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Exploring Learning Needs for Developing a STEAM-Oriented Differentiated Virtual Laboratory in Electroplating and Electropolishing

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Abstract: This study aims to explore the need for virtual laboratory media (V-Lab) that integrates differentiated learning using the STEAM approach for electroplating and electropolishing. The research method used is qualitative-descriptive, with the research subjects comprising 3 teachers and 75 students from two public senior high schools and one vocational high school in Metro City, Lampung. Data collection used questionnaires, learning observations, and interviews. The results of the observations show that chemistry learning is still dominated by lectures and exercises (40%), while limited equipment, materials, and costs, as well as the risk of hazardous waste, continue to limit practical activities. Students experience significant difficulties in visualizing sub-microscopic phenomena, especially in determining ion flow (74%) and reactions at the anode-cathode (62%), resulting in a low ability to calculate Faraday's Law (60%). Cognitive data analysis shows a diversity of student abilities, with the majority being at the "need guidance" level (41%). These findings underscore the need for innovative learning media, with 100% of teachers and 77% of students agreeing with the development of V-Lab integrated with differentiated learning and the STEAM approach. V-Labs are expected to transform abstract concepts into concrete ones, increase motivation, and accelerate the learning pace of diverse students without the physical risks of a laboratory setting.

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INTRODUCTION

Learning chemistry is not just about learning the content available in textbooks or printed books. Learning is more effective when students are able to apply their knowledge to everyday contexts, engage in chemistry-related activities, and make rational decisions based on their own experiences (Gilbert & Treagust, 2009). It is not just about practice; students must also understand what they are doing and the concepts involved.

Electrochemistry is a branch of chemistry that studies the process of converting chemical energy into electrical energy and vice versa. If the chemical reaction that occurs is not spontaneous, an electrical source, often referred to as electrolysis, is needed. Electrochemical processes include battery assembly, metal corrosion, and electroplating, and in the 13th century, they were widely used for decorative purposes, such as coating other metals with gold or silver (Campos, 2024). Nowadays, its use is not only for decorative purposes but has developed according to need.

Electroplating is one of the most widely used techniques in electrolytic coating. It's generally done by applying a thin layer to metals such as nickel, copper, chromium, and zinc to add value, protect against corrosion, prevent damage, and extend the duration of use. The principle of electroplating is based on Faraday's Laws I and II, which state that:

"The mass of the substance produced is directly proportional to the electric charge."

"At the same amount of electric current, the mass of the substance produced is directly proportional to the equivalent mass of that substance."

In addition to electroplating, there is also a technique known as electropolishing. Electropolishing refers to an electrochemical process that removes some of the material from a metal by polishing, passivating, or removing rust. The opposite of electroplating, electropolishing is also known as electrochemical polishing or electrolyte polishing. The metal to be electropolished is placed as an anode and connected directly to a DC electric current. The electric current flowing from the anode to the cathode causes the metal surface to oxidize so that impurities and surface roughness dissolve in the electrolyte and diffuse through the film to the cathode with a controlled current (Yang, 2017; Zaki, 2022). The parameters that influence the electroplating and electropolishing processes are the electrode arrangement, electric current, solution concentration, process duration, temperature, and the metal used (Sutarno, 2021; Widodo A, 2021). Typically, current and time are the two variables that can be controlled to achieve the desired final surface (Yang, 2017).

Electroplating practices have been implemented in several vocational schools, and some have attempted to develop them at the high school level using simple electroplating equipment (Said, 2014; L.G Yusnita, 2020). However, the equipment used for electroplating practices only has one tank for the coating process. Meanwhile, the specimen preparation process is separate and manual. The coating process is only carried out once, without a finishing process for a better appearance (Widodo A, 2021). Meanwhile, no school has implemented electropolishing practices.

The availability of adequate equipment and facilities in high school chemistry laboratories is a problem in chemistry practical learning. There still exist schools that do not have chemistry laboratories. Laboratory activities are relevant to the learning of chemistry because they enable students to see chemical phenomena, build experimental skills, grasp the scientific method, and relate theory to observable reality. Laboratories are an improved experience for students and allow them to achieve better, be motivated, and understand the concept behind chemistry. These, to some extent, depend on both physical infrastructure and the effective management of student learning, qualified personnel, pedagogical approaches, and time allocation.

STEAM is a learning model that emphasizes the elements of design, art, creative thinking, and fun problem-solving in exploring to create solutions (Quigley et al., 2019). Furthermore, STEAM shifts focus from products that solve problems to problem-solving itself. By taking a transdisciplinary approach, the STEAM perspective allows students to use science and technology as access points for questioning, dialogue, and critical thinking. If we present electrochemistry as a rigorous science but an unique surface-transformative process, we will promote students' self-efficacy and motivation. Research findings indicate that when students encounter loosely defined problems in STEAM projects, they are compelled to generate and revise new options rather than simply memorize procedural steps. This is highly relevant for developing higher-order thinking skills such as creativity, collaboration, and complex problem-solving (Ridwan, 2017).

The electroplating and electropolishing work environment is inherently hazardous, involving the use of toxic chemicals such as heavy metals, as well as highly corrosive acids and alkalis (NIOSH). The financial burden of building and maintaining such facilities is often a major obstacle. There is also a significant cognitive gap in traditional instruction (Yesha, 2025). Students often have difficulty visualizing "invisible" phenomena, such as the movement of ions through an electrolyte solution, the formation of layers on the surface of an electrode, or ionization reactions on a microscopic scale (De Jong & Treagust, 2002; Loh et al., 2014; Turner, 2024).

The evolution of virtual laboratories as a strategic solution in chemistry education. Rather, a part of the powerful augmentation to modern education, Virtual laboratories (VLab) emerged gradually, not as an alternative to physical experiments. This virtual world enables pupils to experiment with complex concepts multiple times, while never being at risk of exposure to toxic chemicals, and reducing high expenses related to building unique physical assets. VLabs are best used as preparatory or supplementary elements to actual experimental work, where students can learn common procedures and concepts before stepping into a physical laboratory (Lestari, 2023).

The integration of the STEAM approach in Vlab provides a pedagogical alternative for media development. In the development of Vlab for electroplating and electropolishing, the "Arts" component is not merely a decorative element; rather, it involves intuitive user interface design, aesthetically pleasing yet accurate data visualization, and the application of aesthetics in metal surface engineering. This visual is translated into the use of high-quality animations that can explain fluid dynamics or changes in metal surface color realistically. The integration of arts-based strategies has been shown to increase the participation of underrepresented groups in STEM by creating a more inclusive and emotionally engaging learning environment.

One of the most significant advantages of a well-designed Vlab is its capacity to support differentiated instruction. Through a differentiated Vlab, students can choose from a variety of learning options based on their abilities. In general, much of the literature suggests that visualization can support learning when added to text. However, this advantage relies on the learner's capability of interpreting and "reading" the visualization itself, which highly correlates to individual traits of the learner (Dickmann et al., 2019). More personalized learning opportunities help optimize the development and understanding of each student, especially in the process element, rather than dumping them all together in a big classroom to do work using one approach.

Before developing media, a needs analysis is necessary. On this occasion, the researcher wanted to see how the need for Vlab media differs with the STEAM approach in electroplating and electropolishing material at the high school/vocational school level as a basis for media development.

METHOD

This study used a descriptive qualitative method. This method was chosen to gain a deeper of students' understanding and teachers' perspectives on the need for media. Qualitative research is suitable for exploring complex phenomena in the field of education through descriptive data (Cresswell, 2022). The research subjects involved 3 teachers and 75 students from 2 public high schools and 1 vocational high school majoring in Industrial Chemistry in Metro City, Lampung. The respondents were students who had studied the Electrochemistry chapter. The data sources in this study were questionnaires given to students and teachers and observations during chemistry lessons. Interviews were also conducted with teachers and several students to gain insight into the learning process and the resources used. There were 5 indicators measured and then developed into several questions. The indicators used are described in Table 1.

Table1. Needs Analysis Indicators

No	Need Analysis Indicators
1.	Learning Process by Linking the Phenomenon of Electrolysis
2.	Use of Learning Resources
3.	Need for Electronic Media (Vlab)
4.	Application of Learning with the STEAM Approach
5.	Learning Methods

Data obtained from observations and interviews will be analyzed descriptively, while questionnaire data will be converted into percentages using the following formula:

$$P\ (\%) = n/N \times 100$$

Where:
P = Percentage of scores obtained
n = Number of scores obtained
N = Total score

RESULTS AND DISCUSSION

The needs analysis measured the following aspects: 1) the learning process by linking it to the phenomenon of electrolysis; 2) the use of learning resources; 3) the need for electronic media (Vlab); 4) the application of learning with the STEAM approach; and 5) the learning methods applied.

If we look at how the learning process takes place, based on the questionnaire results in Figure

1, it shows that the chemistry learning process carried out in the three respondent schools generally relates the learning material to real phenomena. From the observation results, at the beginning of the lesson, the teacher provided insight into the phenomenon to give an overview of the application and function of the material. Students appear enthusiastic about learning that is linked to real phenomena, and they share their opinions and information with each other. In the electrochemistry chapter, teachers also provide examples of the application of this theory in industry, such as the process of metal plating, cathodic coating, etc.

There was a difference in how phenomena were presented between senior high schools and vocational high schools. From the observation results, at the senior high school level, teachers provided brief and general narratives and focused on the chemical processes that occurred. Meanwhile, at the vocational high school level, teachers presented the industrial process flow. Based on the results of the questionnaire in Figure 1, 1 of 3 teachers more often provide electrolysis material focusing on formulas/calculations, theory, and example questions. They not only look at the processes that occur but also the types of tools used. After the interviews, the teachers stated that by emphasizing problem-solving, students would become accustomed to solving problems, especially when taking exams. As for the application of electrolysis, they still conveyed it, but only briefly.

During the observation of the learning process, students appeared to have difficulty understanding electrolysis cells. Based on the results of the questionnaire shown in Figure 1, the three teachers also stated the same thing. They needed time to be able to provide explanations from both a microscopic and a mathematical perspective.

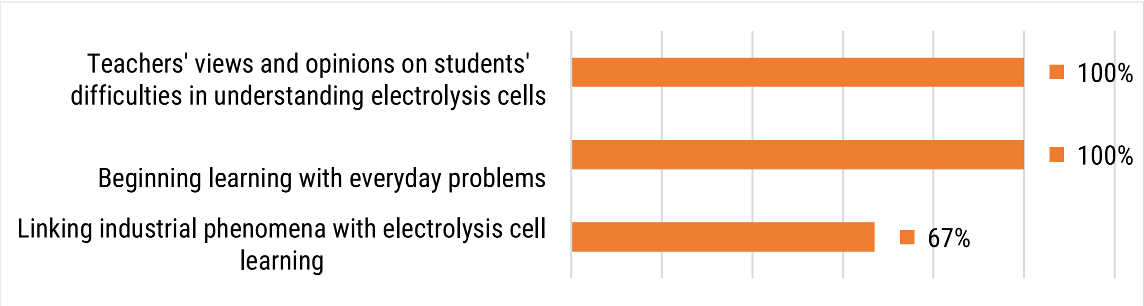

Figure1 . Aspects of the Learning Process from the Teachers' Perspective

According to the student questionnaire results (Fig. 2), a large portion of students, 74% and 62%, respectively, struggled to identify both the passing direction of electrons involved in that process and the reactions occurring on the anode and cathode. The most important processes occurring in electrolysis cells, including electron flow, oxidation-reduction reactions, and ion movement in a solution, can not be directly observed by human eyes (Lin, C. Y., & Wu, H. K., 2021). This lack of direct observation makes it difficult for students to understand these concepts. This inability results in difficulty determining the reduced substance or ions coating in electroplating. Students will be confused when predicting whether there will be bubbles or deposits resulting from the reaction.

From the questionnaire's results in Figure 2, 60% of students had difficulty calculating Faraday's Law. After conducting interviews, it turned out that students with low numeracy and mathematical abilities had difficulty applying Faraday's Law when calculating the mass of substances produced during the reaction. This condition is closely related to the ability to determine the reactions involved. These results are supported by research by Lin, et al (2021) and Thayban et al (2024) that students' difficulties in determining the oxidation number in the total reaction result in errors in calculating the equivalent mass. In this study, students assumed that oxidation numbers were obtained from the number of atoms of an element. As for the concept of electrolysis, students did not find it difficult to learn. From the questionnaire results, only 33% of students had difficulty understanding the concept of electrolysis. After further interviews, it turned out that they did indeed find it difficult to learn chemistry from the beginning.

In general, students found it easy to memorize the theory of the difference between electrolysis cells and voltaic cells. They were able to determine the substances that acted as anodes and cathodes by memorizing the poles of the current source and the names of the processes that occurred in each. However, when directly related to the phenomenon of electroplating, the students began to experience difficulties.

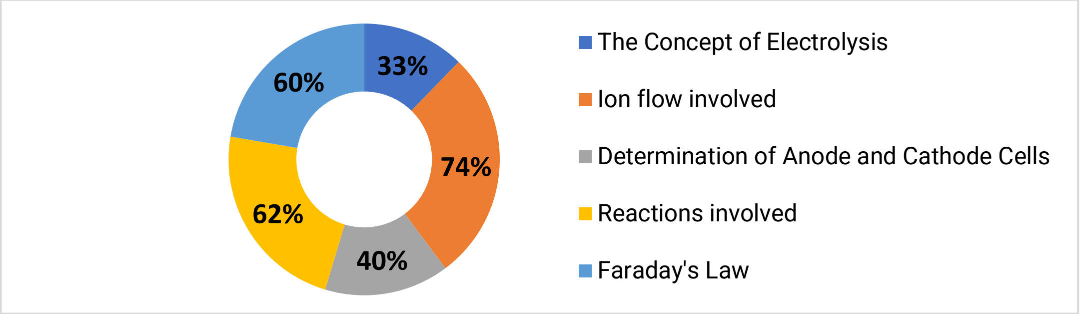

Figure 2 . Percentage of Student Difficulties

Understanding and visualizing the electrolysis process in electroplating requires connections between macroscopic, sub-microscopic, and symbolic levels of understanding. Too much theory-based learning and a lack of practical experience make it difficult for students to understand concepts holistically. Common methods used include lectures, exercises, discussions, question and answer sessions, and several practical sessions. According to the results of the questionnaire in **Figure 3,** the methods most commonly used to teach the electrolysis process are lectures and exercises. Interviews with teachers revealed that practical sessions are often conducted to support chemistry lessons. However, practical work is often only carried out on material that is considered easy to implement in terms of the availability of tools and materials and the practical process itself. This condition is not always wrong, because learning in schools is actually adapted to the conditions and facts in the field, but it does not reduce the essence of the material for students. The same is true for the topics of electroplating and electropolishing.

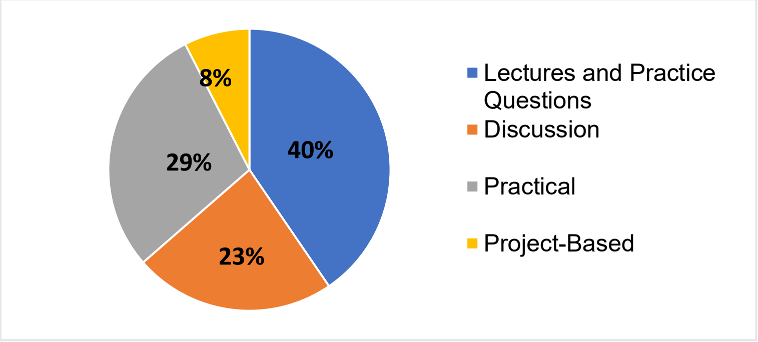

Figure 3 . Electrolysis Cell Learning Method

Doymus in Lin, et al (2021) paper's argues that showing particle movement through animation results in better conceptual understanding at the sub-microscopic level. Instead of explaining how the process occurs in text form, students need to visualize the movement of ions in a solution at the sub-microscopic level. Based on the results of a questionnaire given to teachers and students, as shown in **Figure 4,** they have never practiced electroplating at school. According to the teachers concerned, the availability of tools and materials, as well as practical skills, is the main obstacle. Teachers also stated that the implementation of electroplating and electropolishing practices is expected to provide a realistic picture, especially for vocational school students, so it is necessary to implement electroplating practices as a means of providing students with direct experience. However, the implementation of electroplating practices can pose a risk of environmental pollution from the waste produced if there are no waste treatment facilities. Not to mention, the limited availability of materials is also a concern. Therefore, an alternative that can be used is a virtual laboratory digital media. This Vlab is presented as a support in improving the quality of teaching in technical courses, both as a pre-experiment or as a post-experiment skill (Pastor et al., 2020). Vlab can help transform learning that was previously abstract into concrete (Raziana, 2025).

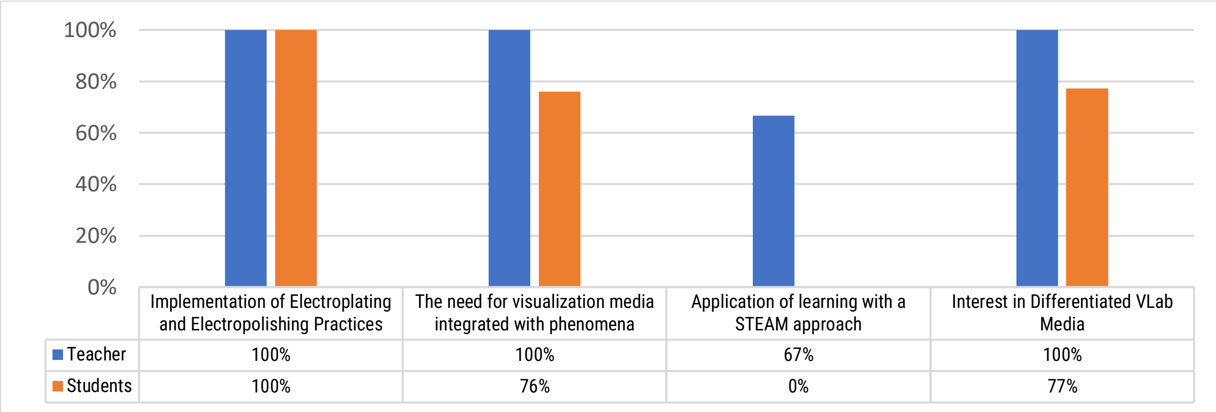

Figure 4 . Analysis of the Need for Electroplating and Electropolishing VLab Media

Based on the questionnaire, it shows that 71% of the 75 students found it difficult to understand the explanations from textbook about applications in electroplating and electropolishing. This was also conveyed by one of the teachers during an interview, who said that reading narratives in printed books requires the ability to interpret text into moving images. Meanwhile, not all students can visualize accurately and quickly. With 94% of learning resources dominated by printed books from schools that mostly contain narratives, other media are needed to help with abstraction problems. From the questionnaire, 76% of students need visual media that are integrated with the phenomenon directly (Fig 4).

Based on interviews with teachers and the documentation of scores in Table 2, students were grouped into three categories of cognitive ability: proficient (M), fairly proficient (CM), and needing guidance (BB). The score threshold used was the lowest minimum passing score from the three schools, which was 73. The results showed that the majority of their chemistry skills were at a lower-middle level. Therefore, teachers always use different methods in teaching, or what is better known as differentiated learning.

Table2 . Students' Cognitive Abilities

Proficient *(Score >85)*	Fairly Proficient *(Score 74-84)*	Needs Guidance *(Score <73)*
17 students	27 students	31 students

According to the teachers, they have often applied differentiated learning, especially in terms of process and content. Teachers provide more assistance to students with below-average abilities. Meanwhile, students with average to advanced abilities only need confirmation that their answers are correct. This process differentiation is carried out to accommodate students' learning speeds so that no student feels left behind. All students have the same learning objectives, and content but with different processes/methods.

As for practical work, according to the teachers, students are grouped heterogeneously during practical work. As a result, students who need guidance often do not understand the process they are doing and do not know the scientific reasons behind it. It would be more effective if practical work also took into account the element of differentiation, so that students who need guidance are not just carrying out practical procedures.

The development of digital media for electroplating and electropolishing by integrating differentiation elements is an interesting innovation for teachers and students. This is illustrated in Figure

4, where 100% of teachers and 77% of students agree with the development of differentiated Vlab digital media.

The integration of STEAM with IT has been widely implemented and proven to provide interactive and engaging educational methods for the digital generation to learn technology, science, and mathematics content quickly and enjoyably (Bati, Yetişir, Çalişkan, Güneş, & Gül Saçan, 2018; Lambert & Gong, 2010; Wang et al., 2023). According to Suriyana & Novianti (2021), the level of student participation and activity increases with the STEAM approach. Additionally, based on interviews with teachers, the STEAM approach can provide new experiences and increase student motivation and achievement. Teachers have tried using the STEAM approach in other chemistry topics, but based on Figure 4, not all aspects of STEAM have been fully implemented in learning. Only certain components appear in learning. Considerations of time allocation, depth of material, and student readiness were highlighted by teachers in the interviews. The implementation of STEAM-based learning is generally in the form of an approach, for example, in atomic structure or colligative material. Colligative material was chosen because the phenomenon is relevant to students and can be packaged simply. Previous research has stated that STEAM-based learning can improve critical thinking, creativity, and *problem-solving* skills (Utomo, 2023).

The results of the questionnaire in Figure 4 show that both teachers and students are interested in differentiated V-Lab media using the STEAM approach. By raising the phenomena of electroplating and electropolishing, it provides real knowledge of the application of the concept of electrolysis. STEAM has a positive influence on students' critical thinking, creativity, and conceptual understanding because it makes them more initiative and active, thereby increasing their self-confidence (Utomo et al., 2023; Budiyono et al., 2020). The STEAM approach provides opportunities to help abstract scientific concepts become more tangible applications. For example, the topics of electroplating and electropolishing will assign students to design metals with specific specifications. This project will require them to integrate knowledge of electrolysis (Science), the use of Vlab (Technology), electrochemical cell design (Engineering), and visual surface analysis (Arts), while performing Faraday's Law calculations (Mathematics). This is in line with chemistry learning, which is considered difficult in connecting its abstract concepts. This is where the role of critical thinking in students is honed.

VLab can be an effective companion to dense texts, providing immediate feedback and immersive exploration (Lin, 2023; Hamilton, 2021; Dickman, 2019; Ali, 2020). For students, VLab media provides broader and more personalized access in a safe and repeatable format for conceptual and procedural practice. For learning and curriculum designers, this medium offers practical guidance for creating adaptive, learner-centered chemistry learning, especially in environments with limited lab resources but access to modern technology such as mobile phones and computers, as well as a focus on environmental pollution. The integration of VLab with a differentiated STEAM approach presents a measurable, cost-effective, and space-efficient solution, an integrated approach that encourages students to view phenomena from a multidisciplinary perspective.

CONCLUSION

The results of preliminary studies conducted through questionnaires, learning observations, and interviews indicate a need for differentiated Vlab digital media with a STEAM approach. The availability of laboratories, equipment, and materials, pedagogical approaches, and student abilities are obstacles to the implementation of practical work at the high school/vocational school level. Even today, there are still schools that do not have chemistry laboratories. The implementation of learning methods is still dominated by lectures and exercises rather than practical activities on electrolysis. In addition, the use of print media in the form of text requires accompanying visual media that can help explain abstract concepts so that they are visible and understandable to students. Visual media in the form of virtual laboratories can complement real practical activities by providing immersive exploration opportunities without the need to use chemicals and physical laboratory equipment. Combining the STEAM pedagogical approach and differentiation elements in the electroplating and electropolishing V-Lab provides an exciting new experience for students and teachers. The addition of differentiation elements provides a platform for students because, until now, experiments have been conducted by "following recipes" in a heterogeneous manner. Heterogeneous grouping in experiments, when observed in more detail, has an impact on the gap in understanding of the experiments carried out. Students who need guidance tend to perform only procedural work.

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