DEVELOPMENT OF A RAINWATER ELECTROLYSIS PRACTICUM TOOL TO ENHANCE STUDENT ENGAGEMENT IN ELECTROCHEMISTRY LEARNING

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Abstract: Electrolysis is a fundamental concept in electrochemistry, yet its real-world applications are often overlooked in classroom settings. This study aims to design and develop a rainwater electrolysis practicum tool that contextualizes electrochemical concepts, enabling students to directly observe chemical processes related to environmental issues such as acid rain. An experimental method was conducted by varying the applied potential difference (4, 6, 8, and 10 V) and measuring pH changes in rainwater. The apparatus was designed and fabricated by the authors, adapting established electrolysis principles into a hands-on practicum tool. The results indicate that increasing potential difference influences localized pH shifts, where the cathode environment becomes more basic while the anode becomes more acidic, visualizing ion distribution during electrolysis. Student responses, collected through questionnaires, revealed high levels of motivation, ease of use, attractiveness, and perceived usefulness of the practicum product. These findings demonstrate the effectiveness of the practicum in enhancing students' engagement and understanding of electrochemistry concepts. In conclusion, the rainwater electrolysis practicum developed in this study bridges the gap between theoretical knowledge and practical applications, fostering a contextualized learning experience that aligns with the objectives of science education while also embedding environmental relevance.

Keywords: Electrochemistry; Rainwater; ESD; Student responses

INTRODUCTION

Amidst the challenges of global climate change, Indonesia is grappling with serious issues related to unpredictable rainfall, causing significant impacts on ecosystems and daily life (Haryanto, 2016; Mardiatmoko, 2022). One specific concern is the escalating acidity levels in rainwater, posing a threat to environmental equilibrium. The electrolysis rainwater device emerges as a potential solution to address this issue. Operating on the principles of electrochemistry, this device utilizes electrodes to alter the composition of rainwater through electrolysis, neutralizing its pH (Mostafa et al., 2018; Sun et al., 2021). Through the implementation of this device, control over the acidity levels in rainwater can be achieved, yielding positive effects on the quality of water used in daily life and contributing to the attainment of Sustainable Development Goal 11 – the development of sustainable cities and communities.

Electrochemistry, the scientific discipline involved in this experiment, is not only relevant in laboratory settings but is also encountered in everyday life (Oberacher et al., 2015; Yan et al., 2017). The electrolysis process, occurring during the experiment, finds applications in many technologies we use, such as batteries, electroplating, and various industrial processes (Suzuki, 1995). Therefore, this experiment helps students see the connection between the scientific knowledge learned in school and its real-world applications.

The rainwater electrolysis experiment directly aligns with the Learning Outcomes of the Merdeka Curriculum, where students are expected to explain the application of chemical concepts in daily life. In the realm of electrochemistry, this practical exercise empowers students to demonstrate their comprehension of chemical energy transformation by applying electrochemistry to rainwater. Consequently, the experiment not only provides a tangible laboratory experience but also stimulates the understanding and application of concepts in everyday life, aligning with the vision of the Merdeka Curriculum. Beyond its substantial benefits in understanding science, engaging students in experimental science learning goes beyond the classroom, significantly impacting their motivation and overall educational experience (Chen & Chou, 2015; Lou et al., 2017). This hands-on approach not only captures students' interest but also allows them to actively participate in the learning process. involving students in practical activities creates an interactive and dynamic learning environment that enhances their comprehension of scientific concepts (Cahyana et al., 2020; Elina, 2021; Weese & Feldhausen, 2017). The practical method and discovery model approach can effectively cultivate students' scientific process skills (Oktafianto, 2014).

The rainwater electrolysis experiment not only fosters an understanding of scientific processes but also serve as an effective tool to instill SDG values in students. As future change agents, students can develop an understanding of their responsibility towards the environment and society through this practical activity, appreciating how scientific concepts can address sustainability challenges (Foster, 2011; Sosa, 2011). While electrochemistry practicum tools have been developed in various educational contexts, recent studies predominantly focus on conventional setups using saltwater electrolysis or battery models, which often lack direct relevance to real-world environmental issues (Krushinski et al., 2024; Marquez et al., 2024). Research on integrating rainwater electrolysis as a learning tool remains limited, particularly in addressing real-world issues like acid rain and its connection to sustainable development education. The primary objective of this study is to design and develop an innovative rainwater electrolysis practicum tool to enhance students' comprehension of electrochemical concepts and improve their learning engagement through contextual, hands-on activities. While the environmental context serves as the real-world application for the practicum, this study primarily focuses on evaluating the tool's effectiveness as a learning medium in secondary science education.

METHOD

Principle of electrolysis

The principle underlying this experiment is based on the electrolysis of water, where an applied potential difference influences both the rate of the electrochemical reaction and the relative production of oxygen and hydrogen gases (Yan et al., 2017) . When the potential difference (voltage) is increased, the rate of electrolysis will increase, leading to the generation of more oxygen and hydrogen (Sun et al., 2021). However, this can also influence the pH of the solution. During the electrolysis of water, water will decompose into oxygen and hydrogen according to the following chemical reaction:

$$2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g)$$

The generated hydrogen gas will increase the concentration of H+ ions (hydrogen cations) in the solution, while the oxygen gas will react with water to form hydroxide ions (OH-) and increase the concentration of OH- ions in the solution. As a result, the solution will become more acidic (lower pH) near the hydrogen electrode and more basic (higher pH) near the oxygen electrode (Mostafa et al., 2018).

Based on the observed phenomena, the hypothesis suggests that an increase in potential difference will impact the pH of the solution. Specifically, it is anticipated that the solution in the vicinity of the hydrogen electrode will become more acidic, leading to a lower pH, while the solution near the oxygen electrode will become more basic, resulting in a higher pH (Ash et al., 2010).

Variable

In this study, the independent variable is the potential difference applied during the electrolysis process, with values set at 4, 6, 8, and 10 V. The dependent variable under observation is the final pH of rainwater following electrolysis. Control variables include maintaining a consistent sample volume of rainwater at 100 ml, utilizing aluminum plates of identical dimensions (2 x 8 cm), and keeping the electrolysis duration fixed at intervals of 10, 20, 30, 40, 50, and 60 minutes.

Research Materials and Tools:

The equipment employed comprises two clear containers, a stop tap, inner and outer threads, alligator cables, a power supply, and a drill. The crucial material involved is the aluminum plate (Al), which acts as the electrode, along with rainwater and cotton for facilitating the experimental setup.

Research Procedure:

Constructing the Prototype:

To ensure a systematic investigation, two clear containers are prepared by drilling symmetrical holes with a diameter matching the valves. The containers are then interconnected with valves, and meticulous checks are conducted to ensure a leak-free connection. The joints are securely sealed using hot glue. Container lids are fitted and drilled to accommodate the attachment of electrodes, and aluminum plates are affixed to both containers. Wet cotton is inserted into the valve connections to maintain the wetness required for the electrolysis process.

The design of this electrolysis apparatus is a modified prototype developed by the authors, specifically designed for this educational research. While the basic principles of water electrolysis are well-established in scientific literature, the adaptation of these principles into a practical learning tool using rainwater as the electrolyte medium

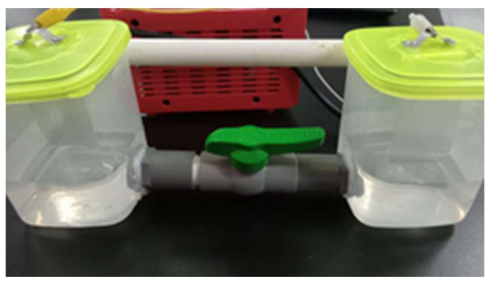

Figure 1 Electrolysis Tools Setting

Testing and Data Collection:

The experimental phase involves filling both containers with rainwater and sealing them with the installed aluminum electrode plates. Alligator cables are connected to the electrode plates and the power supply. The potential differences were systematically varied at 4, 6, 8, and 10 V, and electrolysis was conducted for time intervals of 10, 20, 30, 40, 50, and 60 minutes.

pH measurements were taken using a digital pH meter immediately after each electrolysis period. Measurements were conducted separately at the cathode and anode compartments to capture pH changes near each electrode. Each test was repeated three times to minimize random error and improve data reliability. The average pH values were recorded in a data table for subsequent analysis.

Data Analysis Technique :

The collected data were analyzed using descriptive statistical analysis. For each voltage level and time interval, the mean pH values and standard deviations were calculated. The relationship between potential difference and pH change was visualized through line graphs to illustrate the trend of pH variation over time.

To determine the influence of voltage on pH change, the data were further compared across the four potential differences. Patterns of acidity and alkalinity were interpreted to verify whether higher voltage corresponded to greater pH deviation near the electrodes. This analysis provided quantitative evidence of how variations in potential difference affect the electrolysis process in rainwater.

Student Response Data Collection and Analysis :

To evaluate student engagement with the developed practicum tool, quantitative data were collected using a structured questionnaire distributed after the practicum session. The questionnaire consisted of statements covering three aspects: motivation, ease of use, and usefulness, each rated on a five-point Likert scale ranging from 1 indicate strongly disagree to 5 indicate strongly agree. The instrument was administered to 30 students who participated in the rainwater electrolysis practicum. Responses were analyzed using descriptive statistics, including the calculation of mean scores and percentages for each indicator. This analysis provided supporting data to assess the effectiveness of the developed tool in fostering student engagement and enhancing understanding of electrochemistry concepts.

RESULTS AND DISCUSSION

The Impact of an Potential Difference on the pH of the Solution

The potential difference (voltage) in an electrochemical system can influence the properties of solutions, including pH. pH measurements provide information about the acidity or alkalinity of a solution. In this context, we will explore the results of an experiment that demonstrates the impact of increasing potential difference on the pH of a solution. Variations in applied voltage during water electrolysis affected local pH levels near the electrodes, demonstrating the direct influence of potential difference on solution properties (Sun et al., 2021). figure 2 show the changes of the pH in each voltage.

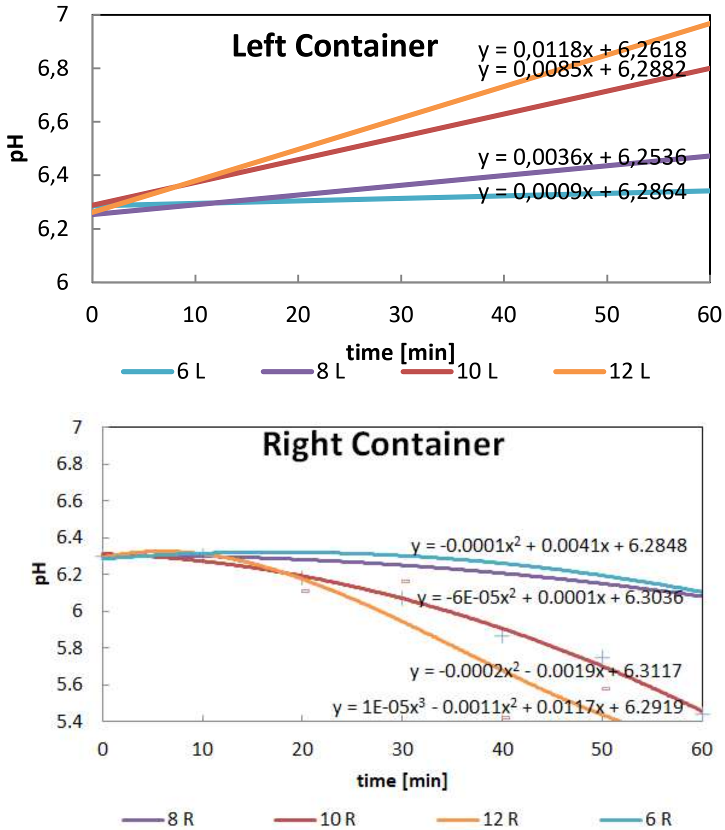

Figure 2 Changes in pH in the Container Affect the Potential Difference.

Based on figure 2, the potential difference at 6 V with a coefficient of 0.0009 indicates that the change in pH at this level is relatively small, but there is still a positive effect on the pH of the solution. At 8 V, the coefficient of 0.0036 is higher than at 6 V, suggesting that the change in potential difference has a more significant impact on the increase in pH of the solution. This graph shows a tendency for a more pronounced increase in pH. At 10 V, the coefficient of 0.00085 indicates that the change in pH with respect to the change in potential difference is still relatively small, but there is a tendency for an increase in pH. At 12 V, the coefficient of 0.0118 is higher, indicating that the change in pH of the solution is more significant compared to the previous conditions. The increase in potential difference at this level has a greater impact on the pH of the solution.

By evaluating the trend line equations of the pH graph at each potential difference in Figure 2, we can observe how the increase in potential difference affects the pH of the solution. With an increase in potential difference, it is evident that the gradient coefficient (m) in the linear pH equation increases. The increase in potential difference in Figure 2 results in an increase in electrical current in the solution. This increase in electrical current subsequently leads to an increase in the production of hydroxide ions at the cathode, thereby increasing the concentration of OH- ions in the solution (Ash et al., 2010; Brighton et al., 1975). This observation aligns with findings from Mostafa et al. (2018), who highlighted that higher applied voltages enhance ion generation at the electrodes, influencing the ionic composition and pH of the solution. This increased concentration of hydroxide ions causes the solution to become more alkaline. Based on the experimental data in Figure 2, the hypothesis that an increase in potential difference will impact the pH of the solution is accepted. With an increase in potential difference, the pH of the solution tends to increase significantly. Thus, there is a positive correlation between potential difference and the pH of the solution.

Based on the figure 2, it illustrates the relationship between potential difference (voltage) and the pH of the solution at four different levels. The hypothesis posits that an increase in potential difference will affect the pH of the solution in the right container by lowering the pH or making it more acidic. localized acidification and alkalinization occurred near the cathode and anode, respectively, due to changes in applied voltage during electrochemical reactions (Yan et al., 2017).

At 6 V, there is a negative quadratic effect ($-0.0001x^2$ - $0.0001x^2$). This suggests that an increase in potential difference can lead to a decrease in the pH of the solution. The positive contributions from the linear coefficient (0.0041x) and the constant (6.2848) may partially offset the negative quadratic effect. At 8 V, the quadratic effect (– $6E\text{-}05x^2$) is still negative. Although there is a positive contribution from the linear coefficient (0.0001x), the hypothesis that an increase in potential difference will lower the pH of the solution remains relevant at this level. At 10 V, both the quadratic effect ($-0.0002x^2$ - $0.0002x^2$) and the linear effect (-0.0019x) are negative. This indicates that an increase in potential difference can accelerate the decrease in the pH of the solution, supporting the hypothesis that an increase in potential difference will make the solution more acidic. At 12 V, there is a positive quadratic effect ($1E\text{-}05x^3$), which may contribute positively to the pH of the solution. However, this effect is likely small compared to the negative effects of other quadratic and linear coefficients.

Based on the analysis, the hypothesis that an increase in potential difference will make the solution more acidic or decrease the pH in the right container aligns with the provided data. The negative quadratic coefficients in each equation indicate that the effect of decreasing pH becomes more significant with an increase in potential difference. Therefore, an increase in potential difference in the container tends to make the solution more acidic. Voltage-controlled modulation of local pH during water electrolysis is a critical factor influencing solution acidity, particularly in pH-sensitive electrochemical applications (Liu et al., 2023). This finding reinforces the pH variation trends observed in this study. Additionally, Marquez et al. (2024) emphasized the importance of contextualizing electrochemical concepts through active learning strategies, which aligns with the educational objectives of this research.

Student response to electrolysis of rainwater practicum

After concluding the practicum, a total of 15 students participated in a questionnaire to provide feedback. The questionnaire, designed to evaluate four aspects, comprised 8 modified questions, with each aspect featuring 2 questions. Upon analyzing the results from the student response questionnaire, specifically focused on the electrolysis of rainwater, an overall average percentage of 78% was attained, placing it within the high category. This indicates that the practicum successfully addressed the four key aspects: Learning Motivation, Ease of Use, Attractiveness of Use, and The usefulness of practicum products, as illustrated in the table 1.

Table 1 Analysis Results of Student Responses to electrolysis of rainwater practicum

Aspect	Strongly Agree	Agree	Disagree	Strongly Disagree
Learning Motivation	43%	57%	0%	0%
Ease of Use	13%	53%	27%	7%
Attractiveness of Use	37%	60%	3%	0%
The usefulness of practicum products	13%	63%	17%	7%
Average	27%	58%	12%	3%

The initial aspect assesses responses related to learning motivation, with students exhibiting an average response rate of 27% respone strongly agree and 58% agree, categorizing it as very high. The remarkably high evaluation by students regarding their learning motivation indicates that the rainwater electrolysis practicum, embedded within the electrochemistry material, has had a positive impact on their learning. The direct hands-on experience gained through the practicum not only heightens student motivation but also stimulates active engagement in the learning process (Irwansyah et al., 2019; Nurjanah et al., 2020; Wenning & Vieyra, 2020). This signifies that an instructional approach involving practical experiments can prove to be an effective method in enhancing students' comprehension and interest in the science subject, particularly electrochemistry.

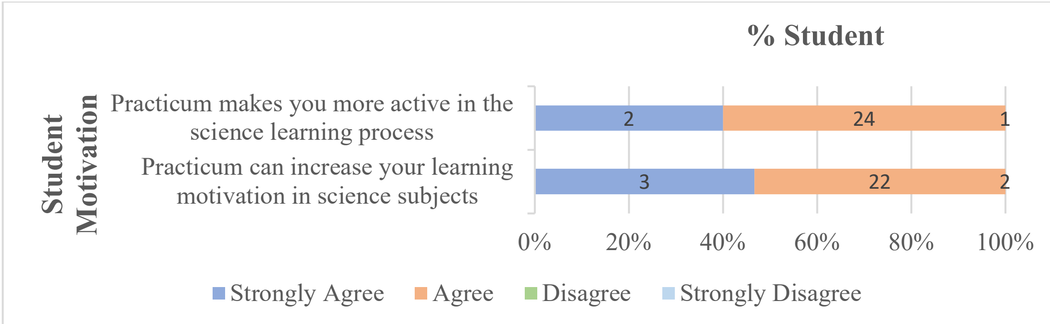

Figure 3 Student responses about the significance of practicum toward learning motivation

The second aspect evaluates responses related to the ease of using the practicum, with students registering an average response rate of 70%, categorizing it as high. The notably positive assessment by students regarding the ease of use of the rainwater electrolysis practicum signifies that this aspect has successfully provided a comfortable and easily understandable experience for the students. This can enhance the effectiveness of learning, as students can concentrate more on grasping the concepts of electrochemistry without being hindered by technical or instructional issues. The simplicity of instructions and the comprehension of tools and materials can also instill confidence in students to actively engage in the experiment, thereby supporting the attainment of learning objectives. Ensuring assignments given to students align with their abilities and promote success not only cultivates confidence but also assists in minimizing failures that may reduce self-efficacy (Britner & Pajares, 2006). Students who have cultivated self-efficacy in science learning are more inclined to manage and regulate their efforts in the process of learning science (Velayutham et al., 2012)

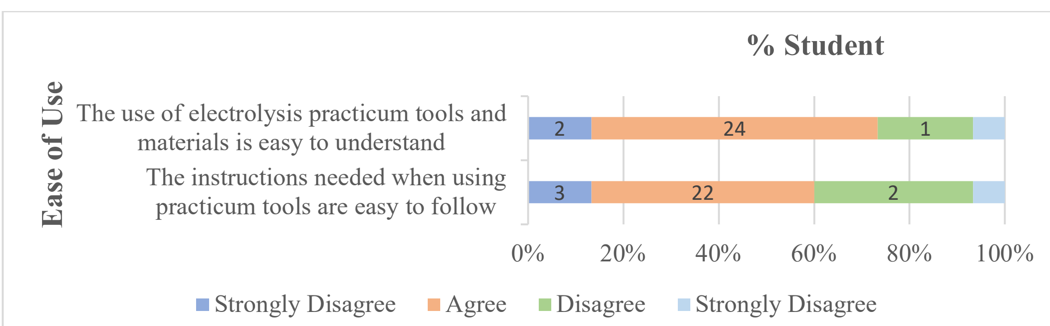

Figure 4 Student responses about the significance of the ease of use practicum

The third aspect evaluates responses related to the ease of using the practicum, with students registering an average response rate of 83%, categorizing it as Very High. The significantly positive evaluation by students concerning the attractiveness of using the practicum indicates that the learning approach involving practical experiments in rainwater electrolysis has successfully captured the students' attention. The attractiveness of the practicum can stimulate students' interest, make learning more enjoyable, and encourage greater involvement in the field of electrochemistry. An engaging practicum also has the potential to create memorable learning experiences, aiding students in retaining the concepts taught (Busher et al., 2015; Scovill & Waite, 2012).

Students have expressed that there is a connection between the theory taught and the rainwater electrolysis practicum. This indicates that the practicum has been well-designed, allowing students to directly observe the correlation between the theoretical concepts they learn and their practical application in real-life experiments. This connection can enhance students' understanding of these concepts and reinforce the significance of the learning experience (Rivet & Krajcik, 2008; Singh et al., 2018)

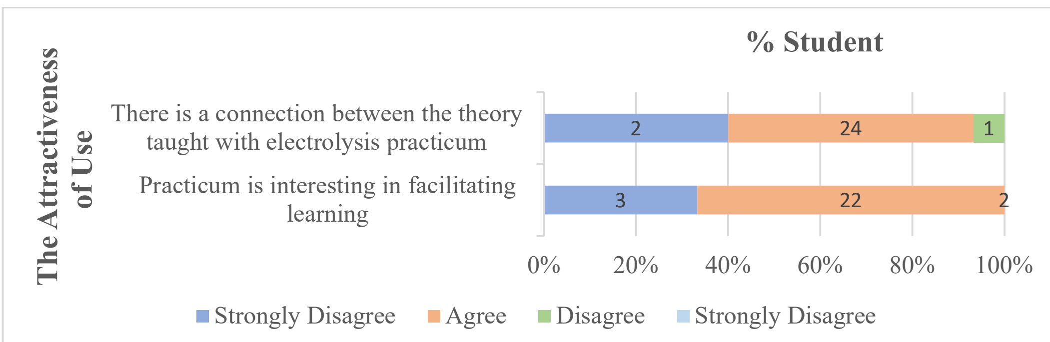

Figure 5 Student Responses about the Attractiveness of Use Practicum

The fourth aspect evaluates responses related to the attractiveness of use the practicum, with students registering an average response rate of 71%, categorizing it as high. The notably positive evaluation by students concerning the usefulness of the practicum products indicates that the rainwater electrolysis practicum is perceived as an effective and beneficial learning tool by the students. The practicum not only aids students in better understanding concepts but also, importantly, students express that it is relevant to the subject matter being taught. This signifies that the design of the rainwater electrolysis practicum is well-structured to align with the curriculum and concepts taught in the electrochemistry material. This relevance is crucial as it ensures that the practicum not only provides practical experience but can also be directly linked to the theoretical concepts that students need to comprehend (Smith & Lev-Ari, 2005).

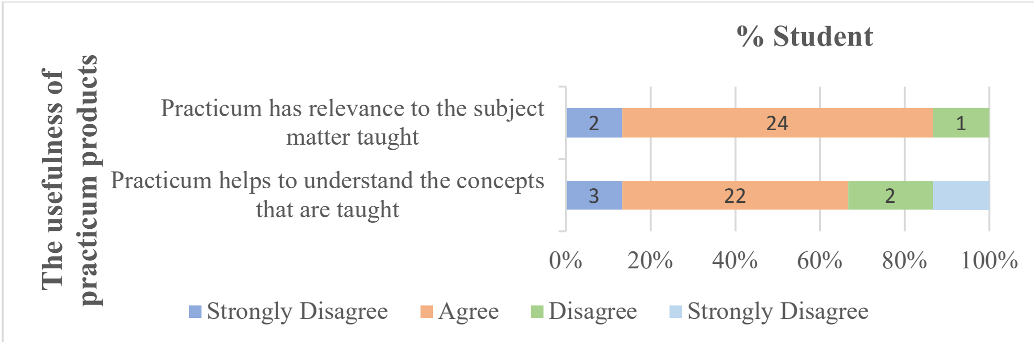

Figure 6 Student Responses about the usefulness of practicum products

The students' overall response to the rainwater electrolysis practicum falls within the high category, indicating a very positive reception from the students. This is evident in their responses to each question, highlighting the effective application of the practicum to the electrochemistry topic. Additionally, the electrolysis of rainwater has the potential to heighten students' awareness and concern for the environment and their surroundings.

CONCLUSION

This study presents the development of a rainwater electrolysis practicum tool that enables students to observe the effect of potential difference on pH changes during electrolysis. The experimental results confirmed that variations in potential difference influence local pH shifts at the electrodes. Additionally, positive student responses regarding motivation, ease of use, and usefulness indicate that the practicum is effective in enhancing student engagement and understanding of electrochemistry concepts. Therefore, the developed practicum not only serves as a contextual learning tool that bridges theoretical knowledge with practical applications, but also provides a model for integrating locally relevant, low-cost experiments into science education. Future studies could explore its implementation across different educational levels or its adaptation for other electrochemical topics to further promote inquiry-based and sustainable learning practices.

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