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Research Article

Development of Learning Cycle 5E Practical Instructions on Acid-Base Titration Using Natural pH Indicators Based on Green Chemistry

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Abstract
This research aims to produce a learning media product in the form of a practical guide for the 5E learning cycle on acid-base titration material using natural pH indicators based on green chemistry that is valid and practical. The type of research used is Research and Development (R&D) with the Borg and Gall model using a descriptive quantitative method. The study was conducted from November 2021 to August 2022 at SMA N 53 Jakarta with 91 student respondents, eight teachers, three subject matter and language experts, and three media experts. The practical guide is equipped with a barcode to facilitate students' access to videos, additional materials, and evaluation questions. The research results show that the pH range of the Red Shoot leaf extract is 2-5 with a color change from pink to yellow and 6-14 with a color change from yellow to brick red. The feasibility test results of the practical guide by the experts showed an average percentage of 85% for subject matter and language experts and 88% for media experts. The reliability test from the experts was categorized as "Very Reliable" with a value of 0.93 for both subject matter and language experts and media experts. The student trial results showed an average of 80% on a small scale and 90% on a large scale. The teacher trial results showed an average of 95% on a small scale. The trial results conclude that the practical guide for the 5E learning cycle on acid-base titration material using natural pH indicators based on green chemistry has met the criteria of "Very Good" and is suitable as a learning media. The attractive, innovative, and creative acid-base titration learning can use this practical guide as learning media.

Keywords: Green Chemistry, Learning Cycle 5E, Practical Instructions

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1. INTRODUCTION

Chemistry is one of the subjects that require a strong grasp of concepts because it studies the structure, composition, properties, and changes of matter as well as the accompanying energy (Chang, 2019). A good understanding of chemistry concepts is not only obtained through theoretical learning but also through practical activities that link theory with experimental results. Chemistry learning is based on factual knowledge, so laboratory practical activities are essential for understanding chemistry material (Melati & Hadinugrahaningsih, 2024; Papadimitropoulus & Pavlatou, 2021).

Practical activities can provide a more concrete illustration for students regarding abstract concepts studied in the classroom or through independent learning. The aim of practical activities is to develop students' thinking patterns and understanding of scientific material, problem-solving skills, science process skills, understanding of the nature of science, self-confidence, and to improve students' cognitive skills (Ural, 2016). Practical activities in chemistry learning are very important because they help students become confident in the theories they have previously learned. Theories need deep explanations derived from hypothesis data obtained through laboratory experiments.

Understanding theoretical material from practical activities is quite difficult to obtain because, in the laboratory, students focus on the experimental procedures that must be followed. Therefore, a practical guide is needed. The practical guide aims to achieve learning objectives and improve the understanding of chemical principles, experimental procedures, and the connection between procedures and chemical principles in a detailed, clear, and directed manner (Haagsman, Koster & Boonstra, 2021). Generally, laboratory practical activities are already provided with practical guides. However, the available practical guides do not meet the standards and often neglect safety and environmental preservation aspects.

A practical guide can facilitate students in carrying out practical activities by following clearly and directed procedures since students often do not know the purpose of each procedural step performed during practical activities. A practical guide is a learning medium containing guidelines for conducting laboratory activities (Eubanks, 2015). The Decree of the Minister of National Education Number: 36/D/O/2001 explains that a practical guide is a manual for practical activities containing preparation, implementation, data analysis, and reporting procedures. Practical guides are expected to make practical activities well-organized, effective, and beneficial for students.

Previous research revealed that teachers are still the primary source during chemistry learning. Teachers usually focus only on discussing and presenting theories from textbooks using visual aids to explain the learning material (Hong & Yang, 2018). During practical activities, students only follow the teacher's instructions without adequate preparation, making it difficult for most students to understand the purpose of the experiments conducted.

Teachers also have not directed students to engage in various learning activities that apply the basic competencies according to the chemistry curriculum, which involves designing, conducting, concluding, and presenting experimental results. According to Hong and Yan (2018), lecture-based chemistry learning only enhances students' knowledge without achieving other learning objectives, such as improving students' skills. Additionally, other inhibiting factors in chemistry practical learning include the lack of teacher confidence and limited facilities and infrastructure in schools (Davenport, 2018).

Based on interviews with two chemistry teachers at SMA Negeri 53 Jakarta, acid-base titration practicals have not been conducted routinely due to the Covid-19 pandemic. The usual acid-base titration practicals still use synthetic phenolphthalein indicators and have never used natural indicators as titration endpoints. This is because there has not been any development of acid-base titration practical guides using natural pH indicators. Previously available practical guides for titration were only photocopies of practical worksheets sourced from the internet or textbooks, containing steps for acid-base titration using synthetic indicators. The instructions in these worksheets were not detailed and clear, making it difficult for students to understand what activities to perform in the laboratory.

The previously available practical guides at SMA N 53 Jakarta also did not comply with the 2013 Curriculum, which states that practical activities should develop students' scientific learning abilities. The Minister of National Education (2013) formulated that the 21st-century learning paradigm emphasizes students' ability to seek information from various sources, formulate problems, think analytically, and collaborate to solve problems. This underlines the need for developing practical guides with a learning model approach that encourages students to be active in learning activities and supports the understanding of chemical concepts. The developed practical guide will include barcodes to facilitate students in accessing videos, additional materials such as explanations of primary and secondary standards, and evaluation questions.

The learning model that is efficient, able to create active learning to encourage students to relate material to daily life while considering safety and environmental preservation aspects is the 5E learning cycle model based on Green Chemistry. The learning cycle model shapes students to be independent, creative, and active learners. According to Riffert, Hagenauer & Kriegseisen (2021), this learning model also builds high curiosity in students, allowing them to connect and develop concepts through physical and social interactions, such as practicals, demonstrations, Q&A sessions, and problem-solving discussions.

The effectiveness of the 5E learning cycle model has been tested in the learning process and proven effective in enhancing students' creativity and skills (Riffert et al., 2021). The 5E learning cycle model is used in this practical guide because it has five phases that align with the scientific approach. In the engagement phase, observations can be made. In the exploration phase, Q&A sessions can be conducted. In the explanation phase, data and information collection can be done. The elaboration phase involves the association process, and the evaluation phase includes communication. One of the phases of the 5E learning cycle model, the elaboration phase, focuses on providing students with knowledge that can be developed and applied in a more real context (Mang, Chu, Martin & Kim, 2021).

Acid-base titration studies the strengths of acids and bases, pH measurement and calculation, and the reactions involved, which are proven through experiments. This topic is considered difficult to learn among students (Rakhmalinda et al., 2024). The acid-base titration experiment requires a pH indicator to determine the titration endpoint. Synthetic pH indicators commonly used have drawbacks, such as being relatively expensive, not readily available in all regions, and harmful to the environment (Roy & Rhim, 2020). Therefore, it is necessary to develop natural acid-base indicators that are environmentally friendly and renewable, yet still function as synthetic indicators.

Natural pH indicators need to be developed because the chemicals used for synthetic indicators tend to produce waste and are hazardous to health (Jain et al., 2013). One solution to minimize practical waste is to apply the principles of green chemistry. The concept of green chemistry in practical activities involves using fewer materials, ensuring safety, avoiding vapor and energy emissions, and using renewable materials. Using fewer chemicals results in less waste from reaction residues, creating a better environmental condition and improving safety during laboratory work. Renewable and environmentally friendly natural materials for practical activities, such as natural pH indicators for acid-base titration, can be easily made using maceration/extraction techniques from various plants (Irfani, 2024; Laurensia, 2024).

Natural pH indicators can be made through the extraction of natural materials from plants, including roots, leaves, flowers, fruits, or seeds containing anthocyanin pigments with suitable solvents. The pigment anthocyanin and its derivatives can change color at specific pH changes (Roy & Rhim, 2020). This color change is the main basis for processing plant natural materials as natural pH indicators for acid-base titration practicals. One plant containing anthocyanin pigments is Red Shoot (Syzygium myrtifolium). The Red Shoot plant is an ornamental plant belonging to the Myrtaceae family, known as Red Shoot because the newly grown leaf shoots at the tips are bright red.

The research by Biswatrish, Pritesh, Inamul & Kunal (2018) showed that the Red Shoot leaf extract with acetonitrile solvent contains six anthocyanins indicated by a red color change. In an acidic environment, anthocyanins are orange-red, while in a basic environment, anthocyanin pigments are blue-purple or yellow. Using natural pH indicators can encourage students to apply green chemistry principles, such as reducing waste, being more economical, and finding renewable materials (Anastas & Eghbali, 2009).

According to the chemistry curriculum, teachers should develop practical guides oriented toward student-centered learning (Eubanks, 2015). Based on the outlined problems, the researcher will conduct a product development study titled "Development of 5E Learning Cycle Practical Guide on Acid-Base Titration Material Using Natural pH Indicators Based on Green Chemistry."

2. METHOD

2.1 Research Design

The type of research used in the development of this practical guide is categorized as Research and Development (R&D) with a descriptive quantitative method. This development research utilizes the Borg and Gall model up to the ninth stage, which involves producing the final product without dissemination, implementation, and institutionalization (Borg & Gall, 2007). This approach aligns with the research objective of developing and testing the feasibility of the product without mass production and distribution, either free or commercial.

2.2 Participants

The respondents in the preliminary analysis and needs assessment stage comprised 30 eleventh-grade students (17 males, 13 females) who had studied acid-base titration material. The quality test of the practical guide was conducted by an expert team consisting of three subject and language experts (1 male, 2 females) and three media experts (1 male, 2 females). The small group trial of the practical guide involved 15 eleventh-grade science students (8 males, 7 females) and eight chemistry teachers from various high schools in Jakarta (3 males, 5 females). The large group trial involved 76 eleventh-grade science students (35 males, 35 females) from SMA Negeri 53 Jakarta. The trials were conducted at SMA N 53 Jakarta during the 2021/2022 academic year, with the research and development of the practical guide carried out from November 2021 to August 2022.

2.3 Data Analysis

The data analysis technique used in this research is descriptive quantitative analysis. This quantitative analysis provides an evaluation of the developed product, allowing for further improvements towards product refinement. The data analysis technique is described as follows: a) Collecting questionnaires from experts, students, and teachers. b) Processing and calculating the data to obtain percentages for each indicator. c) The percentage is obtained by comparing the obtained evaluation scores with the maximum evaluation score, then multiplying by 100% according to the following formula (Johnson & Christensen, 2019):

$$\text{Percentage} = \frac{\Sigma\, OBTAINED\ SCORE}{\Sigma\, MAXIMUM\ SCORE} \times 100\%$$

The percentage results are then categorized according to the feasibility criteria using a rating scale to assess the product's level of feasibility. A product is considered feasible if the rating scale is 61% or higher (Johnson & Christensen, 2019). The descriptive quality criteria with the rating scale are presented in Table 1 (Johnson & Christensen, 2019).

Table 1. Descriptive Quality Criteria)

Rating Scale (%)	Category
0-20	Poor
21-40	Fair
41-60	Neutral
61-80	Good
81-100	Excellent

Table 2. Reliability Categories

Reliability Value (r)	Category
0.0-0.20	Very Less Reliable
0.21-0.40	Less Reliable
0.41-0.60	Quite Reliable
0.61-0.80	Reliable

The product validation stage of the practical guide by experts included a reliability test. The purpose of the reliability test is to assess the consistency of the average agreement between two or more observers in evaluating the developed product (Johnson & Christensen, 2019). Agreement among observers can be achieved when each observer has the same opinion on what is being evaluated and observed. The statistical test used to calculate reliability in this research data is the Hoyt test (Reynold et al., 2010) with the following formula:

$$r = \frac{RJK_b - RJK_e}{RJK_b}$$

Explanation:

r : Reliability of observer agreement
RJKb : Mean Sum of Squares for Rows
RJKe : Mean Sum of Squares for Error

The results obtained are then categorized according to the reliability categories in Table 2 (Johnson & Christensen, 2019).

3. RESULTS

This development research aims to produce a product in the form of practical instructions using the 5E learning cycle model on acid-base titration material using natural indicators based on green chemistry. The development of the practical instructions product was carried out based on the Borg and Gall model.

After validation by experts, field testing (main field testing) was conducted on students and teachers. This stage is also known as small-scale testing aimed at obtaining evaluations from students and teachers regarding the use and feasibility of the practical instructions. The respondents at this stage consisted of 6-12 students. This aligns with Borg and Gall (2007) who stated that small-scale testing is conducted to allow for improvements in the product if there are still errors or inconsistencies based on evaluations from students and teachers before large-scale testing is conducted.

This small-scale testing was conducted by dividing students into several groups, and each group received a hardcopy of the practical instructions. This was done because the practical instructions are supported by the 5E learning cycle model, which involves phases that are conducted in groups. This is supported by Gracia (2021), who showed that in the 5E learning cycle, there is an exploration phase where the teacher acts as a facilitator, and students are given the opportunity to collaborate and discuss in small groups of 4-5 students.

There are five aspects of the evaluation of these practical instructions: material feasibility, presentation feasibility, practical implementation, understanding of green chemistry, and the practicality of the 5E learning cycle. The following is a description of the evaluation results for these aspects:

3.1 Material Feasibility Aspect

The material aspect consists of three indicators: the alignment of the material with learning objectives, relevance to daily life, and alignment with illustrations and chemical terms. Overall, the percentage of evaluation results for the material aspect was 80%, with an interpretation score of "Good." This shows that the material aspect of the practical instructions is categorized as feasible.

The evaluation results for the first indicator, which is the alignment of the material with learning objectives, received a score of 80%. This shows that the material in the 5E learning cycle-based green chemistry practical instructions has been presented in accordance with the Core Competencies (KI) and Basic Competencies (KD). This is in line with the regulations in the 2013 Curriculum syllabus during the Covid-19 emergency.

Additionally, the material presented in the practical instructions indicates that it aligns with the intended learning objectives. Good material affects the content, quality, and efficiency of the learning program, so the material must meet the needs, age, proficiency level, interests of students, and learning objectives. This is in line with Sabarudin (2018), who stated that material can be considered in accordance with KD if it meets the principles of relevance, consistency, and sufficiency.

The acid-base titration practical work presented enhances students' knowledge about the application of acid-base titration, which can be useful for reducing waste in daily life. This is supported by the evaluation percentage for the second indicator, which is relevance to daily life, at 82% with an interpretation score of "Very Good." The acid-base titration material in the practical instructions also includes simple illustrations that students can apply in their daily lives. This aligns with Papadimitropoulus and Pavlatou (2021), who stated that chemistry learning, such as acid-base titration material, is based on factual knowledge, so laboratory practical work is essential for understanding chemistry material.

The evaluation percentage for the third indicator, which is alignment with illustrations and chemical terms, was 78% with an interpretation score of "Good." This shows that the illustrations in the practical instructions are easy for students to understand because they align with the narrative material presented in the practical instructions. However, chemical terms such as green chemistry are not yet common among students and require further understanding. This has been anticipated by the author by providing explanations of the material and chemical terms in certain sections of the practical instructions, such as Glossary, "Let's learn more!", and "Remember this!"

The breakdown of each indicator regarding the material feasibility aspect has met the criteria of "Good" or feasible for testing. The material feasibility aspect is dominated by evaluations of the material alignment and supporting indicators for material feasibility. These evaluation results align with Sabarudin (2018), who stated that material can be considered in accordance with KD if it meets the principles of relevance, consistency, and sufficiency.

3.2 Presentation Feasibility Aspect

The presentation feasibility aspect consists of two indicators: instructional quality and technical quality. Overall, this aspect received a percentage of 81.5% with an interpretation of "Very Good." This shows that the practical instructions are easy to understand and assist students while in the laboratory.

The first indicator, instructional quality, received a percentage of 80%. This result shows that the developed practical instructions have been presented in accordance with the components in the learning module. The parts of the practical instructions have also been arranged clearly, directed, and easily understood by students. The instructions in the practical instructions can also guide students to learn independently. This aligns with Haagsman et al. (2021), who stated that practical instructions can serve as a self-learning package consisting of a series of systematically designed learning experiences to help students achieve learning objectives.

Instructional quality received an interpretation of "Very Good." This is supported by the increased curiosity of students about acid-base titration and green chemistry. The detailed procedural descriptions in the practical instructions can be implemented sequentially and correctly, and are easier to understand with the inclusion of practical videos presented in the practical instructions. The videos available in the form of QR codes help students understand the practical procedures in detail. This aligns with Rayment et al. (2022), who stated that presenting practical videos in practical instructions can enhance students' understanding of the practical work being conducted.

Technical quality received an evaluation percentage of 83%. This result shows that the practical instructions have been made using easy-to-understand language, are neatly arranged, and are designed attractively. The components in the practical instructions are generally complete, using appropriate types and sizes of fonts, and harmoniously selected colors, thereby increasing students' reading interest. This aligns with Haagsman et al. (2021), who stated that the completeness of the presentation components in practical instructions affects students' understanding; the more complete the components, the easier it is for students to understand the content of the practical instructions.

The use of varied and harmonious colors in the technical quality indicator aims to attract readers' attention. The use of colors can be a strategy to facilitate the learning process by motivating students to improve their memory. This aligns with Olurinola and Tayo (2015), who stated that colors serve to attract attention, clarify information, and differentiate images.

The breakdown of both indicators regarding the presentation feasibility aspect is "Very Good" or highly feasible for testing. The presentation feasibility aspect is dominated by evaluations of the presentation of practical procedures that facilitate students and the identification of the completeness of the practical instruction components. The presentation components aspect, according to BSNP (2007), needs to be evaluated by experts to encourage critical, creative, innovative thinking, deep thinking, metacognition, and self-evaluation in students.

3.3 Practical Implementation Aspect

The practical implementation aspect consists of two indicators: the physical appearance of the practical instructions and the feasibility of the practical design. Overall, this aspect received a percentage of 79.5% with an interpretation score of "Good." This result shows that the practical activity design is feasible for testing.

The first indicator, the physical appearance of the practical instructions, received a score percentage of 81%. This result shows that the practical instructions can be considered very good and feasible for use. The acid-base titration practical using natural indicators based on green chemistry is a creative innovation in chemistry learning. This aligns with Burmeister et al. (2012), who stated that green chemistry can shape students into creative and responsible individuals, especially towards the environment.

The second indicator received a percentage of 78%. This result shows that the practical instructions can be used well. However, due to limitations such as the unpreparedness of the laboratory, students could not conduct the acid-base titration experiments directly and could only observe the experiments through practical videos presented.

The breakdown of both indicators regarding the practical implementation aspect is "Good" or feasible for testing. The practical implementation aspect is dominated by evaluations of the feasibility of green chemistry-based practical work, which impacts individual students. Learning using green chemistry is an approach included in Education for Sustainable Development (ESD) that can be applied to ensure safe and environmentally friendly laboratory practical activities.

3.4 Green Chemistry Concept Understanding Aspect

The green chemistry aspect has only one indicator, which is the understanding of green chemistry principles. This indicator received a percentage of 79% with an interpretation score of "Good." This result shows that the practical instructions can be used to enhance students' knowledge of green chemistry. However, the principles of green chemistry are still rarely applied in schools, making this concept new to students.

The practical instructions also help students understand the use of natural materials for acid-base indicators and proper disposal of practical waste. Additionally, students understand the optimization of materials used for practical activities. This aligns with Anastas and Warner (2001), who explained the principles of green chemistry, including the first principle (waste prevention), the fourth (design of environmentally friendly materials), and the fifth (use of safe substances).

3.5 Practicality of the 5E Learning Cycle Aspect

The 5E learning cycle aspect has only one indicator, which is the influence of the 5E learning cycle, receiving a percentage of 80% with an interpretation score of "Very Good." This result shows that practical instructions using the 5E learning cycle model can make students more active and directly involved in the learning process. Additionally, the questions in the practical instructions using the 5E learning cycle model also help students relate their concepts to daily life. This aligns with Mang et al. (2021), who stated that the elaboration phase in one of the 5E learning cycle phases can involve an association process that focuses on providing students with knowledge that can be developed and applied in more real contexts.

The overall data recapitulation of small-scale testing on students for all indicators in each aspect reached an average score percentage of 80% with an interpretation score of "Good." The percentage score results are categorized according to the feasibility criteria using a rating scale to assess the feasibility level of a product. This aligns with Johnson and Christensen (2019), who stated that a product can be considered feasible if the rating scale value is ≤ 61%.

4. CONCLUSION AND SUGGESTIONS

This study produced a practical guide for the 5E learning cycle on acid-base titration using natural pH indicators based on green chemistry principles. The practical guide was provided to schools and students in both PDF and hardcopy formats. It includes barcodes to facilitate students' access to supporting materials, practical videos, and evaluation questions. The presentation of practical videos can enhance students' understanding of the presented experiments.

Based on the theoretical and empirical validity and feasibility tests, it can be concluded that the practical guide meets the criteria of "Very Good" and is suitable for use as a supporting learning medium for acid-base titration material. The feasibility test results by subject matter and language experts yielded an average percentage score of 85%. The feasibility test by media experts yielded an average percentage score of 88%. The evaluations by the experts were tested for reliability, resulting in a "Very Reliable" rating with a reliability score of 0.93 for subject matter and language experts, as well as media experts.

Feasibility tests with teachers and students also resulted in a "Very Good" rating. The teacher trial yielded an average percentage score of 95% on a small scale. The student trial yielded an average score of 80% on a small scale and 94% on a large scale. This practical guide is suitable as an engaging and creative learning medium for acid-base titration material. The presented experiments can also help students understand the acid-base titration process.

Based on the advantages and disadvantages mentioned, the development of the 5E learning cycle practical guide based on green chemistry can be applied to other chemistry topics. Here are some points to consider for further research development:

- The practical guide can be developed in several schools to gather more feedback and suggestions for producing a higher-quality practical guide.
- The development of the 5E learning cycle practical guide based on green chemistry has only reached the product feasibility test stage. Future research can focus on testing the product's effectiveness on specific variables such as critical thinking and science process skills.

Data Availability Statement. All data can be obtained from the corresponding author.

Conflicts of Interest. The authors declare no conflicts of interest.

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