# THE IMPACT OF VIRTUAL LABORATORY INTEGRATION ON ELECTROCHEMISTRY EDUCATION AT ENESSIE SECONDARY SCHOOL, HULET EJU ENESSIE DISTRICT, EAST GOJJAM, ETHIOPIA

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## ABSTRACT

This study, the Impact of Virtual Laboratory Integration on Electrochemistry was carried out in Enessie secondary school, East Gojjam, Ethiopia. The subjects 97 grade 10 students were taught the basics of electrochemistry. They were randomly assigned to a control group (47) and an experimental group (50). The experimental group received computer-animated teaching whereas the control group was taught using traditional lecture method on the same topics. The questionnaire analysis indicates that students in the Control group believed that the traditional lecture method with emphasis on explaining simple facts as the most important aspect to enhance their understanding of electrochemistry concept. Students in the experimental group clearly preferred instruction supported by virtual laboratories. The achievement test instrument was administered as a pre-test and post-test. The overall post-test analyses of the results showed that t(95) = -5.128, and the sig. value is 0.00001. Sig. value is < 0.05, it can be concluded that there is statistically significant difference between the post-test scores of the experimental group and the control group. The result revealed that computer simulation was more effective in enhancing students' achievement in electrochemistry than normal teaching method; minimizing learner's misconceptions, enhances the conceptual understanding of students, makes teaching and learning environment more visual than conceptual so that student can better relate, provide students active thinkers instead of passive observers. *[African Journal of Chemical Education—AJCE 15(1), January 2025]*

## INTRODUCTION

Chemistry, a cornerstone of Ethiopia's secondary school curriculum, plays a vital role in driving the nation's socioeconomic and technological advancement. Among the diverse topics within the chemistry curriculum, electrochemistry holds significant importance. This field explores the interconversion of chemical and electrical energy, encompassing both spontaneous and non-spontaneous reactions. Electrochemistry offers both theoretical insights and practical applications, providing a foundation for understanding and manipulating a wide range of chemical phenomena and processes. Key areas of application include electrolyte solutions, electroplating and electrorefining of metals, chemical production, and battery technology.

Electrochemistry, a fascinating field of study, often poses challenges for students due to its abstract nature. The difficulty lies in connecting the visible, macroscopic world with the invisible, submicroscopic realm of atoms and molecules. This disconnect can lead to misunderstandings and the formation of inaccurate mental models. To address this issue, it is crucial to develop innovative learning tools that can visually represent microscopic chemical processes. By making these abstract concepts tangible, we can enhance student learning and comprehension.

Virtual laboratories (VLs) have gained significant popularity as a valuable teaching tool across various learning contexts [1, 2]. VLs offer a flexible solution for conducting laboratory experiments, particularly when physical constraints or other limitations hinder traditional laboratory work [3]. By integrating information and communication technologies (ICT), VLs can make science more engaging and appealing to young learners. Research has consistently demonstrated the effectiveness of VLs in facilitating knowledge retention and comprehension compared to traditional teaching methods, suggesting that the implementation of VLs in electrochemistry education has the potential to significantly enhance student learning outcomes.

By incorporating animations and simulations into the learning process, particularly for abstract topics, students can become active participants in their own education. This interactive approach allows students to construct and comprehend complex concepts more readily [4]. Moreover, simulations and applications tailored to specific content can significantly accelerate learning by enabling students to express their understanding in real-time [3]. Technology can simplify complex information, providing students with opportunities for hands-on learning [5]. Consequently, the utilization of virtual laboratories or simulation programs can effectively address the limitations of traditional laboratory settings and contribute positively to achieving educational goals.

The integration of computers into science education offers numerous advantages, including personalized learning, simulations, visual representations, and the exploration of both microscopic and macroscopic phenomena. Computers empower students to independently solve problems and conduct research at their own pace. Globally, many students struggle to grasp chemistry concepts due to traditional teaching methods, leading to the development of misconceptions. Computer simulations have emerged as a promising solution to address these challenges [6]. Research suggests that computer simulations can effectively bridge the gap between concrete and abstract concepts [7]. Others emphasizes that these virtual experiences provide learners with valuable opportunities for hands-on learning [8].

Given the widespread popularity of animated characters among both young and adult audiences, it is reasonable to assume that computer-aided visuals incorporating animated characters could significantly enhance student engagement in chemistry education. These animated characters can facilitate discussions and guide students through complex concepts. Additionally, research has demonstrated that the integration of ICT in education can significantly deepen understanding [9].

The Enessie Secondary School in Hulet Eju Enessie Wereda, as reported by the local education office, has faced significant challenges in chemistry education. A concerning trend emerged between 2008 and 2010 E.C., with a substantial portion of grade 10 students scoring below 50% on the EGSECE chemistry exam [10]. This suggests a widespread lack of fundamental understanding of chemistry concepts among students.

Chemistry is often perceived as a challenging subject by researchers, teachers, and educators [11]. One of the primary difficulties in learning chemistry lies in its reliance on abstract concepts and models. Many students struggle to grasp these abstract ideas when they are presented solely at a theoretical level, lacking visual representations [12].

Electrochemistry is often perceived as an abstract and challenging subject for students [13]. Many students struggle to mentally connect the underlying concepts to concrete, real-world experiences. This abstract nature, particularly when dealing with invisible processes like electron movement, can lead to misconceptions and difficulties in understanding key topics such as electrolysis and its mechanisms [14, 15]. For instance, students may struggle to distinguish between anodes and cathodes or visualize the movement of ions and electrons during electrolysis [16].

Given the difficulty in visualizing the movement of electrons and ions during electrochemical processes [17], students often struggle to translate these processes into chemical equations and formulas [16]. To address this challenge, a combination of student-centered, activity-based, and lecture-based approaches has been recommended to enhance understanding of electrochemistry. Computer animations could provide a valuable tool to further support this learning process [18].

Given the limited research in this area, particularly at the secondary school level, there is a clear need to investigate the potential of virtual laboratories to enhance students' understanding of electrochemistry. This study aims to evaluate the impact of virtual laboratories on teaching electrochemistry at the secondary school level. Additionally, as there is a lack of research in the specific woreda, this study can serve as a foundation for future research in the area.

**Research Questions**

This research aims to address the following research questions:

1. **Effectiveness of Virtual Laboratories:** Does the use of virtual laboratory simulations lead to improved student achievement in electrochemistry compared to traditional lecture methods?
2. **Comparative Achievement:** What is the difference in mean achievement scores between students taught electrochemistry using virtual laboratories and those taught using traditional methods?
3. **Support for Teaching and Learning:** To what extent do virtual laboratories support the teaching and learning process of electrochemistry?
4. **Student Perception:** How do students perceive the use of virtual laboratory simulations in learning electrochemistry?

**Scope of the study**

This study was undertaken at Enessie Senior Secondary School, situated in Hulet Ejju Enessie Woreda, East Gojam Zone, during the 2015 E.C academic year. The research was delimited to grade 10 secondary school students, given the inclusion of electrochemistry in their chemistry curriculum. The study's content scope encompassed the following subtopics: electrolysis, electrochemical cells, electroplating, and electro refining.

## RESEARCH METHOD

### Description of the Study Area

The research was undertaken in Hulet Eju Enessie Woreda, one of the 113 woredas constituting the Amhara National Regional State. The woreda is subdivided into 24 administrative kebeles, with Motta serving as its capital city. Motta is situated within the East Gojjam administrative zone [19].

### Research Design

To explore the effectiveness of virtual laboratories in teaching electrochemistry, this study adopted a quasi-experimental design. Two groups were formed: an experimental group (EG) and a control group (CG). The EG experienced a unique learning environment that integrated virtual laboratories into their instruction, while the CG followed a traditional approach with hands-on experiments. To assess the impact of these different approaches, pre- and post-tests were administered to both groups. This design was inspired by similar studies conducted globally [20] but adapted to the specific challenges and opportunities of a developing country.

### Population and Sample

The study was conducted in Enessie senior secondary school with a population of over 2900 learners. The populations of the study include twenty sections of tenth grades each with an average of 55 learners making a total of 1100 students. Of the twenty classes, only two classes were chosen randomly. One class consists of 55 learners and the other class was 54 learners. Each participant from each class was randomly given a number from 1 to 55 and 1 to 54 respectively. They were then assigned to form equivalent EG and CG through random allocation. The participants with even numbers were assigned to the EG with 54 learners, while the other participants with odd numbers were assigned to the CG consisted of 55 learners. The CG and EG consisted of a total of 109 students.

But only 97 students continued all the time of the study. 47 (21 males: 26 femalels) and 50(22 males: 28 females) students from control group and experimental group respectively.

**Data Collection Instruments**

Data was collected through the administration of a pre- and post-test achievement test and a structured questionnaire. The achievement test, comprising 30 items (23 multiple-choice and 7 short answer), was designed to assess learners' prior knowledge of electrochemistry and their subsequent understanding of concepts post-instruction. The test items were selected to align with the grade 10 chemistry curriculum, drawing upon widely used textbooks and past examination questions. To establish reliability, the test was piloted and subjected to a test-retest analysis.

A six-point Likert scale questionnaire was employed to collect data. This even-numbered scale was selected to minimize neutral responses, thereby encouraging respondents to commit to a specific viewpoint [21]. The questionnaire, consisting of 14 items, was designed to assess participants' perceptions of virtual laboratories in electrochemistry instruction. The items were aligned with the Ethiopian chemistry teaching syllabus and validated by three experienced chemistry teachers.

**Data Collection Procedures**

Following the administration of the pre-test, both groups (EG and CG) underwent a three-week instructional period on electrochemistry. The EG was exposed to a blended learning approach, integrating traditional hands-on experiments with computer simulations and animations. In contrast, the CG received traditional instruction, relying solely on textbooks and hands-on experiments. After the intervention, the identical pre-test was re-administered as a post-test to both groups to evaluate their learning outcomes. Furthermore, a closed-ended questionnaire was administered to elicit learners' perceptions of the two instructional approaches.

## Data Analysis

Quantitative data, obtained from pre- and post-tests, were analyzed using descriptive statistics (mean and standard deviation) and inferential statistics (independent samples t-test and one-way ANOVA). The results of the questionnaire were analyzed using descriptive statistics and narrative explanations.

# RESULTS AND DISCUSSIONS

## Analysis of Test Scores

The final scores of the two groups on the pre- and post-tests were subjected to statistical analysis. Standard deviation, t-tests, and one-way ANOVA were employed to determine the significance of differences in performance between the experimental and control groups. Furthermore, mean scores were compared within each group to assess learning gains.

## Analysis of Pre-Test Results

A pre-test was administered to both the control and experimental groups to establish their baseline knowledge of electrochemistry. The results, as presented in Tables 1 and 2, indicate no statistically significant difference between the two groups ($p > 0.05$), suggesting that they were equivalent prior to the intervention.

Table1: Mean scores of pre-test and post-test of the Control and Experimental groups

| | | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| CG | pre test | 11.40 | 47 | 5.6314 | 0.8214 |
| | Post test | 30.34 | 47 | 7.320 | 7.3203 |
| EG | pre test | 11.18 | 50 | 5.9571 | 0.8424 |
| Post test | | 38.42 | 50 | 8.1412 | 8.1412 |

Table 2: Independent Sample T-test Result of Pre-test Scores

| | Mean | SD | SEM | 95% confidence interval Lower | Upper | T | df | Significance 2 tailed (p) |
|---|---|---|---|---|---|---|---|---|
| Pre-test CG | 11.40 | 5.63 | 0.8214 | 9.74 | 13.06 | 0.1902 | 95 | 0.8495 |
| EG | 11.18 | 5.95 | 0.8424 | 9.54 | 12.81 | | | |

**Analysis of Post-Test Results**

A comparison of the post-test scores for the experimental and control groups, as presented in Table 1 and Table 3, revealed a statistically significant difference ($t(95) = -5.128$, $p < 0.001$). This finding indicates that the virtual laboratory intervention had a positive impact on the achievement of learners in the experimental group.

Table 3: Independent Sample T-test Result of Post-test Scores

| | Mean | Sd | SEM | 95% confidence interval Lower | Upper | t | df | Significance 2 tailed (p) |
|---|---|---|---|---|---|---|---|---|
| Post-test CG | 30.34 | 7.3203 | 1.58 | 4.9519 | 11.2073 | -5.128 | 95 | 0.00* |
| EG | 38.42 | 8.1412 | | 36.1063 | 40.7337 | | | |

Table 4: Paired samples test

| | Paired Differences Mean | Std. Deviation | Std.Error Mean | 95%confidence interval of the difference Lower | upper | t | df | Sig |
|---|---|---|---|---|---|---|---|---|
| CG pre test Post test | 18.94 | 5.81721 | 0.8485 | 17.2769 | 20.6030 | 22.315 | 46 | 0.00* |
| EG pre test Post test | 27.24 | 6.3694 | 0.9007 | 25.4745 | 29.0054 | 30.239 | 49 | 0.00* |

The paired samples test shows that there were significant differences between the pre- and post-test scores of each group, favoring the post-test. There was a significant difference in the pre-test scores (Mean=11.40, SD=5.63) of students who were exposed to CG compared to the post-test scores (Mean=30.34, SD=7.32); t (46) =-22.31, p=0.00. Similarly There was a significant difference in the pre-test scores (Mean=11.18, SD=5.95) of students who were exposed to EG compared to the post-test scores (Mean=38.42, SD=8.14); t (49) =-30.24, p=0.00.

When overall pre- and post-test results of the participant students were examined in more detail, it was observed that the mean score of the CG students increased from 11.40 to 30.34, while the mean score of EG students increased from 11.18 to 38.42. Students paired samples test showed that the greatest increase was shown in the EG group. This implies that students taught electrochemistry using virtual laboratory at least as effectively as those taught using normal teaching method.

The results of the one-way ANOVA, comparing pre and post-test scores of the control and experimental group students are presented in Table 5.

Table 5: One-Way ANOVA results comparing pre- and post-test scores of CG and EG students

| Source | | Sum of squares | df | Mean | F | P | Effect size |
|---|---|---|---|---|---|---|---|
| Pre-test | Between groups | 1.218 | 1 | 1.218 | 0.036 | 0.849 | 0.0386 |
| | Within groups | 3197.699 | 95 | 33.660 | | | |
| | Total | 3198.918 | 96 | | | | |
| Pre-test | Between groups | 1581.514 | 1 | 1581.514 | 26.299 | 0.00* | 1.0419 |
| | Within groups | 5712.733 | 95 | 60.134 | | | |
| | Total | 7294.247 | 96 | | | | |

As seen in Table 5, there was no significant difference between the groups at the beginning of the study [F (1-95) = 0.036, p > .05]. However, at the end of the study, there were significant differences between the groups [F (1-95) =26.3, p < 0 .05].

**Responses of Questionnaires**

The questionnaire was meant to assess the responses of Chemistry grade 10 learners from Enessie secondary school. The learners' responses to the questionnaires analyzed using six-point Likert scale. Scores of learners were obtained by summing up the number of responses under each rating on the scale using the codes 1,2,3,4, 5 and 6 representing strongly disagree (StD), disagree (D), slightly disagree (SlD), slightly agree (SlA), agree (A), and strongly agree (StA), respectively.

The six-point Likert scale was further categorized interims of percentage for agreement ("Slightly Agree', 'Agree' and 'Strongly Agree') and disagreement (Strongly Disagree, Disagree and Slightly Disagree) for easy analysis. There were fourteen statements on a six-point Likert scale learners' questionnaire requiring learners to indicate their opinions about the use of virtual laboratory, in the teaching and learning of electrochemistry. The questionnaire was administered to 97 learners.

**The Extent to Which Learners Are Able to Relate Concepts.**

In learning electrochemistry, it is important that learners understand and know how to connect the concepts with all three demonstration levels (macroscopic, symbolic, and sub-microscopic). Table 6 represents the results in terms of percentage for a Likert scale grouped into agreed and disagreed.

Question1 indicated that almost all 92 % (mean=4.8) of the respondents in the EG agreed that virtual laboratory provides to understand the linkage between the concepts compared to63.8 % (mean=3.9) of the respondents in the CG. Question 2 put forward an insight in to the part of the plan to minimize learners' misconception. 88%(mean=4.8)of respondents in the EG agreed that the teacher presentation using virtual lab corrected some of their misunderstandings about the processes occurring in the electrochemical cells compared to only 53.3%(mean=3.8) of the respondents in the CG. Responses from question 3 indicates nearly all 94 % (mean=1.6) of the respondents of the EG shown the high percentage of disagreement compared to only 57.4 % (mean=3) of the respondents in the CG. This suggests that virtual laboratory was accepted as a better method of teaching to relate concepts.

Table 6: The extent to which learners are able to relate concepts

| The extent to which learners are able to relate concepts | Codes | | | | | | Likert scale | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 5 | 4 | 3 | 2 | 1 | agreed | % | disagreed | % | Mean |
| 1a. The instruction was understandable enough for me to see the linkage between the concepts. | 2 | 15 | 13 | 11 | 6 | - | 30 | 63.8 | 17 | 36.2 | 3.9 |
| 1b. The virtual laboratory was understandable enough for me to see the linkage between the concepts. | 14 | 19 | 13 | 3 | 1 | - | 46 | 92 | 4 | 8 | 4.8 |
| 2a. The teacher presentation using traditional lecture corrected some of my misunderstandings about electrochemical processes. | 4 | 12 | 9 | 14 | 8 | | 25 | 53.2 | 22 | 46.8 | 3.8 |
| 2b. The teacher presentation using virtual lab corrected some of my misunderstandings about electrochemical processes. | 6 | 35 | 3 | 4 | 2 | - | 44 | 88 | 6 | 12 | 4.8 |
| 3a. The teacher's explanation cannot help me to relate the electrolytic cells to the refining of blister copper. | 1 | 3 | 16 | 8 | 13 | 6 | 20 | 42.6 | 27 | 57.4 | 3 |
| 3b. The teacher's explanation using virtual lab cannot help me to relate the electrolytic cells to the refining of blister copper. | - | 1 | 2 | 4 | 13 | 30 | 3 | 6 | 47 | 94 | 1.6 |
| 4a. The lessons in the class helped me to identify the deference between voltaic cell and electrolytic cells. | 4 | 11 | 17 | 8 | 6 | 1 | 32 | 68.1 | 15 | 31.9 | 3.9 |
| 4b. The animation in the class helped me to identify the deference between voltaic cell and electrolytic cells. | 8 | 23 | 10 | 5 | 4 | - | 41 | 82 | | 18 | 4.5 |

**Learners' Interest and Attitudes towards Learning Materials**

Virtual laboratories can enhance student motivation in chemistry by providing interactive and immersive learning experiences [22]. Table 7 represents the results in terms of percentage for a Likert scale grouped into agreed and disagreed. In relation to this question 5 and 7 shows that more than 90% of EG respondents agreed virtual laboratory increased their interest to learn the content knowledge compared to only 48.9% and 55.3% of the respondents in the CG respectively. The high percentage of agreement shown by experimental group for question 9 (84%, mean 4.6) and the low percentage of agreement in the control group (40.4%, mean 3.1) indicates that learners expect virtual laboratory was important to give explanation the electrochemical processes at each electrode. The high percentage of disagreement 92% (the question expressed in negative statement) for question 5 shown by EG give an insight in to the importance of animation in learning voltaic cell compared to only 53.2% respondents in the CG. Question 8 shows clearly that 86% (mean=4.8) of the respondents in experimental group strongly agreed that the teacher explanation through virtual lab created good learning environment compared to only 44.7% (mean=3.2) of the respondents in the control group.

Table7: the extent to which Learners' interest and attitudes towards virtual lab.

| The extent to which learners' interest and attitudes towards virtual lab. | Codes | | | | | | Likert scale | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 5 | 4 | 3 | 2 | 1 | agreed | % | disagreed | % | Mean |
| 5a. I think the lessons shown in the class motivates me to learn electrochemical cells. | 6 | 8 | 12 | 11 | 7 | 3 | 23 | 48.9 | 24 | 51.1 | 3.7 |
| 5b.I think the animation shown in the class motivates me to learn electrochemical cells. | 9 | 23 | 13 | 2 | 3 | - | 45 | 90 | 5 | 10 | 4.7 |
| 6a. I find it time consuming to use transparencies in learning voltaic cell. | - | 7 | 15 | 8 | 12 | 5 | 22 | 46.8 | 25 | 53.2 | 3.1 |
| 6b. I find it time consuming to use virtual laboratory in learning voltaic cell. | - | 1 | 3 | 6 | 21 | 19 | 4 | 8 | 46 | 92 | 1.9 |
| 7a I think the teacher explanation using transparencies increased my interest in learning electrolysis. | 4 | 8 | 14 | 16 | 3 | 2 | 26 | 55.3 | 21 | 44.7 | 3.7 |
| 7b. I think the teacher explanation using virtual lab increased my interest in learning electrolysis. | 26 | 16 | 5 | 2 | 1 | - | 47 | 94 | 3 | 6 | 5.3 |
| 8a. The lecture creates good learning environment. | 3 | 8 | 10 | 5 | 16 | 3 | 21 | 44.7 | 26 | 55.3 | 3.2 |
| 8b. Virtual laboratory create good learning environment. | 14 | 22 | 7 | 5 | 2 | - | 43 | 86 | 7 | 14 | 4.8 |
| 9a. The lecture helped me to predict the processes at each electrode. | - | 8 | 11 | 10 | 13 | 5 | 19 | 40.4 | 28 | 59.6 | 3.1 |
| 9b. Virtual lab helped me to predict the processes at each electrode. | 9 | 21 | 12 | 6 | 2 | - | 42 | 84 | 8 | 16 | 4.6 |

**The Extent to Which Learners Understand Difficult and Abstract Concept**

Using animations and simulations in teaching abstract topic, students become active in their learning, providing an opportunity for students to construct and understand difficult concepts more easily [4]. Table 8 shows the results in terms of percentage for agreement and disagreement. In relation to this the teacher explanation should provide learners to know the meaning of the concept and it makes comprehensible to them. Question 10, 11, 12, 13 and 14 try to confine how the respondents understand abstract concepts (the electrochemical chemical processes occur in Daniel cell, the movement of electrons) and electrochemistry concepts in general. Question 13 shows that 86% (mean=4.5) of the respondents in the EG and more than 78% of the respondents in CG agreed that the instruction through animation for EG and the instruction through traditional lecture method offer understandable explanation. On the other hand, for specific abstract concepts about the movement of electrons in question10, 92% (mean=4.8) of the respondents in the experimental group agreed that virtual laboratory makes easier to understand the concept compared to only 32% (mean=2.8) of respondents in control group and in question 12 the high percentage of disagreement 78%, mean=2.4 (the question expressed in negative statement) of the respondent in EG clearly shows they can understand the processes occurring in Daniel cell compared to only 51.1% (mean=3.6) of the respondents in the CG. The high percentage of agreement 90% (mean=4.9) for question 11 in the EG compared to only 38% (mean=3.4) of respondents in CG revealed that the animation used in the teaching process simplifies complex and abstract concepts.

Table 8: The extent to which learners understand difficult and abstract concept

| The extent to which learners understand difficult and abstract concept | Codes 6 | 5 | 4 | 3 | 2 | 1 | Likert scale agreed | % | disagreed | % | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10a. The lecture helps me to understand easily the movement of electrons in the electrolytic cell from one electrode to another in the external circuit. | - | 3 | 12 | 10 | 17 | 5 | 15 | 32 | 32 | 68 | 2.8 |
| 10b. The virtual laboratory helps me to understand easily the movement of electrons in the electrolytic cell from one electrode to another in the external circuit. | 9 | 29 | 8 | 3 | 1 | - | 46 | 92 | 4 | 8 | 4.8 |
| 11a. The teacher simplifies complex and abstract concepts using transparencies, making it easier to understand. | 3 | 7 | 6 | 20 | 11 | - | 16 | 38 | 31 | 62 | 3.4 |
| 11b. The teacher simplifies complex and abstract concepts using simulation, making it easier to understand. | 13 | 25 | 7 | 4 | 1 | - | 45 | 90 | 5 | 10 | 4.9 |
| 12a. I do not understand how to build Daniel cell and the processes occurring in the cell even after attending the class. | 2 | 8 | 13 | 16 | 5 | 3 | 23 | 48.9 | 24 | 51.1 | 3.6 |
| 12a. I do not understand how to build Daniel cell and the processes occurring in the cell even after attending the class | - | 1 | 10 | 3 | 29 | 7 | 11 | 22 | 39 | 78 | 2.4 |
| 13a. I can describe the difference between weak and strong electrolytes after attending the class. | 3 | 18 | 16 | 8 | 2 | - | 37 | 78.7 | 10 | 21.3 | |
| 13b. I can describe the difference between weak and strong electrolytes after attending the class. | 4 | 22 | 18 | 6 | 1 | - | 44 | 86 | 7 | 14 | |
| 14a. It was very simple to write the overall reactions occurring in voltaic cells after the class. | 1 | 6 | 8 | 7 | 24 | 1 | 15 | 31.9 | 32 | 68.1 | |
| 14b. It was very simple to write the overall reactions occurring in voltaic cells after the class. | 9 | 21 | 5 | 13 | 2 | - | 35 | 70 | 15 | 30 | |

**Discussion**

The pre-test achievement scores of students in the experimental group (EG) and control group (CG) were compared using a t-test. No statistically significant difference was found between the two groups ($t(95) = 0.19$, $p > 0.05$). This indicates that both groups had similar levels of electrochemistry knowledge at the outset of the study. Therefore, Hypothesis 1, which states that there is no significant difference in pre-test scores between students taught using computer simulations and those taught using the lecture method, is supported.

The results of this study highlight the positive impact of virtual laboratory instruction on students' understanding of electrochemistry. A t-test revealed a significant difference in post-test achievement scores between the experimental group (EG) and control group (CG) in favor of the EG ($t(95) = -5.128$, $p < 0.05$). This indicates that the use of virtual laboratories significantly enhanced students' learning outcomes compared to traditional teaching methods. Therefore, Hypothesis 2, which states that there is no significant difference in post-test scores between students taught using computer simulations and those taught using normal methods, is rejected.

These findings align with previous research that has highlighted the potential of technology-enhanced instruction to improve students' learning outcomes in electrochemistry. Different research has shown that students who are exposed to innovative instructional methods, such as animation-integrated, computer-animated, or simulation-based approaches, tend to outperform those who are taught using traditional methods [23, 24, 25].

The questionnaire findings suggest that virtual laboratory instruction was well-received by students in the experimental group. A significant number of students strongly agreed that virtual labs enhanced their learning experience by creating an engaging environment, stimulating interest in electrochemistry, and providing visual representations of abstract concepts that were otherwise difficult to grasp.

## CONCLUSION

The significant difference in mean achievement scores between the experimental and control groups highlights the positive impact of virtual laboratory instruction on students' understanding of electrochemistry. Students exposed to virtual laboratories demonstrated significantly higher performance, indicating that this innovative approach can effectively enhance learning outcomes.

This study demonstrated the significant benefits of using virtual laboratories in teaching electrochemistry. By minimizing the abstract nature of hazardous concepts, providing interactive learning experiences, and fostering active engagement, virtual laboratories can enhance students' conceptual understanding, improve their perception of the subject, and ultimately lead to more effective learning outcomes.

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**APPENDIX**

A Questionnaire for Learners on using Computer Simulations in Teaching Electrochemistry

Name: …………………………………… Date: …………… Section: ……

All responses provided in this questionnaire will be kept strictly confidential.

**Instructions:** Please indicate your response by checking the appropriate box. Use the codes given, 1 for strongly disagree, 2 for disagree, 3 for slightly disagree, 4 for slightly agree, 5 for agree and 6 for strongly agree by writing a code ✓or x of your choice against the questions.

| No | Questionnaires | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1. | The virtual laboratory was understandable enough for me to see the linkage between the concepts. | | | | | | |
| 2. | The teacher presentation using virtual lab corrected some of my misunderstandings about electrochemical processes. | | | | | | |
| 3. | The teacher's explanation using virtual lab cannot help me to relate the electrolytic cells to the refining of blister copper. | | | | | | |
| 4. | The animation in the class helped me to identify the deference between voltaic cell and electrolytic cells. | | | | | | |
| 5. | I think the animation shown in the class motivates me to learn electrochemical cells. | | | | | | |
| 6. | I find it time consuming to use virtual laboratory in learning voltaic cell. | | | | | | |
| 7. | I think the teacher explanation using virtual lab increased my interest in learning electrolysis. | | | | | | |
| 8. | Virtual laboratories create good learning environment. | | | | | | |
| 9. | Virtual lab helped me to predict the processes at each electrode. | | | | | | |
| 10. | The virtual laboratory helps me to understand easily the movement of electrons in the electrolytic cell from one electrode to another in the external circuit. | | | | | | |
| 11. | The teacher simplifies complex and abstract concepts using simulation, making it easier to understand. | | | | | | |
| 12. | The teacher simplifies complex and abstract concepts using simulation, making it easier to understand. | | | | | | |
| 13. | I do not understand how to build Daniel cell and the processes occurring in the cell even after attending the class | | | | | | |
| 14. | I can describe the difference between weak and strong electrolytes after attending the class | | | | | | |