green chemistry-based chemistry practicum guide of 78%, and student interest of 80%.

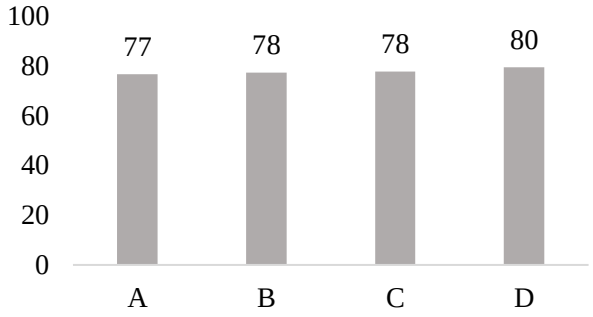

Figure 3. Student Response Questionnaire for Class XII-2

Explanation:
A: ease of understanding the material
B: activity in learning
C: Green chemistry-based chemistry practicum guide
D: student interest

Disscussion

Practicality of Green Chemistry-Based Chemistry Laboratory Manual

Practicality was assessed to measure how easy and practical it is to use these green chemistry-based chemistry lab instructions at SMAN 16 Samarinda. The indicators measured in the teacher practicality questionnaire were the readability of the green chemistry-based chemistry lab instructions, the ease of use of the green chemistry-based chemistry lab instructions, and the usefulness of the green chemistry-based chemistry lab instructions. The indicators measured in the student practicality questionnaire were the readability of the green chemistry-based chemistry laboratory instructions, the ease of use of the green chemistry-based chemistry laboratory instructions, the independence of learning, and the usefulness of the green chemistry-based chemistry laboratory instructions.

Readability of Green Chemistry-Based Chemistry Laboratory Manuals

Table 10 shows that the results of the teacher practicality questionnaire on the indicator of the readability of green chemistry-based chemistry practicum instructions are very practical. Table 11 shows the results of the student practicality questionnaire with an average on the same indicator, namely practical. The results of the teacher and student practicality questionnaires are proven through the aspect of language quality.

The choice of language is a very important aspect in learning media to make it easier for students to understand the content of the media itself. According to Rahmi & Silvina (2019) in Saputra et al., (2022), practical instructions should generally use concise and succinct language and simple sentences. The readability of practical instructions not only affects students' understanding but can also influence their motivation to learn (Widyantari & Lestari, 2024).

Ease of Use of Green Chemistry-Based Chemistry Laboratory Manuals

According to Davis in Sibuea et al., (2021), ease can be defined as the degree of confidence a person has that using a technology does not require much effort. In line with the previous opinion, the perception of ease of use of technology is defined as the extent to which a person believes that the technology is easy to understand and use (Sibuea et al., 2021). Based on Tables 10 and 11, this indicator falls into the category of very practical for teachers and practical for students.

The ease of use of the practical guidelines can make students enthusiastic and more active and beneficial during the learning process. This is because the practical guidelines that have been

developed (Febry, 2024) have a brief theory that is easy to understand, simple and uncomplicated steps, videos of the steps in conducting the practical, and tables of observation results and conclusions that are easily accessible. The features in the developed laboratory manual also have an attractive design, making it easier for students to use the developed laboratory manual.

Independent Learning

Independent learning is self-awareness and the ability to learn on one's own to achieve goals. With independent learning, students are expected to be able to control themselves in various situations they face and actively participate in the learning process (Brookfield in Andri et al., 2023). According to Karuna (2010) in Fidiana et al. (2020), teaching materials are necessary for students to be independent in their learning. The benefits of teaching materials are that they make it easier for teachers to design, implement, and evaluate teaching and learning activities so that students can achieve knowledge, skills, and competencies in learning. The results of Table 11 show that this indicator falls into the practical category.

Many students choose to bring laptops or electronic devices rather than textbooks due to advances in science and technology. Students find it difficult to carry thick and heavy textbooks to school. Students want everything to be practical, such as soft files that can be accessed through devices, so they don't have to bring large books to school. Computer-based technology is a method of creating or delivering materials using microprocessor-based resources. The materials or information transmitted are stored digitally rather than in printed form (Pramana & Dewi, 2019). The practical guidelines developed by (Febry, 2024) have content and features that make it easier for students to learn independently, such as concise theories presented clearly, practical guidelines written concisely but easily understood, and practical videos that make it easier for students to see the practical steps. With these features, students can conduct independent practical work to verify the theories they have learned by performing simple experiments directly. The practical guide developed in this study provides work procedures in the form of videos, not just in written form like existing practical guides. The availability of work procedure videos means that this guide facilitates students with audio-visual learning styles. Learning media that provide videos as a facility for audio-visual learning styles play a role in increasing student motivation and learning outcomes as well as creating a pleasant learning atmosphere (Kalang et al., 2025). The tools and materials used in this study are very easy to obtain and allow the practical work to be carried out anywhere, not necessarily in a laboratory. Easy-to-do chemistry practical work requires critical thinking skills that connect everyday chemical-physical phenomena that occur in the surrounding environment and science (Aliyatulmuna et al., 2023).

The Usefulness of Green Chemistry-based Chemistry Practicum Guidelines

The last indicator in the teacher and student practicality questionnaire was the usefulness of the Green Chemistry-Based Chemistry Practicum Guidelines. Based on Tables 10 and 11, the results of this indicator were in the very practical category. This is certainly supported by several factors such as practical activities that are easy to do, practical videos that enable students to learn independently, brief theories that can help students obtain information, and the use of observation tables and conclusions that are easily accessible.

The practicality of green chemistry-based chemistry laboratory instructions can also be observed from the results of teacher and student activity observation sheets during the learning process and response questionnaires given to students. Effectiveness in learning is a measure of the success of a process of interaction between students or between students and teachers to achieve learning objectives in an educational situation. The effectiveness of learning is meaningful and purposeful learning for students, enabling them to acquire specific skills,

knowledge, and attitudes in an easy, enjoyable, and effective manner, thereby achieving the expected learning objectives (Fathurrahman et al., 2019). Based on Figure 1, the average teacher activity in class XII-2 was 100, categorized as very good, while the average student activity in class XII-2 was 93, also categorized as very good.

Based on the results obtained, the green chemistry-based chemistry laboratory manual that has been developed is considered practical as a learning medium for simple laboratory experiments. This can be seen from the average percentage of the teacher practicality questionnaire of 96% in the very practical category and the student practicality questionnaire of 79% in the practical category. Additional support comes from the data on teacher activity observation results, which were 96% and student activity results, which were 88%, both categorized as "very good," as well as positive feedback from students with an average of 80.

The Effectiveness of Green Chemistry-Based Chemistry Laboratory Manuals

The effectiveness of conducting practical work using practical guidelines developed by previous researchers has a positive impact on student learning outcomes. This is evident from the increase in the average test scores of students, as measured by pre-tests before the treatment and post-tests after the treatment, where the average pre-test score of class XII-2 students increased from 23 to 69 in the post-test. According to Fathurrahman et al. (2019), the success of learning can be measured by the achievement of desired objectives, both in terms of learning objectives and students' maximum performance. This aligns with the pretest and posttest results, which showed an improvement before and after using the chemistry laboratory guidelines based on green chemistry.

The implementation of practical work using green chemistry-based chemistry practical guidelines aims to facilitate students in carrying out practical activities on acid-base indicator material. These practical guidelines help students carry out practical work either with guidance from subject teachers or independently. The features in the developed laboratory manual facilitate independent learning for students, making it easily accessible to them. Additionally, the green chemistry-based laboratory manual includes clear and easy-to-understand procedures or steps for conducting the laboratory experiments.

The effectiveness of these green chemistry-based chemistry lab instructions is also supported by student response survey data. Based on Figure 2, all student response indicators are in the good category. The indicator of ease of understanding the material is 77% in class XII-2, which is in the good category. The effectiveness of these lab instructions is supported by the fact that the material presented is easy for students to understand and encourages them to discover new ideas.

The indicator of activity in learning was 78% in class XII-2, which is categorized as good. This indicates that the practical exercises using the developed practical guidelines effectively engage students actively in the learning process, as the knowledge gained by students from the green chemistry-based practical guidelines enhances their active participation. This aligns with Hisyam Zaini's statement in Siregar et al. (2023), which states that active learning is a method that encourages students to actively participate in the learning process. Finally, the student interest indicator of 80% in Class XII-2, categorized as good, shows that the use of chemistry laboratory guidelines based on green chemistry can motivate students to learn chemistry, particularly the acid-base indicator.

Research conducted by Harahap & Sutiani (2023), who developed a green chemistry-based chemistry practicum guidebook on reaction rate material, shows that similar media have been developed before, but with different material and content. The novelty of the practical guide developed in this study lies in the procedures available in two forms (video and written), observation results that can be directly linked to Google Forms, easily obtainable tools and

materials, and the ability to be conducted anywhere. In addition, the limitations of this study include the small sample size, short testing period, and the absence of a control group.

Based on the results obtained, the green chemistry-based chemistry practicum instructions on acid-base indicators were found to be effective as a medium for teaching chemistry. This result can be seen from the N-Gain of 0.60, which is in the moderate category. In addition, this is supported by data from student response questionnaires, with an average of 78% in class XII-2, which is in the good category.

CONCLUSION

Based on the research conducted, it can be concluded that Green chemistry-based chemistry laboratory instructions on acid-base indicators are practical for use in simple laboratory learning with acid-base indicator material. The green chemistry-based chemistry laboratory instructions on acid-base indicator material are very effective for use in simple laboratory learning with acid-base indicator material because they can improve student learning outcomes in the moderate category, with an effect size in the very strong category and receiving good responses from students.

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