



Comparative Analysis of SMK Students' Understanding of Electrochemistry Through Laboratory-Based and Virtual Laboratory-Based Learning Modalities



Vol. 10, No. 2, 2025, Page: 80-89

Alvin Annayya Habibah¹, Hartinah Pratiwi¹, Kurnia Larasati², Anugrah Ricky Wijaya¹

¹PPG Universitas Negeri Malang, Jl. Semarang No. 5, Malang 65145, Indonesia.

²SMK PGRI 3 Malang, Jl. Raya Tlogomas Gang 9 No. 29, Malang, Indonesia.

*Corresponding Author: anugrah.ricky.fmipa@um.ac.id

Abstract

This study investigates the comparative effectiveness of Lab-Based Learning (LBL) and Virtual Lab-Based Learning (VLL) models in enhancing electrochemistry comprehension among Vocational High School (SMK) students. Employing a quasi-experimental, pre-test-post-test non-equivalent control group design, the research involved two groups of Industrial Chemistry students, each subjected to either LBL or VLL instructional methods. Data collection instruments included a concept understanding test and a student perception questionnaire. Initial assessments indicated similar baseline understanding, with pretest mean scores of 39.00 across all participants. Post-intervention results demonstrated significant improvements in both groups: the VLL group's mean score increased from 39.67 to 80.47, while the LBL group's mean rose from 38.33 to 88.67. Statistical analysis confirmed that both models effectively enhanced students' electrochemistry understanding, with the LBL group exhibiting a greater mean increase. Student perceptions further revealed a preference for the LBL model, citing increased engagement and ease of comprehension. These findings suggest that, despite the advantages of virtual laboratories, authentic laboratory experiences remain more effective for vocational students in mastering complex electrochemical concepts.

Keywords:

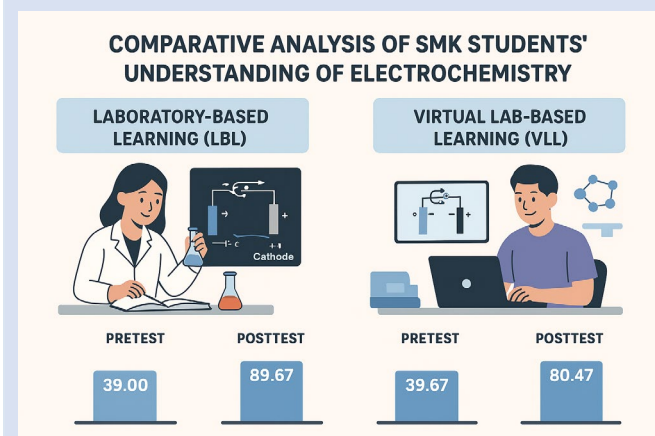
Electrochemistry; Lab-Based Learning; Virtual Lab-Based Learning; SMK students'; Conceptual Understanding

Submitted: May 24th, 2025

Revised: Aug 5th, 2025

Accepted: Nov 5th, 2025

Graphical Abstract



Introduction

Vocational high schools (SMK) play a crucial role in preparing skilled labour ready for the industrial world. Unlike general senior high schools (SMA), SMKs emphasise vocational learning that demands both technical skills and applicable conceptual understanding (Siregar et al., 2022). Therefore, the learning process at SMK must be aligned with industrial demands and designed to suit students who favour practice-oriented learning over abstract theoretical approaches.

One of the challenges in SMK learning, particularly in the Industrial or Analysis Chemistry program, is the difficulty students encounter in understanding theoretical concepts such as those in electrochemistry. These concepts require a deep understanding of redox reactions, electron movement, and the principles of electrochemical cells, which are inherently abstract and complex. This difficulty is exacerbated by students' limited ability to relate electrochemical concepts to their industrial applications. Moreover, the lack of contextual, practice-based learning models further hinders comprehensive understanding. Mastery of this material is crucial as many chemical industries utilise electrochemical principles in production processes such as electroplating, corrosion control, and industrial batteries (Nurdiansah et al., 2024).

This aligns with the findings of Asworo (2024), who demonstrated that electroplating experiments could strengthen students' understanding of electrochemistry through project-based learning. Students directly performed metal plating experiments, created posters, and presented their results via video reports. The approach significantly improved their understanding of electrolytic cells, with average scores rising from 65 in the pretest to 93.06 in the post-test. Besides reinforcing cognitive aspects, this method also fostered an active, collaborative, and meaningful learning environment (Asworo, 2024). Therefore, an effective instructional approach is essential to enhance students' understanding of this material. In this context, laboratory experiments are crucial to support students in mastering electrochemistry. Such practices help them understand how to properly set up and conduct experiments, including electrode cleaning and pre-treatment, accurate recording of results, data analysis, and evaluation of changes in oxidation or reduction peaks when experimental parameters are altered (Brett & Oliveira-Brett, 2024).

Aligned with laboratory-based approaches, the use of Virtual Labs (VLL) has also proven effective in enhancing understanding of complex and abstract chemical topics like electrochemistry. Amid the rapid advancement of digital technology, education must adapt and integrate digital innovations to remain relevant to current student generations. According to Andhini et al. (2024), virtual lab media not only support cognitive development but also foster critical thinking and self-efficacy in understanding chemistry. Through two- and three-dimensional simulations mimicking real laboratory conditions, students can conduct experiments independently without time, space, or safety constraints (Mulyani et al., 2023; Siregar et al., 2022). This is particularly important for schools lacking adequate lab facilities, while SMK students require learning that is more applicable and contextual. Virtual

labs thus offer an active, flexible, and comprehensive alternative for electrochemical learning (Andhini et al., 2024; Mulyani et al., 2023).

Previous studies show that SMK students generally comprehend material more easily when delivered in an application-based, experiential format (Sophia et al., 2021). Unfortunately, the current teaching methods in the observed SMK remain conventional and theoretical, lacking materials that link electrochemistry to industrial contexts, thereby widening the understanding gap (Sophia et al., 2021).

To address these issues, innovative instructional models like Lab-Based Learning (LBL) and Virtual Lab-Based Learning (VLL) have been developed. LBL emphasises hands-on experiments in real laboratories, allowing students to empirically observe and understand electrochemical principles. Conversely, VLL utilises technology to digitally simulate experiments, offering conceptual exploration without equipment limitations and enabling repeated experiments with no safety risk (Rahardjanto et al., 2019). While both models have the potential to improve student understanding, their effectiveness in SMK electrochemistry learning needs further investigation. Thus, this study aims to analyse differences in student understanding using the LBL and VLL models, identify their respective advantages and limitations, and evaluate their effectiveness in improving SMK students' competencies to meet industrial demands.

Method

This study used a true experimental design with a pre-test-post-test control group structure. The design was intended to measure the difference in students' understanding of electrochemistry after being taught using two different instructional models: Lab-Based Learning (LBL) and Virtual Lab-Based Learning (VLL).

The study was conducted at a Vocational High School (SMK) offering an Industrial Chemistry expertise program. Participants were two groups of 15 students each, selected purposively based on their academic equivalence. Group 1 received instruction through the Virtual Lab-Based Learning (VLL) model, which utilised digital media such as animated instructional videos on electrochemistry from YouTube and virtual simulation tools: [Teach Chemistry](#) (for voltaic cell simulations) and [Pearson Chemistry Simulation](#) (for electrolysis simulations). Meanwhile, Group 2 received instruction through the Lab-Based Learning (LBL) model, conducted in the school laboratory under direct supervision, involving real electrochemical experiments.

Before the intervention, both groups were given the same pretest to assess their initial understanding of electrochemical concepts. Following the instructional sessions using the respective models, students completed a post-test to evaluate changes in their comprehension.

Instruments used in this study consisted of a conceptual understanding test and a student perception questionnaire. The conceptual understanding test comprised 20 multiple-choice questions and one essay question that measured students' mastery of oxidation-reduction

reactions, identification of anode and cathode, direction of electron and ion flow, the relationship between redox processes and electrical energy, and applications of electrochemistry in industrial practices. Meanwhile, the perception questionnaire gathered students' responses toward both instructional models, covering indicators such as learning motivation, ease of understanding, engagement in activities, and relevance of learning to industrial applications.

All instruments were validated by expert judgment and tested for reliability before implementation. Data were analysed quantitatively to compare learning outcomes between the two groups. To ensure fairness, both groups received equal instructional duration, similar learning objectives, and identical assessment coverage.

This approach was designed to provide an objective comparison of the effectiveness of LBL and VLL in enhancing students' understanding of electrochemistry, as well as their respective contributions to vocational learning in SMK contexts.

Table 1. True Experimental Design (Pre-test-Post-test Control Group Design)

Group	Pre-Test	Independent Variable (Treatment)	Post-Test
Experimental 1	O ₁	X ₁	O ₂
Experimental 2	O ₃	X ₂	O ₄

- O₁ : Pre-test scores of the experimental group 1
- O₂ : Post-test scores of the experimental group 1
- O₃ : Pre-test scores of the experimental group 2
- O₄ : Post-test scores of the experimental group 2
- X₁ : Treatment using VLL instructional model
- X₂ : Treatment using LBL instructional model

Results & Discussion

This study aimed to compare the effectiveness of Virtual Lab-Based Learning (VLL) and Laboratory-Based Learning (LBL) in improving vocational high school (SMK) students' understanding of electrochemistry. The assessment involved administering the same pretest to all students before instruction and a post-test after implementing the respective learning models. A total of 31 students participated in this study, with 15 students in the VLL group and 16 students in the LBL group.

Evaluation of Learning Outcomes

Prior to the learning intervention, the average pretest score for all students was 39.00. After instruction, the VLL group's average score increased from 39.67 to 80.47, while the LBL group's average rose from 38.33 to 88.67. These results indicate that both groups experienced significant learning gains.

Table 2. Average Pre-test and Post-test Scores for VLL and LBL Models

Learning Model	Pre-Test Score Average	Post-Test Score Average	Gain
Virtual Lab Learning (VLL)	39.67	80.47	40.80
Lab-Based Learning (LBL)	38.33	88.67	50.33

The improvement in pre-test to post-test scores is presented in the following graph:

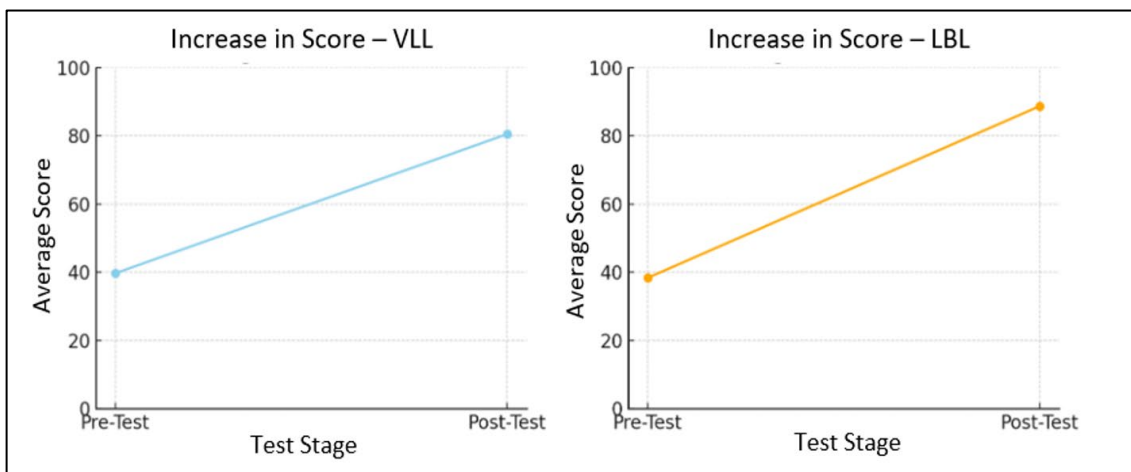


Figure 1. Average Score Improvement from Pre-Test to Post-Test for VLL and LBL Learning Models

The comparison of post-test results is presented in Figure 2.

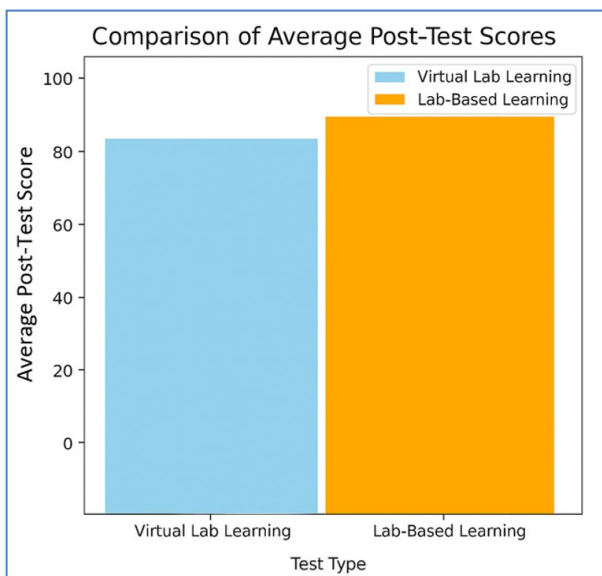


Figure 2. Comparison of Post-Test Score Averages Between VLL and LBL Models

Based on **Table 2** and **Figures 1** and **2**, both instructional models positively impacted student understanding, as reflected in substantial increases in post-test scores. However, LBL demonstrated a greater effect than VLL, with an average difference of 9.53 points.

Comparison of Instructional Model Effectiveness

The Lab-Based Learning model offers the advantage of direct, hands-on experience, which is highly relevant for SMK students who are expected to master technical skills aligned with industrial practices (Shana & Abulibdeh, 2020). Laboratory activities allow students to observe electrochemical processes firsthand, manipulate equipment, and experience redox and electroplating phenomena as they occur in real industrial settings (Brett & Oliveira-Brett, 2024). This model supports the holistic development of vocational competencies—not only cognitive, but also affective and psychomotor—which are crucial in SMK education. The effectiveness of LBL is further demonstrated by higher post-test scores, indicating that experiential learning contributes significantly to conceptual mastery (Shana & Abulibdeh, 2020).

Meanwhile, the Virtual Lab-Based Learning model still contributes positively to students' conceptual understanding, particularly in terms of flexibility, efficiency, and broader accessibility (Chan et al., 2021; Nirmala & Darmawati, 2021; Siregar et al., 2022). VLL is well-suited as a supplementary medium for independent study and practical simulations when equipment or materials are limited. Interactive simulations allow students to explore electrochemical concepts without safety risks and repeat experiments independently. Virtual labs are also considered more effective than passive methods such as lectures and texts (Chan et al., 2021). This aligns with findings from Andhini et al. (2024), who reported that virtual labs effectively enhance self-efficacy, critical thinking, and student engagement.

Nonetheless, VLL falls short in providing real-world laboratory experiences and skill development, which are vital for SMK graduates. Although conceptual understanding may be equivalent, students who learned through traditional laboratory models were more capable of correctly applying experimental techniques, such as the use of a salt bridge and the overall assembly of electrochemical cells (Hawkins & Phelps, 2013). This highlights the limitations of virtual laboratories in developing psychomotor skills (Hawkins & Phelps, 2013). In learning electrochemistry, where understanding work procedures, handling equipment, and observing real-time reactions are essential, the LBL model proves more comprehensive. This is reinforced by Asworo (2024) who found that project-based electrochemistry instruction using real experiments significantly improved students' readiness for industry-based practice.

In addition to the quantitative results, a qualitative analysis of students' open-ended responses also highlighted a key limitation of the Virtual Lab-Based Learning (VLL) model in vocational education. A comparison of student responses to a case study question on electroplating in electrolysis showed apparent differences between the two groups. When presented with a contextual problem involving a common industrial electroplating issue—uneven zinc coating and easy peeling—students in the VLL group provided minimal or

incomplete answers. For example, one student simply identified "unstable electric current" as the cause, without elaborating on necessary process adjustments or corrective actions.

In contrast, a student from the Lab-Based Learning (LBL) group provided a detailed explanation of both the causes and practical steps to improve coating quality. These included regulating current density, optimising electrolysis time, ensuring proper surface cleaning, maintaining electrolyte concentration and purity, and monitoring temperature and pH.

This stark difference demonstrates that while VLL may support conceptual understanding, it may not sufficiently build the procedural knowledge and industrial work-readiness skills required in SMK settings. Practical competencies, such as troubleshooting real-world process issues and executing standard operational procedures, are more effectively developed through direct laboratory experience (Shana & Abulibdeh, 2020; Zhang et al., 2022). These findings support the notion that LBL remains crucial for building the psychomotor domain in vocational chemistry education.

Student Perception Questionnaire Results

A questionnaire administered to 30 students revealed that 77.42% preferred the LBL model due to its engaging, real-life, and easier-to-understand activities. In contrast, 22.58% favoured VLL for its appealing visuals and safety advantages. This finding suggests that hands-on learning in LBL better supports students' emotional and cognitive engagement. The direct lab experience enhances not only cognitive understanding but also stimulates their interest in learning and fosters critical psychomotor skills necessary for vocational training, supporting the constructivist theory which highlights the role of direct experience in building scientific knowledge (Shana & Abulibdeh, 2020).

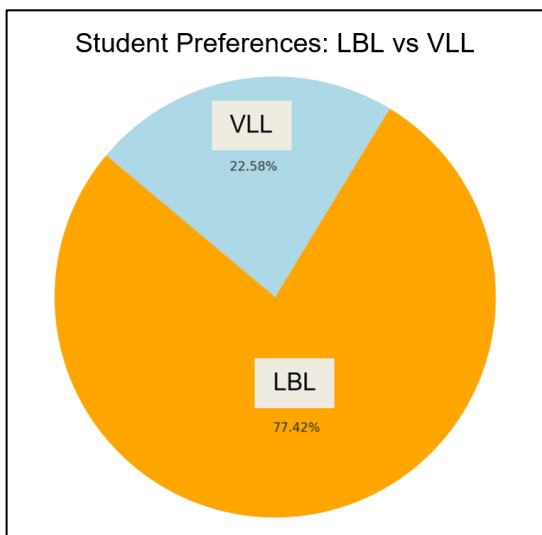


Figure 3. Student Preferences Between VLL and LBL Models

Instructional Implications

The difference in effectiveness between VLL and LBL in this study indicates that both approaches have their respective advantages. LBL is highly recommended for schools with adequate laboratory facilities and that prioritise the development of practical skills in vocational high school (SMK) students—skills that are crucial for entering the workforce. Meanwhile, VLL can serve as an adaptive solution to overcome infrastructure limitations and support hybrid or remote learning.

Therefore, it is recommended that teachers and schools integrate both learning models in a complementary manner. so that electrochemistry instruction in SMKs can be implemented holistically. A combination of hands-on laboratory activities and digital simulations will strengthen conceptual understanding, train laboratory work skills, and prepare students to become competent, adaptive vocational graduates ready to compete in a dynamic industrial environment. This is consistent with the findings of Chan et al. (2021) which states that the greatest effectiveness in chemistry education can be achieved through the integration of virtual and real laboratories (blended learning) as a unified instructional approach.

Conclusion

The implementation of Laboratory-Based Learning (LBL) and Virtual Lab-Based Learning (VLL) models has been shown to effectively enhance the understanding of electrochemistry among vocational high school (SMK) students. Notably, the LBL model demonstrated superior effectiveness compared to VLL, with an average learning gain of 49.67 points versus 41.47 points for VLL. The strength of the LBL approach lies in its hands-on experiential learning, which closely aligns with industry practices and is crucial for developing practical skills essential for students entering the chemical industry. Conversely, VLL offers advantages in flexibility and efficiency, particularly in settings with limited access to laboratory facilities. Based on these findings, an integrated approach that combines both models is recommended to create a comprehensive, effective, and contextually relevant electrochemistry learning environment that aligns with industrial demands. Specifically, LBL should be employed as the primary method for practice-oriented topics, supplemented by VLL to reinforce conceptual understanding and facilitate flexible, autonomous learning. This blended pedagogical strategy is anticipated to better prepare SMK students as competent, industry-ready graduates capable of adapting to modern technological environments.

AI-assisted technology statement (First-Level Heading)

While preparing this manuscript, the authors used ChatGPT (OpenAI) to improve grammar, language clarity, readability, and to assist in the visual layout of the graphical abstract. All AI-assisted outputs were carefully reviewed and refined by the author to ensure that the manuscript accurately reflects the actual research findings.

Acknowledgement (First-Level Heading)

The author expresses their sincere gratitude to the Program Pendidikan Guru (PPG), Sekolah Pascasarjana Universitas Negeri Malang, for funding this study. The authors also express an appreciation to SMK PGRI 3 Malang for granting permission and providing support in the implementation of this research. Special thanks are extended to the Grade X students of the Industrial Chemistry Program for their active participation throughout the learning activities and data collection process. The authors further thank the supervising lecturers, who greatly contributed to the refinement of this research and publication.

References

- Andhini, A. R., Mahmudah, H. A., Maudrey, L. I. A., Wahyuni, R., & Sulistina, O. (2024). Systematic Literature Review: Penggunaan Media Pembelajaran Virtual Lab pada Pembelajaran Kimia. *UNESA Journal of Chemical Education*, 13(2), 100–107. <https://doi.org/10.26740/ujced.v13n2.p100-107>
- Asworo, Y. D. (2024). Elektroplating Eksperimen sebagai Penguatan Konsep Elektrokimia. *JRPK: Jurnal Riset Pendidikan Kimia*, 13(2), 108–117. <https://doi.org/10.21009/JRPK.132.04>
- Brett, C. M. A., & Oliveira-Brett, A. M. (2024). An integrated perspective of electrochemistry teaching in science and technology. *Journal of Solid State Electrochemistry*, 28(3–4), 1007–1013. <https://doi.org/10.1007/s10008-023-05641-4>
- Chan, P., Van Gerven, T., Dubois, J.-L., & Bernaerts, K. (2021). Virtual chemical laboratories: A systematic literature review of research, technologies and instructional design. *Computers and Education Open*, 2, 100053. <https://doi.org/10.1016/j.caeo.2021.100053>
- Hawkins, I., & Phelps, A. J. (2013). Virtual laboratory vs. traditional laboratory: Which is more effective for teaching electrochemistry? *Chem. Educ. Res. Pract.*, 14(4), 516–523. <https://doi.org/10.1039/C3RP00070B>
- Mulyani, S., Lutfiyani, A., & Mahardiani, L. (2023). Development of a Virtual Chemistry Laboratory Based on Green Chemistry to Increase Technological Literacy Focusing on Factors Affecting Reaction Rates. *PAEDAGOGIA*, 26(1), 48. <https://doi.org/10.20961/paedagogia.v26i1.71851>
- Nirmala, W., & Darmawati, S. (2021). *The Effectiveness of Discovery-Based Virtual Laboratory Learning to Improve Student Science Process Skills*. 5.
- Nurdiansah, I., Surahman, E., Makiyah, Y. S., & Kurnia, E. (2024). The Effect of Laboratory-Based Blended-Project Based Learning Model on The Science Process Skills of Students. *Jurnal Pendidikan Fisika Indonesia*, 20(1), 74–84. <https://doi.org/10.15294/jpfi.v20i1.43491>
- Rahardjanto, A., Husamah, H., & Fauzi, A. (2019). Hybrid-PjBL: Learning Outcomes, Creative Thinking Skills, and Learning Motivation of Preservice Teacher. *International Journal of Instruction*, 12(2), 179–192. <https://doi.org/10.29333/iji.2019.12212a>

-
- Shana, Z., & Abulibdeh, E. S. (2020). Science practical work and its impact on students' science achievement. *Journal of Technology and Science Education*, 10(2), 199. <https://doi.org/10.3926/jotse.888>
- Siregar, E., Kusumawardani, D., & Bunyamin, E. M. (2022). Virtual Laboratory for Practical Learning in Vocational Education Using Nine Events of Instruction Approach. *Journal of Education Research and Evaluation*, 6(3), 457-467. <https://doi.org/10.23887/jere.v6i3.47691>
- Sophia, A., Rosbiono, M., & Anwar, S. (2021). Reconstruction of Chemistry Curriculum Elements of Vocational School (SMK) of Mechanical Engineering Study Program. *Journal of Educational Sciences*, 5(4), 622. <https://doi.org/10.31258/jes.5.4.p.622-637>
- Zhang, H., Su, S., Zeng, Y., & Lam, J. F. I. (2022). An Experimental Study on the Effectiveness of Students' Learning in Scientific Courses through Constructive Alignment—A Case Study from an MIS Course. *Education Sciences*, 12(5), 338. <https://doi.org/10.3390/educsci12050338>