UNIVERSITY OF EDUCATION, WINNEBA

THE DIFFERENTIAL EFFECTS OF PHYSICAL AND VIRTUAL LABORATORY RESOURCES ON STUDENTS' PERFORMANCE IN ELECTROCHEMISTRY: A COMPARATIVE STUDY

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BY

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A thesis in the Department of Science Education, Faculty of Science Education, submitted to the School of Graduate Studies in partial fulfilment

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NOVEMBER, 2023

DECLARATION

Candidates Declaration

I, MAWULI KWAME MENSAH, hereby declare that except references to other people's works which have been duly cited and acknowledged, this thesis is the result of my own work and that no part of it has been presented for another dissertation in the University or elsewhere.

MAWULI KWAME MENSAH	……………………..	22/ 11/ 2023
CANDIDATE	SIGNATURE	DATE

Supervisor's Declaration

I, PROF. JOHN K. EMINAH hereby declare that the preparation and presentation of this thesis was supervised by me in accordance with the guideline on supervision of thesis laid down by the University of Education, Winneba.

PROF. JOHN K. EMINAH	……………………..	……………………
SUPERVISOR	SIGNATURE	DATE

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DEDICATION

This research work is dedicated to God almighty, my late father, Mr. D.B.K. Mensah, my mother Mad. Juliana Kpedegbo and my three lovely daughters, Selinam, Seyram and Setriakor Ekpe- Mawuli.

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ABSTRACT

This research sought to compare the effectiveness of using physical and virtual laboratory resources on students' performance in electrochemistry lessons. The study evaluated the effect of traditional physical laboratory resources in enhancing students' performance. Additionally, it examined the effect of virtual laboratory resources, including augmented reality tools, on students' performance, focusing on benefits and limitations in facilitating learning, practical skills development, and problem-solving abilities. The study was conducted in Reverend John Teye Memorial Institute, Senior High school (RJTMISHS). It is a private Christian school located at Ofankor in the Greater Accra Region of Ghana. The study employed Action Research design. SHS2 science class made up of ten (10) males and nine (9) female students were used for the study. The students were put in Plab group and Vlab group. The students were chosen based on their individual scores on the pre-intervention test. The scores of male and female students were segregated. They were then organized into groups by selecting students with the highest scores for one group, the second-highest for another group, and so on, until all male students were placed into two separate groups. The same process was applied to group the female students. One representative from each group volunteered for a ballot. Those who selected the virtual lab option formed the virtual lab group, while those who chose the physical lab option became part of the physical lab group. They were then taught same electrochemical topics simultaneously using Physical and virtual laboratory resources respectively. The Vlab group is made of 10 students, consist of 5 male and 5 female, while Plab group is made of 9 students, consisting of 5males and 4 females. Data was collected through students' laboratory reports, quizzes, end of term examinations and questionnaire. Descriptive statistics such as mean and variance as well as inferential statistics mainly t-test were used to analyze the data obtained. Pie chart and bar graph were also used for better interpretation. The findings revealed a positive improvement in students' performance in electrochemistry when taught using both physical and virtual laboratory resources. Both groups benefitted significantly from their respective interventions, and there was no significant difference in their understanding of electrochemical concepts, leading to improved performance. Statistical analysis of the mean post-test scores indicated that the differences between the physical laboratory (Plab) and virtual laboratory (Vlab) groups were not statistically significant (p-value = 0.71, greater than 0.05). Regarding gender comparison, male and female students performed equally when taught using virtual laboratory resources. There was no significant difference between the mean post-test scores statistically, as indicated by a p-value of 0.96 (greater than 0.05). However, in the physical laboratory group, male students performed better than their female counterparts, although the difference was not statistically significant (p-value = 0.054, slightly greater than 0.05). Additionally, the female students performed better when taught using virtual laboratory resources than physical laboratory resources. The majority of students demonstrated ease in measuring, analyzing, and interpreting data obtained from both virtual and physical experiments. Additionally, the results showed a significant increase in students' motivation and interest in learning electrochemistry when either of the laboratory resources was used. While acknowledging the usefulness of virtual laboratories, the overwhelming majority of students believed that they cannot fully replace physical laboratories. Reasons cited included the lack of real-world experience and the potential unpreparedness for hands-on activities in the field. Students emphasized the importance of hands-on experience and the potential for inaccurate results in virtual experiments. Challenges and limitations identified for

physical laboratories included limited accessibility, higher costs, lower student engagement, and potential safety concerns. Challenges for virtual experiments included inadequate guidance, difficulty in simulating certain experiments, lack of real-world context, technical issues, and limited hands-on experience. The study concludes that while virtual laboratories have their benefits, they should complement rather than fully replace physical laboratories. It provides insights into the comparative advantages and limitations of physical and virtual laboratory resources, informing educational practices and curriculum development in electrochemistry.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter discusses the background to the study which includes a review of the research area and some current information surrounding the issue of the study and a written statement of the problem indicating some contentious issues. The purpose and objectives of the study also form part of this chapter. The research questions and the conclusion of this chapter comprises the delimitations, limitations of the study, definition of terms, abbreviation and acronyms, and organization of the research report.

1.1Background to the Study

As part of the preparation for the final external examination in chemistry, the researcher conducted a Grand Final Mock Examination (GFME). This helped to accurately predict the possible grades that students would score in the final external examinations, conducted by WAEC. West African Senior School Certificate Examination (WASSCE) chemistry consists of three papers, namely Paper 1(multiple choice question), Paper 2 (Free-response question), and Paper 3 (practical questions).

In examining the scores on mock examination papers over the last three years (2019-2021), in Reverend John Teye Memorial Institute, Senior High school, the researcher observed that, on average, 56% of the students selected a multi-part, open-ended question regarding oxidation/reduction and electrochemistry. This question emerged as the second most favoured optional choice among the students. However, out of a maximum mark of 25, the marks scored ranged from 3 to 15. The students who opted for this question cast across all the ability groups in the various classes. The most interesting thing is that the average score is 8 out of 25 marks. Clearly, this is an area that needs attention.

In the past, the researcher used lectures and diagramming on a board to teach this topic with the objectives as an outline since the researcher has very limited laboratory resources available. In this study, the researcher intended to teach with the physical laboratory resources and AR virtual laboratory resources and do a comparative analysis on the improvement of students' performance in the electrochemistry.

During lockdown as a result of the covid-19 Pandemic, the researcher used virtual laboratory and computer simulation to teach a few topics. As much as it's been acknowledged that it is useful, the researcher was wondering if virtual laboratories have the same or better effect on the performance of the students. Reading a few reports on the subject matter, it has been realized that there is an academic debate on whether virtual laboratories and computer simulations can be substituted to physical traditional laboratories.

While conceding the usefulness of the virtual laboratory and computer simulation, Larbi-Apaau (2020), cautioned competency-based institutions such as technical universities on e-learning requirements as far as hands-on training and assessment strategies are concerned. Also, there is a need to design effective learning environments which are more suitable to students' characteristics in the digital age and can help them to acquire science inquiry and practical skills (Hamed & Aljanazrah, 2020). Oser (2013), cited in Russel (1999), intimated that the integration of technology into science laboratories has begun but several researchers note the lack of empirical evidence concerning its effectiveness in general and the effectiveness of using virtual laboratories in particular.

1.2 Statement of the Problem

Laboratory work is an essential component of the study of natural science disciplines. This helps the students to learn concepts, develop practical skills, and illustrate theory (Johnstone & Al-Shuaili, 2001). The laboratory work also increases students' curiosity and positive attitudes toward science learning (Bretz, Fay, Bruck, & Towns, 2013).

Regrettably, the performance of students in practical chemistry which is supposed to enhance a meaningful learning is very poor in the researcher's school, due to limited laboratory space and insufficient laboratory facilities. Therefore, hands-on practical activities are rarely performed and when they are organized, only a few students take an active part in the activities. For these reasons, the researcher explored the possibility of exposing selected students to virtual laboratory resources, obtained from the internet using the school's internet and computer laboratory and physical laboratory resources so as to compare their facility and effectiveness.

1.3 Purpose of the Study

The purpose of this study is to compare the effect of virtual laboratory resources and physical laboratory resources on students' performance in electrochemistry.

1.4 Objectives of the Study

The objectives of the study are to determine:

1. the difficulties students encounter during electrochemistry practical activities.
2. the effect of physical laboratory resources on the student's performance in electrochemistry.
3. the effect of virtual laboratory resources on students' performance in electrochemistry.

4. the students' perceptions of the use in virtual and physical laboratory resources for electrochemistry lessons.

1.5 Research Questions

Based on the objectives of the study, the following research questions were formulated:

1. What difficulties do the students encounter during electrochemistry practical sessions?
2. What is the effect of physical laboratory resources on the student's performance in electrochemistry?
3. What is the effect of virtual laboratory resources on the student's performance in electrochemistry?
4. What are the students' perceptions of the use of physical and virtual laboratory resources for electrochemistry practical activities?

1.6 Null Hypotheses

The following Null hypothesis were formulated:

1. There is no significant difference in students' performance in electrochemistry between those utilizing physical laboratory resources and those using virtual laboratory resources.
2. There is no significant difference in the performance of male and female students taught electrochemistry, using virtual laboratory resources.
3. There is no significant difference in the performance of male and female students taught electrochemistry, using physical laboratory resources.

1.7 Significance of the Study

The significance of the study is enumerated below:

1. Educational Improvement: The study holds significant implications for enhancing the quality of education in the field of electrochemistry. By comparing the effectiveness of physical and virtual laboratory resources, educators and curriculum developers can make informed decisions regarding the integration of these resources to improve students' learning experiences, knowledge acquisition, and practical skills development.
2. Technology Integration: The study explores the integration of virtual laboratory resources, including augmented reality (AR), in electrochemistry education. Understanding the impact of these emerging technologies can pave the way for future advancements in educational practices and promote the integration of technology in STEM fields.
3. Evidence-Based Decision Making: The study provides empirical evidence and insights into the effectiveness of different laboratory resources. The findings can guide educational policymakers, administrators, and instructors in making evidence-based decisions when selecting and implementing laboratory resources in electrochemistry education.
4. Pedagogical Strategies: The study contributes to the development of effective pedagogical strategies by examining how different types of laboratory resources influence students' performance and engagement. The findings can help educators design instructional approaches that align with students' learning needs, preferences, and technological competencies.
5. Student Performance Enhancement: By comparing the impact of physical and virtual laboratory resources, the study aims to identify strategies that can enhance students' performance in electrochemistry. This knowledge can lead to

the development of interventions and educational interventions that target specific areas of improvement and facilitate better learning outcomes.

6. Curriculum Development: The study's findings can inform curriculum developers in designing and revising electrochemistry curricula, incorporating the most effective laboratory resources. By aligning the curriculum with the outcomes of the study, educational institutions can ensure that students receive a comprehensive and engaging learning experience in electrochemistry.
7. Future Research Directions: The study identifies research gaps and areas for further investigation in the field of physical and virtual laboratory resources in electrochemistry education. It sets the foundation for future studies that can delve deeper into specific aspects, such as the impact of AR, the influence of different virtual laboratory platforms, or the long-term effects of integrating virtual resources in the curriculum.

Overall, the significance of this study lies in its potential to inform educational practices, advance technological integration, and contribute to the continuous improvement of electrochemistry education. The findings can benefit students, educators, curriculum developers, and policymakers, ultimately leading to better learning outcomes and preparing students for success in the field of electrochemistry.

1.8 Limitations of the Study

The following are the limitations of the study.

- Power source and internet reception affected the conduct of the virtual experiment.
- The study encountered issues related to research attrition, as the initial group of 21 students was reduced to 19 students by the end of the study.

Additionally, a few students were absent from the lesson due to various reasons. These circumstances could potentially impact the integrity of the collected data.

- Data collected from only one school may affect the generalizability of the findings of the study to other schools.

1.9 Delimitations of the Study

This study involved only SHS2 students. SHS1 and SHS3 students were excluded from the research subjects. The study focused on some selected electrochemistry topics. The other chemistry topics in the SHS chemistry syllabus were excluded.

1.10 Definition of Terms

The following terms are given with their operational definition.

Augmented Reality	An interactive experience that enhances the real world with computer-generated perceptual information.
Electrochemistry	Electrochemistry is a branch of chemistry that deals with the study of the relationship between electrical and chemical phenomena. It involves the interconversion of chemical energy and electrical energy, as well as the understanding of how chemical reactions occur at the molecular level in the presence of an electric current.
Grand final mock examination	A grand mock examination is a comprehensive and thorough practice test that simulates the format and difficulty level of a final examination. It is designed to assess a student's knowledge, understanding, and skills across multiple subjects or topics. The term "grand" emphasizes the extensive nature

	of the examination, covering a wide range of subjects or a substantial portion of the curriculum.
Students' performance	This is the student's scores obtained in an electrochemistry exercise or examination.
Physical/ traditional laboratory	A physical laboratory refers to a dedicated space equipped with specialized tools, equipment, and materials for conducting scientific experiments and research. It is a controlled environment where scientists, researchers, and students can perform hands-on experiments, make observations, collect data, and analyze results.
Virtual laboratory	A virtual laboratory, also known as a virtual lab or virtual simulation, refers to a digital environment that replicates the experience and functionality of a physical laboratory. It provides a computer-based platform where students, researchers, and educators can engage in simulated scientific experiments and explore various scientific concepts.
Resources	The term "resources" generally refers to the available means, assets, or materials that can be used to achieve a particular goal or fulfill a specific purpose. Resources can be tangible or intangible and can vary depending on the context in which they are used.
Pre-intervention test	A test given to students before exposing them to teaching methods.

Post-intervention test	A test given to students after exposing them to teaching methods.

1.11 Abbreviations and Acronyms

AR	Augmented Reality
Plab	Physical laboratory
Vlab	Virtual laboratory
WASSCE	West African Secondary School Certificate Examination.
SHS	Senior High School
STEM	Science, technology, engineering, and mathematics
CAI	Computer Assisted Instruction
RTMISHS	Reverend John Teye Memorial Institute, Senior High school
Vles	Virtual learning environments

1.12 Organization of the study Report

The thesis comprised five chapters that were organised as follows: chapter one discusses the background to the study which includes a review of the research area and some current information surrounding the issue of the study and a written statement of the problem indicating some contentious issues. The purpose and objectives of the study also form part of this chapter. The research questions and the conclusion of this chapter comprises the delimitations, limitations of the study, definition of terms, abbreviation and acronyms, and organization of the research report.

Chapter two dealt with the literature review of the study. By looking at theoretical framework, practical and experimental skills (pes), goals for laboratory experiences, types of laboratory work, virtual laboratories and simulations, virtual laboratory vs physical laboratory, virtual experiments and students' achievement, Electrochemistry and related topics, understanding electrochemistry, problem – Solving Skills in Electrochemistry, learning difficulties in electrochemistry, misconceptions in electrochemistry and techniques for teaching electrochemistry. Chapter three dealt with the methodology, which includes research design, population, and sampling procedures, the instrument used for the study, data collection procedure, data analysis, and ethical considerations. Chapter Four dealt with the results and discussion of the study. Chapter Five dealt with the summary of key findings, conclusions, recommendations, suggestions for further research, and contributions of the study to chemistry educators.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter focuses on other previous studies that related to this research. The literature is reviewed under the following headings; Theoretical framework, practical and experimental skills, goals for laboratory experiences, types of laboratory work, virtual laboratories and simulations, virtual laboratory vs physical laboratory, virtual experiments and students' achievement, definition of electrochemistry, understanding electrochemistry, problem–solving skills in electrochemistry, learning difficulties in electrochemistry, misconceptions in electrochemistry, techniques for teaching electrochemistry.

2.1 Theoretical Framework

It is expected that virtual and physical labs will inspire active learning in the students. Active learning is a set of strategies that posits the responsibility for learning with the student (Amineh & Asl, 2015). Discovery learning, problem-based learning, experiential learning, and inquiry-based instruction are examples of active learning. Discussion, student questioning, think-pair-share, quick-writes, polling, role-playing, cooperative learning, group projects, and student presentations are a few of the many activities that are learner driven (Herr, 2007).

Virtual and physical labs can also be great tools for constructivist teachers. Constructivism is a major learning theory and is particularly applicable to the teaching and learning of science (Herr, 2007). Piaget suggested that through accommodation and assimilation, individuals construct new knowledge from their experiences. Constructivism views learning as a process in which students actively construct or build new ideas and concepts based on prior knowledge and new information. The constructivist teacher is a facilitator who encourages students to discover principles and construct knowledge within a given framework or structure (Herr, 2007).

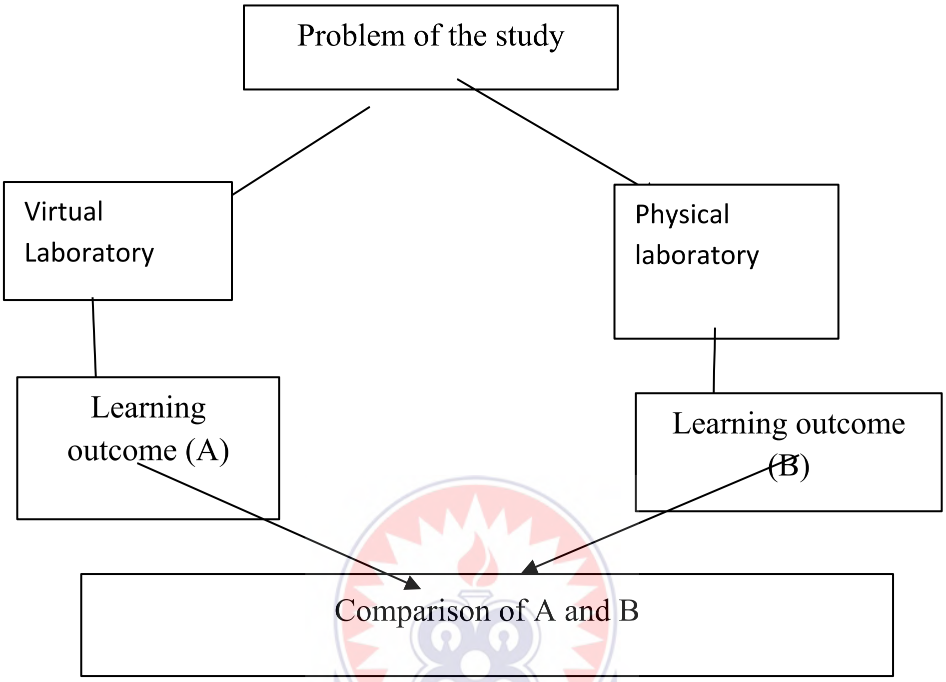


Figure 1: Theoretical framework of the study

Figure 1. shows how problems identified in the study and how they are to be addressed by the two interventions, namely practical laboratory resources and virtual laboratory resources. The researcher integrates constructive learning theory in the two interventions respectively. This theory builds on the active involvement of students during the learning process (Amineh & Asl, 2015). It also encourages peer interaction so that a collaborative learning process occurs among status equals. Also, students can be able to see, touch, smell, and taste the product of the experiment (Afyusisye & Gakuba, 2022). Though this may vary between the two laboratory resources, this act can raise their interest in chemistry, and they become motivated in the learning process (Afyusisye & Gakuba, 2022). The whole teaching process is kind of learner-centred as

it involved the active participation of students. The learning outcomes are being compared in terms of their academic performance, and their perceptions.

2.3 Goals for Laboratory Experiences

National Research Council (2006) identified the following being the goals of the laboratory experiences

1. Enhancing mastery of subject matter. Laboratory experiences may enhance student understanding of specific scientific facts and concepts and of how these facts and concepts are organized in the scientific disciplines (National Research Council, 2006).
2. Developing scientific reasoning. Laboratory experiences may promote a student's ability to identify questions and concepts that guide scientific investigations; to design and conduct scientific investigations; to develop and revise scientific explanations and models; to recognize and analyze alternative explanations and models; and to make and defend a scientific argument. Making a scientific argument includes such abilities as writing, reviewing information, using scientific language appropriately, constructing a reasoned argument, and responding to critical comments.
3. Understanding the complexity and ambiguity of empirical work. Interacting with the unconstrained environment of the material world in laboratory experiences may help students concretely understand the inherent complexity and ambiguity of natural phenomena. Laboratory experiences may help students learn to address the challenges inherent in directly observing and manipulating the material world, including troubleshooting equipment used to make observations, understanding measurement error, and interpreting and aggregating the resulting data.

4. Developing practical skills. In laboratory experiences, students may learn to use the tools and conventions of science. For example, they may develop skills in using scientific equipment correctly and safely, making observations, taking measurements, and carrying out well-defined scientific procedures.
5. Understanding of the nature of science. Laboratory experiences may help students to understand the values and assumptions inherent in the development and interpretation of scientific knowledge, such as the idea that science is a human endeavour that seeks to understand the material world and that scientific theories, models, and explanations change over time based on new evidence.
6. Cultivating interest in science and interest in learning science. As a result of laboratory experiences that make science "come alive," students may become interested in learning more about science and see it as relevant to everyday life.
7. Developing teamwork abilities. Laboratory experiences may also promote a student's ability to collaborate effectively with others in carrying out complex tasks, to share the work of the task, to assume different roles at different times, and to contribute and respond to ideas.

Although most of these goals were derived from previous research on laboratory experiences and student learning, the committee identified the new goal of "understanding the complexity and ambiguity of empirical work" to reflect the unique nature of laboratory experiences. Students' direct encounters with natural phenomena in laboratory science courses are inherently more ambiguous and messier than the representations of these phenomena in science lectures, textbooks, and mathematical formulas (Millar, 2004). The committee thinks that developing students' ability to recognize this complexity and develop strategies for sorting through it is an essential goal of laboratory experiences. Unlike the other goals, which coincide with the goals of science education more broadly and may be advanced through lectures, reading, or other forms of science instruction, laboratory experiences may be the only way to advance the goal of helping students understand the complexity and ambiguity of empirical work (N.R.C., 2006)

Having now looked at the purposes of laboratory work, we shall turn our attention to the skills that need to be developed through laboratory experience.

2.4 Practical and experimental skills (PES)

2.4.1 Practical skills

This involves the demonstration of manipulative skills using tools, machines, and equipment for practical problem-solving. The teaching of practical skills should involve projects, case studies, and field studies where students will be intensively involved in practical work and in the search for practical solutions to problems and tasks (Ministry of Education, Science and Sports, Ghana (MESS Ghana), 2008).

2.4.2 Experimental Skills

This involves the demonstration of the inquiry processes in science and refers to skills in planning and designing of experiments, observation, manipulation, classification, drawing, measurement, interpretation, recording, reporting, and conduct in the laboratory/field. Practical and Experimental skills refer to the psychomotor domain. (MESS Ghana, 2008).

A summary of the skills required for effective practical and experimental work are the following:

2.4.3 Observational skills

Observation is a cognitive process and it becomes scientific when it has a purpose and theoretical perspective (Johnstone & Al-Shuaili, 2001).

However, what is scientific observation? Young (1986) made it clear that there is a difference between 'seeing' and 'observing' when he stated that learners 'see' many things, but they do not always 'observe' them. Kempa and Ward (1988), reported that students failed to notice or record one in every three observations. They reported that 'observability' is a function of both the nature and intensity of a stimulus and the observer's perceptual characteristics.

The observational stimulus must reach a certain level below which, observation will not be made this is known as Observation threshold (Kempa & Ward, 1988). They pointed out that as the intensity or magnitude of an observational stimulus is reduced, it becomes more difficult to detect. Moreover, when there are multi-stimuli, the 'detectability' of one stimulus can be seriously affected by the presence of another; the dominant stimulus obscuring, or masking completely, the less dominant ones. This psychological factor affects learners throughout their lives. It is not enough to tell students to observe; they have to be shown how (Johnstone & Al-Shuaili, 2001). However, some of the greatest observations in science have been made by chance, such as the discovery of polyethylene, but the observers had to have prepared minds to see the possibilities behind their observations. In practice, by using interactive demonstration techniques Al-Shuaili (2000) showed that visual observational changes, which might go unnoticed in a normal laboratory, could be made to appear well above the detection threshold. Therefore, whilst demonstrating a particular task, the instructor can highlight the kind of things learners should be looking for in order to fulfil the task's aim of focusing on 'signals' and suppressing 'noise' (Johnstone & Letton, 1990). Teachers also have to ensure that 'signals' offered to students should have enough observational magnitude and intensity as to be above the threshold. They should also be aware of the dominant observation in situations of multi-stimuli and manage them accordingly. The dominant stimulus may have to be played down if it is in danger of masking other important observations. This does not imply that the teacher should give all the answers before the laboratory, but rather prepare the observational faculties for what is to come (Johnstone & Al-Shuaili, 2001).

There may well be occasions when demonstration, rather than individual laboratory work, may be the best procedure when there is a danger of vital observations being obscured by powerful, but less important stimuli. In a demonstration, the teacher has control and can focus attention on the salient observations. Raw sense data can be 'seen' almost unconsciously, without having any significance attached to them. However, when this 'seeing' is registered and interpreted in the light of previous knowledge and expectation, it becomes an observation (Johnstone & Al-Shuaili, 2001). This emphasizes the importance of having a prepared mind before setting out in a laboratory and clearly calls for some pre-laboratory experience.

2.4.4 Manipulative skills

It is true that laboratories are the only place to learn hand skills, but many of the skills depend upon the particular piece of equipment available. Not all infrared machines are the same, each having its own peculiar 'flicks of the wrist' to make it operate well. Although the student has to learn the manual skills with the apparatus available, what is important is to know how to handle and interpret the spectra from *any* machine and this can be done without a laboratory! Manipulative skills have to be encountered often if they are to be well established. A large gap between learning to operate a particular balance and using it again requires almost total relearning. Problems with facility in manipulative skills can seriously get in the way of other desirable skills. A student struggling to operate a piece of equipment may fail to make important observations and gather poor data. A classical information overload can occur under these circumstances. It is essential so to establish the manipulative skills so that they can 'go on autopilot student's attention for other things such as observation and accurate recording (Johnstone & Letton, 1990).

2.4.5 Attitudinal Skills

Development of basic process skills is important as well as the development of proper scientific attitudes and values. Science Education aims to train students to think like scientists and emphasis would be expected on the development of attitudes that good scientists can display (Opulencia, 2011). One of the purposes of teaching is the inculcation of desirable attitudes and values (Pacia, 2014). Shaping students' attitudes, behaviours, and motivations is necessary today. For, without these broader skills and strengths, students will be unprepared for the challenges they, and their world face (Miller, 2017). Attitudinal skills can be divided into two main categories; attitudes to science and scientific attitudes (Gardner & Gauld, 1990). Attitudes to science include interest, enjoyment, satisfaction, confidence, and motivation. Scientific attitudes apply to styles of thinking such as objectivity, critical-mindedness, skepticism, and willingness to consider the evidence (Garnett & Hackling, 1995).

2.4.6 Planning experiments skills

This skill is usually exercised in laboratories where there is a measure of problem-solving at the bench. Conventional laboratories, with closely prescribed procedures, tend to omit any exercise of this skill (Johnstone & Al-Shuaili, 2001). Some forms of practical problem-solving require students to plan their experiments on the way to solving problems.

2.5 Types of laboratory work

Having now looked at the skills to be developed through laboratory work, we shall turn our attention to the variety of methods (or styles) available for laboratory work.

The following section attempts to review laboratory instruction types and to relate them to the goals and the practical and experimental skills to be developed.

Domin (1999) asserted that four distinct styles of laboratory instruction have been utilized throughout the history of chemistry education: expository (traditional), inquiry, discovery, and problem-based. He reiterated that, though these instructional styles share many commonalities and oftentimes their labels are used interchangeably, each style is unique and can be distinguished from the others by a set of three descriptors: outcome, approach, and procedure. The outcome of any laboratory activity is either pre-determined or undetermined (Johnstone & Al-Shuaili, 2001).

Expository, discovery, and problem-based activities all have predetermined outcomes (Domin, 1999). For expository lessons, both the students and the instructor are aware of the expected outcomes. For discovery and problem-based activities, usually, it is only the instructor who knows the expected result. Expository and problem-based activities typically follow a deductive approach, in which students apply a general principle to understand a specific phenomenon.

Discovery and inquiry activities are inductive. By observing particular instances, students derive the general principle. This procedure can be criticized on the grounds that students are unlikely to discover, in three hours, what the best minds took many years to find.

The procedure to be followed for any laboratory activity is either designed by the students or provided for them from an external source (the instructor, a laboratory manual, or a handout). Inquiry and problem-based methods require the students to develop their own procedures. In expository and most discovery activities the procedure is given to the students (Domin, 1999).

2.5.1 The Expository Laboratory

According to Domin (1999), Expository instruction is the most common type in use. Within this learning environment, the instructor defines the topic, relates it to previous work, and directs students' action. He explained that the role of the learner here is only to follow the teacher's instructions or the procedure (from the manual) that is stated in detail. The outcome is predetermined by the teacher and may also be already known to the learner.

So, as Pickering (Pickering , 1987) stated Never are the learners asked to reconcile the result, as it is typically used only for comparison against the expected result, nor confronted with a challenge to what is naively predictable. Lagowski (1990) reported that, Within the design of this laboratory (expository), activities could be performed simultaneously by a large number of students, with minimal involvement from the instructor, at a low cost, and within a 2-3-hour time span. It has evolved into its present form from the need to minimize resources, particularly time, space, equipment, and personnel. However, this procedure, although administratively efficient, may defeat the main purposes of laboratory work, leaving the student uneducated in this area of learning (Johnstone & Al-Shuaili, 2001). The most popular, and yet the most heavily criticized, style of laboratory instruction is the expository (also termed traditional or verification) style (Domin, 1999). He identified the following weakness as the cause of the criticism.

1. It places little emphasis on thinking.
2. Its 'cookbook' nature emphasizes the following of specific procedures to collect data.
3. It gives no room for the planning of an experiment
4. It is an ineffective means of building concepts.
5. It is unrealistic in its portrayal of scientific experimentation.

It is possible that little meaningful learning may take place in such traditional laboratory instruction (Johnstone & Wham, 1979). Two reasons can be suggested to explain the inability of this type of laboratory to achieve good learning. Firstly, it has been designed so that students spend more time determining if they have obtained the correct results than they spend thinking about planning and organizing the experiment. Secondly, it is designed to facilitate the development of lower-order cognitive skills such as rote learning and algorithmic problem-solving (Johnstone & Al-Shuaili, 2001).

It has been reported by Meester and Maskill (1995) that most university laboratory experiences are of this kind. When placed beside the aims of laboratory work already discussed, the expository laboratory seems to be incapable of helping students to achieve many of them (Johnstone & Al-Shuaili, 2001). It may be a place for exercising manipulative and data gathering skills, but may fail to provide training in design and planning and may offer little motivation and stimulus. However, small modifications of expository laboratories can offer the possibility of introducing some of those desirable experiences.

2.5.2 Inquiry Laboratory (Open-Inquiry)

This is best represented by a final year research project, but it need not be confined only to final year. Inquiry-based activities are inductive. They have an undetermined outcome and require the learners to generate their own procedures. They are more student-centred, contain less direction, and give the student more responsibility for determining procedural options than the traditional format (Johnstone & Al-Shuaili, 2001). It effectively gives students ownership of the laboratory activity, which can result in the students' showing improved attitudes towards laboratories. Student ownership, represented in such activities, requires learners to formulate the problem, relate the investigation to previous work, state the purpose of the investigation, predict the result, identify the procedure and perform the investigation (Johnstone & Al-Shuaili, 2001).

This type is designed to help the learner to construct thinking processes, which, if done properly, will allow students to engage in authentic investigative processes.

This practice reflects what scientists do in the real world as they engage in the scientific inquiry process such as asking questions, planning and carrying out investigations, analysing and interpreting data, engaging in arguments by using evidence and evaluating and communicating information (Kim, 2016).This type of practical work could be criticized for placing too much emphasis on the scientific process and not enough on scientific content. It can provide an environment in which many of the aims can be fostered, but it is time-consuming, potentially costly, and data-gathering for those who have to organize large laboratory classes. However, there is a strong case for its use from time to time and at all levels. There is no reason why a short inquiry should not be attached to the end of an expository laboratory using the skills and knowledge gained in the laboratory but with no fixed instructions (Johnstone & Al-Shuaili, 2001).

2.6 Virtual laboratories and simulations

A virtual laboratory is an interactive environment for creating and conducting simulated experiments. It involves the conduct of experiments with domain-dependent simulation programs. Indeed, a virtual reality technology can be adapted to create a virtual laboratory to simulate the processes and actions in physical laboratories (Larbi-Apaau, 2020). It was also argued that virtual laboratories present cheap ways for schools to obtain laboratories for all courses (Alexious, Bouras, & Giannaka, 2005). Bajpai (2013) also defined a virtual laboratory as an online environment that consists of a set of experiments, simulations, and videos that allow students to run experiments virtually. Computer simulations are techniques that aim to provide the student with a highly simplified reproduction of part of a real or imaginary world. They are considered one of the most effective ways to promote a deep conceptual understanding of the real world (O'Haver, 2000). Computer simulations are computer-generated versions of real-world objects, for example, a skyscraper or chemical molecules or processes, for example, population growth or biological decay (Strangman & Hall, 2003).

However, research has shown that:

- Simulations are most suitable for students who already have some experience and a basic conceptual framework.
- Not all students find simulations plausible or meaningful.
- Simulations produce the largest gains in student reasoning ability when used in the classroom, rather than in computer labs (O'Haver, 2000).

2.7 Virtual laboratory vs physical laboratory

In examining earlier research, conflicting reports were found on the effectiveness of virtual laboratory at increasing students' content knowledge. Mintzes and Leonard (2006) completed a review of the literature on the early stages of the virtual movement, pre-2006. Their review was inconclusive as they found no clear-cut answer to the question, 'Does technology increase learning'? One clear answer emerged from their review. It depends on how it is used. (Russell T. L., 2001) suggested that there is no significant difference in the use of virtual and physical laboratory resources as a means of educational instruction when it comes to the desired outcome achievement. His conclusion was based on the summation of 355 studies that formed his 2001 book' No significant difference phenomenon'. There are few studies that suggest that the use of physical laboratory resource give a better learning outcome. Stucky-Mickell and Stuckey-Darner (2007) evaluated the possibility of fully online human biology lecture and laboratory. They find out that, though the students responded well, to the virtual laboratory, the students believed that physical laboratories were more effective in learning course materials.

However, Larbi-Apaau (2020) acknowledging the shortcomings of physical laboratories, remarked; compared to the limited space offered by physical workstations, virtual laboratories can be used with display technology such as interactive projectors or smart boards for an all-inclusive class. They can complement existing ones or be used as stand-alone, especially for courses where the physical laboratories cannot be developed for lack of resources and actual practices. (Larbi-Apaau, 2020).

2.8 Virtual experiments and students' achievement

Studies explored the effect of using virtual experiments on students' learning outcomes and acquisition of knowledge. Many studies revealed that virtual experiments improved students' level of achievement (Alneyadi, 2019).

While other studies' results showed no difference (Crandall, et al., 2015). Adegoke and chukwunenye (2013) examined the effect of computer-simulated experiments on student's learning outcomes in practical physics. There were three groups: computer-simulated experiment only, computer-simulated experiment with hands-on experiments, and hands-on experiment. The results showed that the students who have studied by computer-simulated and hands-on experiments are the best among the three groups. They explained that the computer-simulated experiments removed the mathematical reasoning effect and reduced the abstract nature of physics that will attract students to learn physics (Adegoke & Chukwunenye, 2013)

Penn and Ramnarain (2019) examined the effects of using virtual learning environments (vles) on students' achievement in a physics content test. A sequential mixed method explanatory research methodology was followed, sixty-eight (n=68) third-year physical sciences education students participated in this study. A physics content test was given pre and post-physics education technology (phet) simulation laboratories and the activities, then it was followed by semi-structured focus group interviews. Findings from the study revealed that mean achievement scores in physics content tests improved significantly post-intervention in vles.

2.9 Electrochemistry and Related Topics

Electrochemistry is a branch of chemistry that deals with the relationship between electricity and chemical reactions. It involves the study of how chemical reactions can be caused or influenced by an electric current, as well as how the flow of electric current can be affected by chemical reactions. Electrochemistry has many practical applications, including the production of electricity through batteries and fuel cells, the use of electrodes to measure chemical concentrations and properties, and electroplating metals.

2.10 Understanding Electrochemistry

An in-depth understanding of electrochemistry requires both conceptual and algorithmic knowledge. High schools in the U.S. tend to emphasize and assess the algorithmic, quantitative, problem-solving of electrochemistry, neglecting conceptual understanding (Sanger & Greenbowe, 1997). Unfortunately, research has shown that algorithmic understanding of a topic does not necessarily translate into conceptual understanding in chemistry (Nakhleh, 1993). In research done regarding student difficulties with electrochemistry, Niaz (2002) reports that "the ability to solve routine problems based on memorized formulae does not transfer readily to problems that require conceptual understanding" (p. 435). Researchers, Ceyhun and Karagolge (2005) also report that students who held misconceptions regarding electrochemical concepts were still able to calculate cell potentials correctly. Ozkaya (2002) attributes learning difficulties in electrochemistry to a general lack of conceptual understanding and attributes this to insufficient textbook explanations of these concepts. A small variation in the complexity of questions about electrochemistry "increases the degree to which the problem requires conceptual understanding" (Niaz, 2002, p. 435). When teachers focus on teaching and assessing the particulate nature of the electrochemical processes, conceptual knowledge is improved (Sanger & Greenbowe, 1997), thereby improving students' overall understanding of electrochemistry. So how can a teacher best build student understanding of the particulate nature of electrochemical processes? One possibility is the use of visual aids.

2.11 Problem–Solving Skills in Electrochemistry

Electrochemistry is a fundamental topic in chemistry. It involves many problems such as balancing redox reactions, electrochemical cells; standard electrode potentials (E°); Nernst equation; electrolysis; and corrosion (Necor, 2021). Consequently, solid mathematical operations are necessary to solve electrochemistry problems that students prove hard to do (Tsaparlis & Malamou, 2014).

The voltaic and electrolytic cells are challenging to understand because these topics are abstract, and the process is invisible to the eye, while only the effect is observable (Corriveau, 2011). An investigation of pre-service chemistry teachers conducted by Ekiz, Kutucu, Akkus, and Boz (2011), revealed that pre-service teachers could not distinguish electrolytic cells from galvanic cells. Moreover, pre-service teachers have difficulty identifying the anode and cathode in an electrolytic cell; hence, they could not identify the product of the electrolysis processes. From these difficulties, teachers should find ways to improve the conceptual knowledge and algorithmic ability of the students. One possibility is using varied teaching strategies with an integration of technology (Necor, 2021). Many researchers reported success in utilizing computer animation to correct misconceptions. This is apparent in the particle movement in a voltaic and electrolytic cell (Ekiz et al., 2011).

One of the goals of science education is to develop the student's problem-solving skills. Problem-solving requires overcoming all the impediments to reaching a goal. Relatively, various scholars defined problem-solving in a variety of ways. Reid and Yang, (2002) stated that inappropriate chemical knowledge prevents students' problem-solving ability in chemistry. It becomes unsuccessful if chemistry instruction does not provide an adequate set of rules to follow or does not help them to understand chemical knowledge during the learning process. Hence, it is essential to help students to understand the pre-requisite knowledge and skills of problem-solving (Necor, 2021).

2.12 Learning difficulties in Electrochemistry

Electrochemistry teaching and learning is one of the difficult lessons in high school chemistry and tertiary education elsewhere. Many chemical educators reported learning difficulties in understanding electrochemistry concepts which are prevalent in Africa (Amponsah, 2020); Asia (Akram et al., 2014); Europe (Tsaparlis G. , 2019); Australia (Garnett & Treagust, 1992); and United States of America (Sanger & Greenbowe, 1997). For instance, high school students, and teachers, come across problems in comprehending electric current, oxidation-reduction, electrolytes, galvanic cells, and electrolysis (Garnett & Hackling, 1995). Students' limitations in understanding the 'particulate nature of matter' are reckoned the root cause for the challenges in learning chemistry concepts in general and electrochemistry in particular (Ali T. , 2012). Thus, visual (what can be seen, touched, and smelled); sub-microscopic (atoms, molecules, ions, and structures), and symbolic (representations of formulae, equations, mathematical expressions, and graphs) should be employed for effective chemistry teaching (Gilbert & Treagust, 2009). In addition, students' limited knowledge of core or big ideas in chemistry also creates difficulty to give scientific explanations and describe structure—property relationships (Ali, Woldu, & Yohannes, 2022).

Amponsah (2020) Reported the effect of using teaching models to minimize the known misconceptions in electrochemistry at South African university students. Their results revealed that students showed an improvement in understanding electrochemical cells at the microscopic level along with the reduction of students' misconceptions. But students were found to entertain some of the misconceptions, after completing the lesson, such as: "current is a flow of electrons"; "ions will be able to conduct the electrons and complete the circuit"; "potassium sulphate has delocalized electrons and positive protons that move to the opposite electrodes when a current is applied"; and "anions produce electrons which conduct [electricity]". Similar results were found in studies that take place on American students (Sanger & Greenbowe, 1997) and Australian students (Garnett & Treagust, 1992).

Akram et al., (2014) investigated Pakistani high school students' conceptual difficulties in the areas of redox reactions, galvanic and electrolytic cells. The results of their study suggested that students' correct response was only 67% of the concept-based test. The main factors that caused conceptual difficulties in comprehension were: (i) poor background knowledge, (ii) absence of teaching aids, and (iii) misinterpretation of everyday language into chemistry.

Lu and Bi (2016) investigated high school students' (grade 10-12) conceptual understanding of the electrolyte concept in China. These authors found out that students faced difficulty in acquiring a deep knowledge of electrolytes. They studied 559 grade 10 to 12 students' conceptual understanding of electrolytes by using the Rasch measurement instrument, which serves to measure both summative and diagnostic assessments of misconceptions in electrolyte concepts in two cities in China. The results indicated that students' conceptual understanding was enhanced with increasing grade levels while each of the different grade levels was found to hold misconceptions. They reported the 10th-grade students' understanding of the concept of *electrolytes* in China high schools using a phenomenography method by interviewing eight students to qualitatively assess their level of understanding. Their research findings revealed that the electrolyte concept was found to be difficult to be understood by students.

Sia, Treagust, and Chandrasegaran, (2012) examined Malaysian high school students' conceptual understanding of electrolysis. In a study of 330 Malaysian high school students, they reported a two-tier 17-item multiple-choice Electrolysis Diagnostic Instrument (EDI) to investigate students' understanding of basic electrolysis concepts. They identified more than twenty misconceptions pertaining to different electrolysis concepts such as (i) the nature and reaction of the electrodes; (ii) the migration of ions; (iii) the preferential discharge of ions; (iv) the products of electrolysis; and (v) changes in the concentration and colour of the electrolyte. According to them, high school students in Malaysia face difficulties in explaining basic electrolysis concepts and lacking confidence in correctly answering test questions. They recommended that teachers should help select the teaching materials such as the appropriate use of models, illustrations, and definitions of new terminology to help students learn chemistry concepts more effectively.

Rahayu, Treagust, Chandrasegaran, Kita, and Ibnu (2011) investigated 244 Indonesian and 189 Japanese public senior high school students' conception of electrochemical concepts (e.g. electrolysis, electricity flow, the voltaic cell, and the electrode reactions). The result revealed that both samples exhibited difficulty in understanding of the concepts and held misconceptions.

A related study was conducted by Marohn, Schmidt and Harrison, (2007). Their study focused on four areas, namely, electrolytes; the transport of electric charges in electrolyte solutions; the anode and the cathode; and the minus and plus poles. They found that students' reasoning was based on the misconceptions: "The electric current produces ions"; "electrons migrate through the solution from one electrode to the other"; "the cathode is always the minus pole, the anode the plus pole" and "the plus and minus poles carries charges" (Marohn, Schmidt, & Harrison, 2007).

Student teachers showed teaching difficulty of electrolysis whereby they were unable to explain what an electrolysis is and why the electrochemical phenomena in the electrolysis process have happened as well as they did not ponder the actual electrolysis mechanisms to their students (Ahtee, Asunta, & Palm, 2002). Their results revealed that only two students were able to explain electrolysis as a process where an electric current drives the reaction in a non-spontaneous direction. Some student teachers also hold misconceptions about electrolysis. All the aforementioned difficulties and misconceptions related to students and teachers necessitate remedies that could lead to an effective classroom discourse and robust understanding of electrochemistry.

2.13 Misconceptions in electrochemistry

Misconception is referred to as learners' scientific views and beliefs that are inconsistent with the commonly accepted views of the scientific community (Ozkaya A. R., 2002). Science educators also coined various terms for misconceptions such as alternative conceptions (Garnett, Garnett, & Hackling, 1995), children's science (Duit & Treagust , 2003), alternative frameworks (Garnett & Treagust, 1992), and conceptual or propositional knowledge to describe students' understanding that is in conflict with the scientific view. An awareness of the misconceptions in electrochemistry would guide high-school teachers, textbook writers, curriculum developers, and policymakers so as to design and execute an effective instruction, assessment, and implementation of a curriculum so that students' scientific conception would be in harmony with the consensus of the scientific community.

As Piaget cited in (Cooper & Stowe, 2018), contended, when there is inconsistency in the understanding of a new concept and our pre-existing knowledge, the conceptual schema of the learner tends to modify in a way that fits the 'new sensory data'. Thus, the students can have different views on a particular concept to accept it as correct or incorrect since they are in a position to compile and integrate knowledge under a constructivist paradigm. The chance of creating their own wildly accepted perspectives to understand chemical phenomena is the cause for holding misconceptions (Ali, Woldu, & Yohannes, 2022).

The misconceptions about research in electrochemistry are well-documented in various studies. However, several chemical educators strongly criticized that many misconception research has paid little attention to the possible sources of the learning difficulties and misconceptions. Tümay) (2016) clearly argued that Chemistry educators who strongly emphasized that developing effective instructional approaches to overcome misconceptions requires identifying and considering the underlying sources of these misconceptions, rather than merely listing them. Creative exercises that promote meaningful conceptual links between prior knowledge and new knowledge, pretest and post-test exams, and interviews and students' reflections about their own learning, and small group discussions are used to trace misconceptions held by students in electrochemistry. Integrated concept mapping and visual animation are also important in identifying students' misconceptions and attracting their interest and enhancing the performance of learning in electrochemistry (Ali, Woldu, & Yohannes, 2022). The possible origins of misconceptions are (1) inadequate prerequisite knowledge; (2) frequent overloading of students' working memory; inability to think about the same chemical processes at the macroscopic, particulate, and symbolic levels; misinterpretation of everyday language in chemical contexts; (3) the use of concepts and algorithms in a rote fashion without any attempt to understand fully and analyze the problem; (4) Teachers and textbook-derived misconceptions ; and (5) the format and order used in chemistry textbooks (Sanger & Greenbowe, 1997). These learning difficulties and misconceptions necessitate an effective instructional approaches and strategies such as conceptual change approach (Niaz & Chacón, 2003) .

Conceptual change instruction is referred to as a teaching method that requires restructuring learners' existing conceptual frameworks to a much more organized scientific knowledge structure (Duit & Treagust , 2003). It should create an opportunity for learners' dissatisfaction with their misconceptions and the new conception should be intelligible (understandable), plausible (believable), and fruitful (worthwhile) so as to extinguish their misconceptions and for a sound understanding to occur (Garnett, Garnett, & Hackling, 1995). The strategies that are very helpful for cognitive restructuring to be feasible include: providing opportunities to exchange ideas in the classroom and encouraging group discussions, eliciting students' experiences, guiding students to reflect on their own learning, and giving them the freedom to take responsibility for their own learning as well as make meaning to their experiences (Garnett, Garnett, & Hackling, 1995). However, students' misconceptions of electrochemistry could not be fully avoided due to its nature of resistance to change (Garnett, Garnett, & Treagust, 1990). While students' active engagement in scientific activities is a prerequisite for cognitive restructuring to occur, learning science involves a complex interplay between personal experience, language, and socialization.

Previously, the conceptual understanding of high school students (grades 9-12) has been studied and an overwhelming number of misconceptions about oxidation-reduction and electrochemistry were identified (Ali, Woldu, & Yohannes, 2022). The most common misconceptions about oxidation-reduction and electrochemistry were grouped into five subcategories: (1) Electric circuits; (2) Oxidation-Reduction; (3) Galvanic/Electrochemical cells; (4) Electrolytic cells, and (5) Electrolytes.

2.14 Techniques for Teaching Electrochemistry

Various teaching techniques have been used to successfully teach electrochemistry and to correct common misconceptions. Thompson and Soyibo (2010) report that the addition of student practical work to the usual combination of lectures, teacher demonstrations, and class discussions improved students' test scores and attitudes toward chemistry.

Niaz (2002) used a carefully orchestrated set of algorithmic questions to "generate situations/experiences in which small groups of students are forced to grapple with alternative responses leading to cognitive conflicts/contradictions" (p. 430).

The results of this approach were significantly better post-test scores for the experimental group, leading the researcher to conclude that the student's conceptual understanding of electrochemistry had surpassed that which was needed for routine algorithmic problem-solving.

Ozkaya, Uce, Saricayir and Sahin (2006) used "conceptual change texts that evoke learners' preconceptions, caution learners about common misconceptions, and contrast the misconceptions with scientifically accepted conceptions by using examples and explanations" (p. 1719). These conceptual change texts were immediately followed by two-tier assertion-reason style questions to better assess learning and uncover misconceptions. Improved post-test scores were noted on both conceptual and algorithmic test questions, which the researchers attributed to an improved understanding of how electrochemistry concepts are related and an ability to "organize relevant concepts in related categories" (p. 1721). These researchers and others advocate explicitly informing students about common misconceptions during the course of instruction.

There are also several options available to teachers to help students visualize abstract electrochemistry concepts. Analogies can be made to macroscopic phenomena. For example, the attraction of a positively charged particle and a negatively charged particle can be compared to the attraction between opposite poles of a magnet (Brown, LeMay, & Bursten, 2006). Visible effects resulting from submicroscopic particle interactions can be demonstrated, as in the case of new and different-looking products formed in a chemical reaction. But often, a chemistry teacher must resort to concrete models, for example, ball and stick models, to help visualize molecular shapes (Brown, LeMay, & Bursten, 2006). More recently, computer animation has been added to the chemistry teacher's toolbox.

Acar and Tarhan (2006) report success with using student cooperative learning groups and computer animations. Other researchers also report improved understanding with the use of computer simulations (Ceyhun & Karagolge, 2005; Sanger & Greenbowe, 1997). In a case where computer access was lacking, South African teachers have used physical models made of wooden compartments containing Styrofoam balls and marbles representing atomic and subatomic particles (Huddle, White, & Rogers, 2000). In this case, it was found that the "use of the model led to significant improvement in students' understanding of what was occurring at the microscopic level in an electrochemical cell and helped to address known alternate conceptions" (p. 109).

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter focuses on the design of the study, population and sampling procedure, instrumentation, validity of the main instruments, reliability of the main instrument, data collection procedure, data analysis and ethical considerations.

3.1 Research Design

The research design used in this study was action research. The following are the working definition of action research methodology in the classroom.

Bassey (1998) offers a very practical definition and describes action research as an inquiry which is carried out in order to understand, to evaluate and then to change, in order to improve educational practice. Cohen, Manion and Morrison (2017) situate action research differently, and describe action research as emergent, writing:

> essentially an on-the-spot procedure designed to deal with a concrete problem located in an immediate situation. This means that ideally, the step-by-step process is constantly monitored over varying periods of time and by a variety of mechanisms (questionnaires, diaries, interviews and case studies, for example) so that the ensuing feedback may be translated into modifications, adjustment, directional changes, redefinitions, as necessary, so as to bring about lasting benefit to the ongoing process itself rather than to some future occasion.

Lastly, Koshy, Koshy and Waterman (2010) describes action research as:

> a constructive inquiry, during which the researcher constructs his or her knowledge of specific issues through planning, acting, evaluating, refining and learning from the experience. It is a continuous learning process in which the researcher learns and also shares the newly generated knowledge with those who may benefit from it.

From the above stated definitions, action research is a valuable methodology for conducting educational research in the field of electrochemistry education. By using action research, one can actively engage with the educational environment, make improvements, refinement, reformation and gain a deeper understanding of the teaching and learning processes.

The researcher used a spiral model of action research as proposed by Kemmis and McTaggart (2005). The spiral model emphasizes the cyclical process that moves beyond the initial plan for change. The spiral model also emphasizes revisiting the initial plan and revising based on the initial cycle of research:

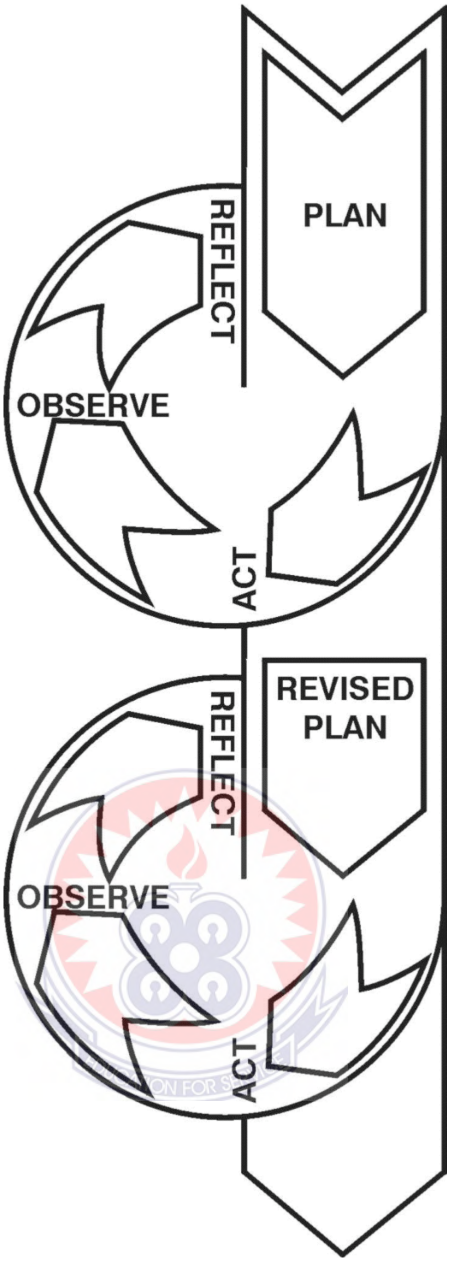


Figure 1: The action research spiral (Kemmis & McTaggart, 2005)

The diagram shows the four steps in action research, according to Kemmis and McTaggart (2005) are briefly explained below:

Planning:

This is the initial phase of an action research. The process begins with identifying a specific problem or issue that needs attention. This problem should be clearly defined and relevant to the research context. Once the problem is identified, researchers set clear and measurable goals and objectives for what they want to achieve through the research. Researchers decide on the most appropriate data collection methods, which can include surveys, interviews, observations, or a combination of these. An action plan is created, outlining the strategies and actions that will be taken to address the problem. The plan specifies who is responsible for what and when each action will be executed. Ethical considerations, such as informed consent and the protection of participants' rights, are addressed during the planning phase.

Acting:

In this phase, the planned actions are put into motion. Researchers and other stakeholders involved in the research execute the strategies and interventions outlined in the action plan. Data collection methods are used to gather information on the effects of the interventions. This may involve collecting quantitative and qualitative data to measure changes and progress.

Observing:

Collected data is analyzed to assess the impact of the interventions and to determine if the goals and objectives are being met. Researchers closely monitor the situation to ensure that the actions are carried out as planned and to identify any unexpected developments.

Reflecting:

Researchers interpret the data, drawing conclusions about the effectiveness of the actions. They assess whether the interventions have produced the desired outcomes.

If the results indicate that the desired goals are not being met, researchers consider adjustments to the action plan. This may involve modifying strategies or trying new approaches. Insights gained from the research process are used to inform future actions and decision-making. Researchers may also share their findings with stakeholders, colleagues, or the wider community.

Action research is an ongoing, cyclical process, and these steps are repeated as necessary until the problem is adequately addressed and the goals are achieved (Kemmis & McTaggart, 2005).

3.2 Population and Sampling Procedure

The study was conducted in Reverend John Teye Memorial Institute, Senior High school (RJTMISHS). It is a private Christian school located at Ofankor in the Greater Accra Region of Ghana. A research population is a large well-defined collection of individuals or objects having similar characteristics (Castillo, 2007). The accessible population was all the forty (40) science students of RJTMISHS.

Sampling refers to the process of selecting a portion of the population to represent the entire population (Fraenkel & Wallen, 2000). Purposive sampling technique was used to select the sample for the study. Makhado (2002) supports the use of purposive sampling technique for action research design by stressing on the fact that it is important to select information rich cases as this will help the research to address the purpose of the research. Mcmillan and Schumacher (2001) further recommended purposive sampling because the samples that are chosen are likely to be knowledgeable and well informed about the phenomenon the researcher is investigating. Purposive sampling may involve studying the entire population of some limited group. It was this background that the researcher used purposive sampling to select the sample for the study. The sample selected for this study was made up of the entire second year science class of 19 students.

3.3 Instrumentation

Questionnaires, test, end of term examination and laboratory reports were the instruments used for collecting data about the students before, during and after the interventions.

3.3.1 Test

According to Airasian (2000), a test is a formal, systematic, usually paper-and- pencil procedure for gathering information about student's behaviour. The test items were selected from the past final chemistry examination paper set by West African Examination Council (WAEC). The test items were two sets of ten (10) each, one for pre-test and the other for post-test. They were content validated based on the existing course content of electrochemistry.

3.3.2 Questionnaire

A questionnaire is simply a tool for collecting and recording information about a particular issue of interest. It is mainly made up of a list of questions, but should also include clear instruction and space for answers or administrative details (Asare, 2014). Questionnaire should always have a definite purpose that is related to the objectives of the research and it needs to be clear from the onset how the findings will be used. The students' questionnaire items were chosen to gather the data on the merits and demerits and other opinions on the effectiveness of the two laboratory resources.

The general benefits of a questionnaire which includes consistency of presentation of questions to the respondents, the assurance of anonymity for the respondents and the less time it takes to administer (Fraenkel & Wallen, 2000) was appropriate for this study which was time bound. A questionnaire was also found to be appropriate for the study because the study employed a discussion of the students' perceptions, opinions and reflections on the comparative effectiveness of the two laboratory resource types on their performances.

Questionnaire is probably the most common data collection instrument used in educational research which is more familiar to respondents (Ologo, 2014). However, the disadvantages are that they often have low response rate and cannot probe deeply into respondents' opinions and feelings (Fraenkel & Wallen, 2000), but this was not the case with this study because the sample size was well manageable. Close-ended items made respondents to choose between answers of the researcher while open-ended items allow respondents to formulate their own answers. The research used both open and closed ended items in the questionnaire because respondents are more inclined to answer close-ended items and open-ended items provides a greater depth of responses since there was no standardized answers across responses (Oppenhein, 2000).

Scoring the questionnaire

A Likert scale with options (Excellent, very good, Good, Average and poor) was used to score the questionnaire items. The items on the questionnaire were positively and negatively worded in order to minimize participant satisfying responses. Likert scale was used to completing a scale of this type. Again. Likert scale is easier to construct, interpret and also provide the opportunity to compute frequencies and percentages as well as statistics such as the mean and standard deviation of the scores. This in turn allows for a more sophisticated statistical analysis such as analysis of variance (ANOVA), t-test, chi square and regression analysis (Fraenkel & Wallen, 2000). Likert scales are also found to provide data with relatively high reliability (Oppenhein, 2000).

3.3.3 Reliability of the main instruments

The reliability of research instrument refers to the consistency of data when multiple measurements are gathered (Ologo, 2014). To ensure the reliability of the achievement test (AT) developed for the study, the researcher carefully selected, analyzed and modified WAEC chemistry past questions both practical and theoretical on electrochemistry from 2011 to 2021. The selection of questions from WAEC past chemistry questions was to ensure that they meet the standards of WAEC in accessing students in electrochemistry.

3.3.4 Validity of the main instruments

Validity seeks to determine whether the instrument actually measures what is intended to measure (Ologo, 2014). The researcher constructed the test items of the AT based on the selected topics taught and research questionnaire, which were face-validated by the researcher's supervisor and an experienced chemistry teacher in a senior high school. Based on their criticisms the necessary corrections were made to ensure the adequacy and appropriateness of the instrument. The instruments were then piloted.

3.3.5 Pilot-Test

The instruments were pilot-tested to evaluate their quality. The quality of a research instrument is determined by both its validity and reliability (Aikenhead & Ryan, 1992). This was done using a different set of students from the one in the main study. This pilot test was not only to establish reliability, but also to identify defective items in order to avoid any ambiguities that might arise and get the expected response before they are administered to the actual participants of the study. The pilot was carried out a term before the actual data collection in order to ensure that all weaknesses observed in the instructional package during the pilot test stage were addressed. The pre and post-test items internal consistency was determined by the use of test-retest method of reliability co-efficiency. The Crombach alpha value calculated for the questionnaire was 0.75 and that for the tests, both pre and post-test was 0.8. These were in line with Gall, Borg, and Gall's (2007), suggestion that the coefficient of reliability values above 0,75 is considered reliable. Therefore, the instruments used for collecting data for this research work were reliable.

3.4 Pre-Intervention

The pre-intervention involved the administration of the pre-test. The test was administered to the targeted population. All the scripts were marked, recorded and the scores were collated for further processing. Topics such as electrovalent and metallic bonding were also reviewed.

3.4.1 Intervention

Lessons were carried out for each group, utilizing both physical and virtual laboratories, by adhering to the subsequent procedures.

Group Selection:

The students were chosen based on their individual scores on the pre-intervention test. The scores of male and female students were segregated. They were then organized into groups by selecting students with the highest scores for one group, the second-highest for another group, and so on, until all male students were placed into two separate groups. The same process was applied to group the female students. One representative from each group volunteered for a ballot. Those who selected the virtual lab option formed the virtual lab group, while those who chose the physical lab option became part of the physical lab group. This was done to ensure that each group is balanced in terms of student characteristics and abilities

Lesson Planning: Lessons were planed thoroughly for the term (11 weeks). A curriculum was developed that integrates both physical laboratory experiments and virtual laboratory simulations. The researcher also ensured that the lessons cover the same topics for both groups. The areas covered were; redox reactions, reducing and oxidizing agents and electrochemical series.

Resource Preparation:

Physical Laboratory: All the necessary materials and equipment were gathered, and safety measures for the physical laboratory experiments were put in place.

Virtual Laboratory: Appropriate virtual laboratory simulations or software were selected and tested to ensure they function correctly and align with the curriculum. These were the virtual reality tools used;

1. https://vlab.amrita.edu/index.php?sub=2&brch=190&sim=361&cnt=4
2. https://chemcollective.org/vlab/106
3. https://teachchemistry.org/classroom-resources/galvanic-voltaic-cells-2
4. https://www.simbucket.com/simulation/436/

Lesson Schedule: A schedule was created that alternates between physical laboratory and virtual laboratory lessons. For example, one week dedicated to physical experiments and the next week for virtual simulations. This schedule was communicated clearly to both groups.

Classroom Setup:

The Plab group had their lessons in a dedicated physical laboratory, whilst the Vlab group had theirs in the school computer laboratory, where there is availability of necessary technology, such as computers, projector and internet.

Teaching Methodology: For physical laboratory lessons, hands-on guidance and demonstrations were provided and students encouraged to actively participate in the experiments. For virtual laboratory lessons, students were guided on how to use the virtual software and explore concepts.

Assessment: Various assessments, both formative and summative were developed to measure the learning outcomes for both groups effectively. These assessments were fair and aligned with the specific learning objectives of each type of laboratory.

Monitoring: The two groups were continuously monitored and feedback provided to track their progress.

Therefore, the instruments used for collecting data for this research work were reliable.

3.4.2 Lesson Plans

Lesson One

Subject: Chemistry

Class: SHS 2

Average age: 16years

Strad: Electrochemistry

Sub Strand: Oxidation and reduction reaction

Duration: 80 minutes

Indicators: By the end of the lesson, the pupil will be able to

1. define oxidation and reduction in terms of (a) addition and removal of oxygen, (b) electron transfer (c) oxidation numbers (d) addition and removal of hydrogen
2. 2. Identify oxidizing and reducing agent

Resources:

Plab group;

Magnesium ribbon, kindle wax , bursen burner

vlab group

https://www.youtube.com/watch?v=k6C2dETQ0bw

https://www.youtube.com/watch?v=nNG5PMlHSoA

Entry Behaviour: Students familiar metals and ionic compounds

Stater: Review students' previous knowledge on the chemical and physical properties of metals (group 1,2,3and transition metals) and ionic compounds.

Phase One

Plab group

With safety precaution supervise them to burn a given strip of magnesium ribbon and observe.

Vlab group

Let them log on to:

https://www.youtube.com/watch?v=nNG5PMlHSoA

Let the two groups respectively identify what is been produced and write a chemical equation for the reaction. The expected answer is: magnesium oxide is produced. $2Mg + O_2 \rightarrow 2MgO$.

Let them do same with few other materials such as kindle wax etc.

Guide students based on the above activity to define oxidation as the addition of oxygen to a substance and the converse, which is the removal of the oxygen is the reduction. Expose them now to other reactions which they can identity as oxidation and reduction, eg; $2H_2 + O_2 \rightarrow 2H_2O$ etc.

With their basic knowledge in ionic bonding, guid them to appreciate that the equation

$2\,Mg + O_2 \quad \rightarrow \quad 2MgO$ can be written in ionic form as;

$Mg + O \quad \rightarrow \quad Mg^{2+} + O^{2-}$ this can be interpreted to mean, Mg loss 2 electrons and O gain the 2 electron loss by Mg.

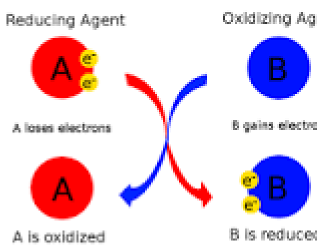
Guide students to define oxidation as loss of electron and reduction being gain of electron and hence introduce them to the mnemonic " **OILRIG.**" **O**xidation **I**s **L**oss **R**eduction **I**s **G**ain

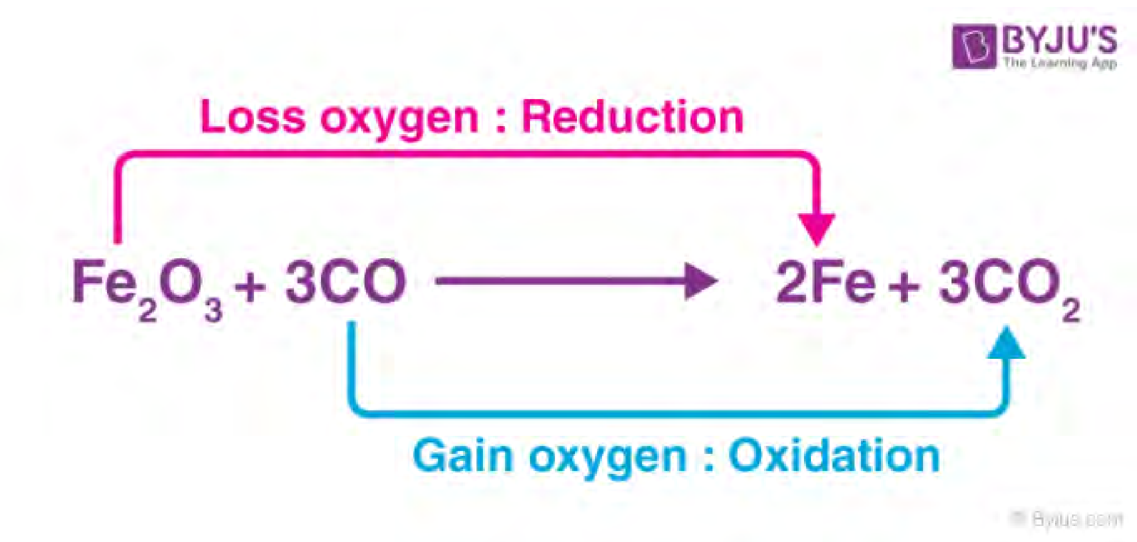
For easy remembrance.

Guide students to determine the oxidation states of each of the atoms in the magnesium reaction. And also define oxidation and reduction in terms of oxidation numbers.

Phase Two

From the definitions guide students to explain oxidizing and reducing agents and identify them in a redox equations.





- The reactant that **accepts** electrons is called the **oxidising agent**.
  - It brings about oxidation in another reactant.

The reactant that **donates** electrons is called the **reducing agent**.

  - It brings about reduction in another reactant.
  - Sometimes the terms reductant and oxidant are used instead of reducing agent and oxidising agent.

Evaluation

- Identify the element that has been oxidized in the following reactions:
  - $Co + 2Ag^{+} \rightarrow Co^{2+} + 2Ag$
  - $5H_2O_2 + 2MnO_4^{-} + 6H^{+} \rightarrow 5O_2 + 2Mn^{2+} + 8H_2O$
  - $Cl_2 + 2Br^{-} \rightarrow 2Cl^{-} + Br_2$

Conclusion

- Prepared worksheet on the topic have been given to the students as assignment.

Lesson Two

Subject: Chemistry

Class: SHS 2

Average Age: 16years

Strand: Electrochemistry

Sub Strand: Balancing Redox Equation

Duration: 80 minutes

Resources: Periodic table

https://www.learner.org/series/chemistry-challenges-and-solutions/the-metallic-world-electrochemistry-and-coordination-compounds/redox-explained-animation/

Indicator: By the end of the lesson, the pupil will be able to:

1. Write half- cell reaction
2. Balance redox reaction

Entry Behaviour: Students can identify redox reactions.

Stater:

(a) Ca(s) + Sn2+(aq) → Ca2+(aq) + Sn(s)

(b) 4NH3(g) + 5O2(g) → 4NO(g) + 6H2O (l)

(c) Deduce which species is

(d) (i) oxidised (ii) reduced (iii) oxidising agent (iv) reducing agent

Phase One

Although Redox reactions do not happen in isolation it is useful to separate the two processes out. Guide the students to separate a given redox reaction into the oxidation and reduction halves. For example to deduce the two half equations for the reaction,

$$Zn(s) + Cu^{2+(}aq) \rightarrow Zn^{2+} (aq) + Cu(s);$$

Assign oxidation state so that we can see what is being oxidised and what is being reduced

$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s);$

0 +2 +2 0

Here we can see that Zn is oxidized whilst $Cu^{2+}(aq)$ is reduced

Oxidation: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e$; Loss of electrons

Reduction: $Cu^{2+}(aq) + 2e \rightarrow Cu(s)$; Gain of electron

Let them note that there must be equal number of electrons in the two half- equations, so that when they are added together the electrons cancel out.

Phase Two

Introduced students to how to write and balance redox equations. Many of these reactions take place in acidified solutions and therefore H_2O and/or H^+ ions are need to balance the half equations.

Give them the following steps to follow in order to balance a given redox equation

1. Assign oxidation states to determine which atoms are reduced and which are oxidised
2. Write half-equations for oxidation and reduction as follows
3. a) balance atoms other than H and O;

   b) balance each half-equation for O by adding H_2O as needed

   c) balance each half-equation for H by adding H^+ as needed

   d) balance each half-equation for charges by adding electrons to the side with more positive charge

   e) Check that each half-equation is balanced for atoms and for charges
4. equalise the number of electrons in the two halve-equations by multiplying each appropriately
5. add the two half- equations together cancelling out anything that is the same on both sides.

Phase Three

Give them enough to practice. Go round to mark and assist those in difficulty.

Conclusion

Conclude the lesson by giving worksheet on the topic. For example:

State the relevant half equations and then deduce the overall redox equation for the reactions that occur when:

- Iron is added to dilute sulfuric acid solution (H^+ ions).
- Nickel metal is added to a solution of silver(I) ions.
- Bromine water is added to an aqueous solution of iodide ions.
- Sodium metal is added to water (use the data booklet).

Lesson Three

Subject: Chemistry

Class: SHS 2

Average Age: 16years

Strand: Electrochemistry

Sub Strand: Galvanic cell

Duration: 80 minutes

Resources:

Pab Group

1. Voltmeter or multimeter with alligator clip wires
2. One 12---well reaction plate
3. Filter paper (for salt bridge) soaked in 1M KCl
4. Small beakers for KCl
5. Plastic forceps (for handling the salt bridge)

6. 1---2 cm metal strips of Zn, Mg, Cu, and Sn
7. 15 drops of each of the following 1M solutions: ZnSO4, MgSO4, CuSO4, and SnCl2
8. Sandpaper (fine)

Vlab group

5. https://vlab.amrita.edu/index.php?sub=2&brch=190&sim=361&cnt=4
6. https://chemcollective.org/vlab/106
7. https://teachchemistry.org/classroom-resources/galvanic-voltaic-cells-2
8. https://www.simbucket.com/simulation/436/

Indicator: By the end of the lesson, the pupil will be able to:

1. Describe the operation of a galvanic cell (using such terms as anode, cathode, electron flow, salt bridge, and ions).
2. Build simple galvanic cells and measure cell potential.
3. Describe, write, and balance anode and cathode half reactions.

Entry Behaviour: Students can define redox reactions and balance redox equations. Students have been using dry cell

Stater: Ask students to balance few redox equations.

Phase One

Plab Group

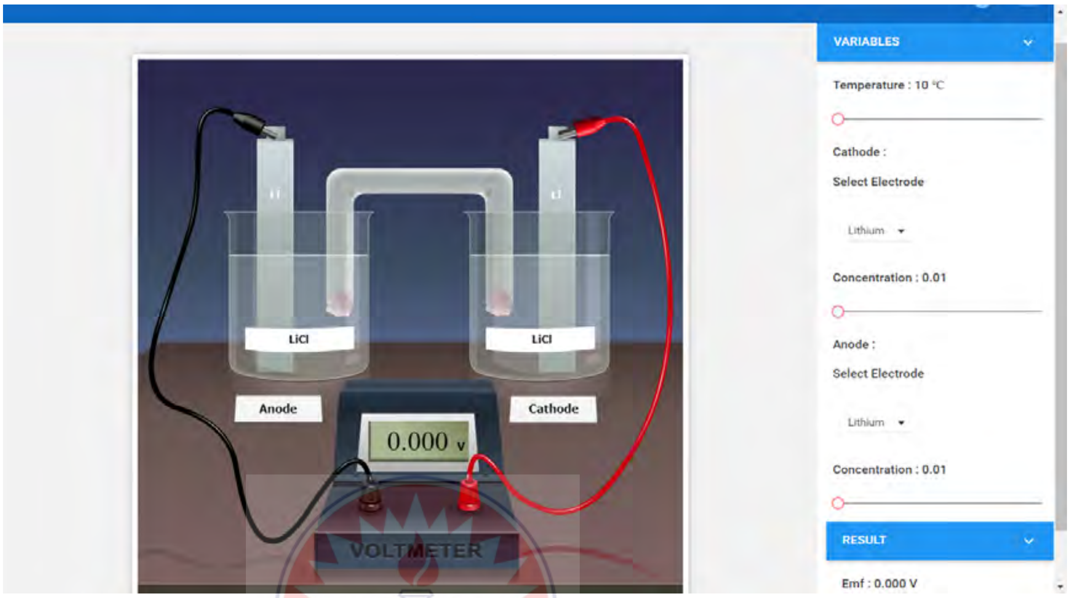
Begin the lesson by letting the students work in pairs. Demonstrate to them how a half-cell is constructed using a metal rod (electrode) and putting it into its own salt solution (electrolyte). Let them appreciate the flow of the electrons and the movement of the ions. Introduce the concept of electrode, cathode and anode.

Vlab group

Let them log on to the websites below:

https://teachchemistry.org/classroom-resources/galvanic-voltaic-cells-2

https://vlab.amrita.edu/index.php?sub=2&brch=190&sim=361&cnt=4



Guide them as to how to navigate through and select appropriate virtual materials.

Explain the background of the galvanic cells as it is been done for the Plab group.

Phase Two

Give both groups their respective practical worksheet/ report as shown in the appendix I to follow the instructions and start constructing their own galvanic cells.

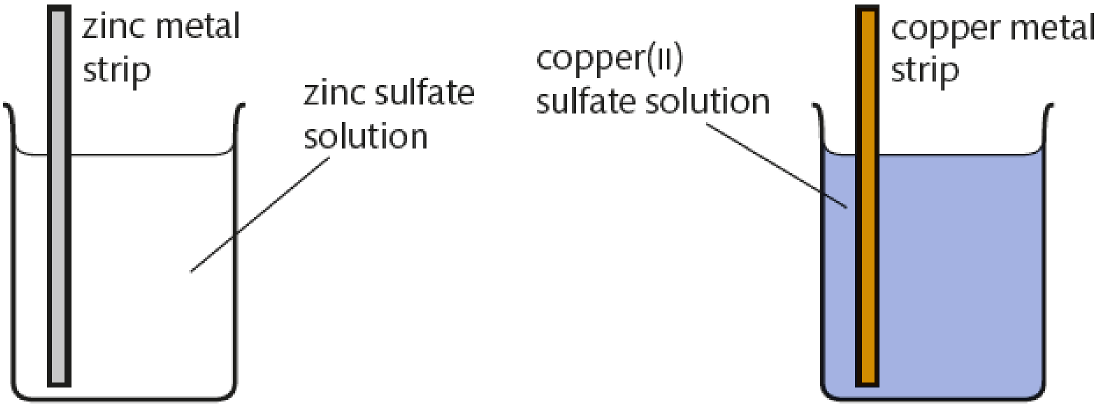
Phase Three

Monitor them and give guidance as when necessary as they work in pairs.

Conclusion

Conclude the lesson by giving the core points what hat has been done, for example:

There are many types of half-cell but the simplest is shown below:



Is is made by putting a strip of metal into a solution of its own ions.

Etc.

Lesson four

Subject: Chemistry

Class: SHS 2

Average Age: 16years

Strand: Electrochemistry

Sub Strand: Electrochemical Series

Duration: 80 minutes

Resources:

Pab Group

1. Voltmeter or multimeter with alligator clip wires
2. One 12---well reaction plate
3. Filter paper (for salt bridge) soaked in 1M KCl
4. Small beakers for KCl
5. Plastic forceps (for handling the salt bridge)
6. 1---2 cm metal strips of Zn, Mg, Cu, and Sn

7. 15 drops of each of the following 1M solutions: ZnSO4, MgSO4, CuSO4, and SnCl2
8. Sandpaper (fine)

Vlab group

1. https://vlab.amrita.edu/index.php?sub=2&brch=190&sim=361&cnt=4
2. https://chemcollective.org/vlab/106
3. https://teachchemistry.org/classroom-resources/galvanic-voltaic-cells-2
4. https://www.simbucket.com/simulation/436/

Indicator: By the end of the lesson, the pupil will be able to:

Arrange Al, Zn, Mg, Fe and Cu in an electrochemical (activity) Series

Entry Behaviour: Students can construct galvanic cells

Stater: Ask students to balance few redox equations.

Phase One

Begin the lesson by letting students construct galvanic cells both physically and virtually respectively, following the instructions on their respective practical worksheets as shown in the appendix E and E and answer the questions on them respectively.

Phase Two

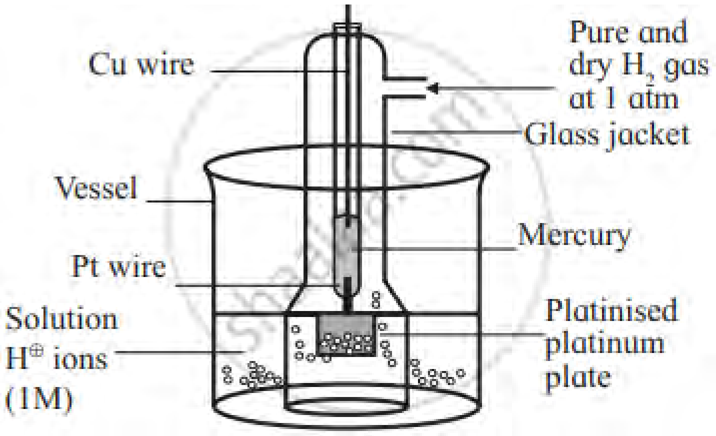
After constructing the respective galvanic cells, let them be guided how to Calculate the standard Reduction Potential Using : $E^{\theta}_{cell} =$

$E^{\theta}_{half-cell\,reduction} - E^{\theta}_{half-cell\,oxidation}$

Take the standard reduction potential of cu to be E° = +0.34 V.

Phase Three

Introduce the students to Standard Hydrogen Electrode potential, (SHE).



Conclusions

Conclusions

Conclude the lesson by giving the summary, for example below:

The following points should be remembered:

1. All E^{θ} values refer to the reduction reaction.
2. The E^{θ} values do not depend on the total number of electrons, so do not have to be scaled up or down according to the stoichiometry of the equation.
3. The more positive the E^{θ} value for a half-cell, the more readily it is reduced.
4. Electrons always flow through the external circuit in a voltaic cell from the half-cell with the more negative standard electrode potential (anode) to the half-cell with the more positive electrode potential (cathode).
5. Etc.

Lesson five

Subject: Chemistry

Class: SHS 2

Average Age: 16years

Strand: Electrochemistry

Sub Strand: Single displacement reaction.

Duration: 80 minutes

Resources:

Plab Group

Solids: Copper metal, zinc metal, Iron metal and Lead metal

Solutions: 0.1M hydrochloric acid, all other solutions are 0.1 M and include silver nitrate, lead (II) nitrate, iron (III) chloride, copper (II) nitrate, zinc nitrate, copper (II) sulphate,

Vlab Group

https://teachchemistry.org/classroom-resources/metals-in-aqueous-solutions-simulation

Indicator: By the end of the lesson, the pupil will be able to:

1. to perform and observe the results of a variety of single displacement reactions,
2. to become familiar with some of the observable signs of these reactions,
3. to identify the products formed in each of these reactions,
4. to write balanced chemical equations for each single displacement reaction studied.

Entry Behaviour: Students are familiar with electrochemical series

Stater: Ask students to arrange a given set of metals in their order of reactivity.

Phase One

Provide the groups with their respective resources together with the practical work report form as shown in the appendices G and H. Ask them to perform the following reactions and record your observations for each on the report form. Note that some reactions take longer than others. Thus, if results are not obtained immediately, give the reaction some time.

a). Zinc metal + hydrochloric acid

b). Lead metal + aqueous copper (II) sulphate

c). Copper metal + aqueous silver nitrate

etc.

Phase two

When done with the activities, ask them to complete the report.

Conclusion

Conclude the lesson by summarizing the key points as for example given below:

- Zinc is reacting as a reducing agent (which makes it the more reactive one). It has a greater reducing strength and so 'forces' copper ions to accept electrons.
- This reaction can be confirmed by putting copper metal into zinc sulphate solution and there will be no reaction. This is because copper is not a strong enough reducing agent to reduce zinc ions.
- By comparing these displacement reactions with different combinations of metals and their ions, a list of relative strengths can be produced. This is known as an activity series and it enables us to predict whether a redox reaction will be feasible.
- Etc.

3.4.3 Post-Intervention

Regular formative assessments, including quizzes, assignments, laboratory reports and summative assessments such as end-of-term examinations were conducted, to evaluate students' performance in electrochemistry. These assessments covered both theoretical knowledge and practical skills.

Questionnaires to collect data on students' perceptions, attitudes, and satisfaction regarding the laboratory resources were administered. These included Likert-scale questions, open-ended responses, and rating scales.

The progress of students was continuously monitored throughout the study duration. This involved tracking their completion of laboratory exercises, analyzing their lab reports, and recording any challenges or difficulties encountered.

3.5 Data Analysis

The data were analyzed using the research questions as a guide. Data were analyzed in terms of frequency count (percentages), bar graphs, pie charts, and t-tests. The t-test is the main statistical tool used to test the null hypothesis. The t-test is deemed appropriate since it is used to determine whether a significant difference exists between the two groups being compared. Here the performance of students taught using virtual resources and those of their colleagues taught using physical resources, the performance of male students and female students taught using virtual resources and the performance of male students and female students taught using physical laboratory resources were compared.

3.6 Ethical Considerations

In implementing the design of the study, permission was first of all sought from the head of the JTSHS schools. After the permission was granted, the researcher visited the school on separate days to familiarize with the chemistry teachers and the subjects (the students). The familiarization was to enable the researcher to settle well into the school climate of the schools and to brief students about the study. Students' consents were sought and were free to stop participation anytime any of them deemed it fit. The researcher needs to protect the identity of the students and the institution, develop a trust with them and promote the integrity of the research. In order to ensure the proactive participation of the respondents and their school, the confidentiality of their information and the opportunity that was offered in this study was made known to them in order to protect the rights and welfare of participants and to minimize the risk of physical and mental discomfort from the information they provided. To maintain confidentiality when answering the questionnaire, names were not used to identify the respondents. Instead, codes were assigned to each respondent for easy data analysis. After the data collection, gratitude was expressed to all respondents, the staff, and the headmaster of the school for the permission, participation and commitment granted for this study to be done.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter includes the results of the study and discussion of the results or the data obtained during the study. The results and discussion are presented based on the research questions and hypotheses.

4.1 Demographic Description of the Participants

"The term demographics refers to particular characteristics of a population. The word is derived from the Greek words for people (demos) and picture (graphy). Examples of demographic characteristics include age, race, gender, ethnicity, religion, income, education, home ownership, sexual orientation, marital status, family size, health and disability status, and psychiatric diagnosis (Lee & Schuele, 2010). Demographic information provide data regarding participant and is necessary for the determination of whether the individuals in a particular study are a representative sample of the target population for generalization purposes (Lee & Schuele, 2010). The profile of the participants in the study is focused on age and gender.

4.1.1 Age Distribution of the students

Table 3: Age distribution of the students

Age of students (years)	Frequency	Percentage (%)
12	1	5
13	0	0
14	1	5
15	4	21
16	6	32
17	5	26
18	2	11
Total	19	100

From the table 1 above, one student representing 5% are of age 12 and 14 respectively. 4 students representing 21% are of age 15, while 6 students representing age 16. 5 students, 26%, are of age 17 and finally 2 students, 11% are of age 18. The majority of the students falls within the standard age (15-18 years, representing 90%) for their academic level.

4.1.2 Gender Distribution of the students

Table 4: Sex of the students

Age of students (years)	Frequency	Percentage (%)
Male	10	53
Female	9	47
Total	19	100

The gender distribution is almost even, though the male students are one more than their female counterparts in the SHS2 science class.

4.2 Presentation of the Results by Research Questions

The results of the study are now presented by the research questions.

Research question one: What difficulties do the students encounter during electrochemistry lessons?

This question was posed to find out some difficulties students encounter during electrochemistry lessons. The below diagnostic test items were administered to the students who were previously taught electrochemistry prior to the study. The test item and its result are shown below.

Diagnostic test item

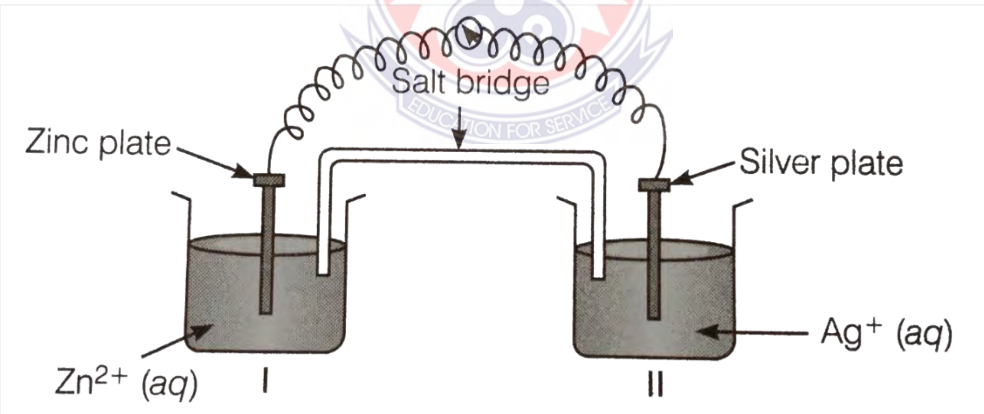


Figure 3: Galvanic cell

(i) Redraw the diagram to show the direction of electron flow.

(ii) Is silver plate the anode or cathode?

(iii) what will happen it salt bridge is removed?

(iv) When will the cell stop functioning?

(v) How will concentration of Zn^{2+} ions and Ag^{+} ions be affected when the cell function?

(vi) How will the concentration of Zn^{2+} ions and Ag^{+} ions be affected after the cell becomes dead?

(vii) Write the equations for the two half-cells and hence the overall cell equation.

Results

Table 3: Result table of diagnostic test

(i) Direction of electron flow

Response	Number of students	% Number of students
Correct answer	5	33.3
Incorrect answer	7	46.7
No response	3	20.0
Total	15	100.0

(ii) Identifying anode and cathode in electrochemical cell

Response	Number of students	% Number of students
Correct answer	6	40.0
Incorrect answer	8	53.3
No response	1	6.7
Total	15	100.0

(iii) Removal of salt bridge

Response	Number of students	% Number of students
Correct answer	4	26.7
Incorrect answer	6	40.0
No response	5	33.3
Total	15	100.0

(iv) When will the cell stop function?

Response	Number of students	% Number of students
Correct answer	5	33.3
Incorrect answer	6	40.0
No response	4	26.7
Total	15	100.0

(v) How will concentration of Zn^{2+} ions and Ag^{+} ions be affected when the cell function?

Response	Number of students	% Number of students
Correct answer	4	26.7
Incorrect answer	5	33.3
No response	6	40.0
Total	15	100.0

(vi) How will the concentration of Zn^{2+} ions and Ag^{+} ions be affected after the cell becomes dead?

Response	Number of students	% Number of students
Correct answer	1	6.7
Incorrect answer	11	73.3
No response	3	20.0
Total	15	100.0

(vii) Write the equations for the two half-cells and hence the overall cell equation.

Response	Number of students	% Number of students
Correct answer	3	20.0
Incorrect answer	8	53.3
No response	4	26.7
Total	15	100.0

From the diagnostic test results, the following difficulties were identified;

(i) they get confused between the flow of electrons in metallic conductors and in the electrolytes;

(ii) students get confused identifying anode and cathode/negative and positive poles in both galvanic and electrolytic cells;

(iii) their inability to explain the process happening at the anode and cathode;

(iv) mixing up the oxidation and reduction processes that occur at the electrodes,

(v) they have difficulty in understanding an electrolyte concept.

(vi) Inability to balance redox reactions, most especially, the charges.

These findings are corroborated by Ali, Woldu and Yohannes (2022). They reported that high school students have learning difficulties and misconceptions in electrochemical concept such as anode and cathode, electrolyte and the flow of electrons in electrochemical cells. Lu and Bi (2016) also investigated high school students' conceptual understanding of electrolyte concept and found out that students faced difficulty in acquiring deep knowledge of electrolyte.

Research Question Two: What is the effect of physical laboratory resources on the students' performance in electrochemistry?

This research question focused on the effect of the physical laboratory resources on the students' performance in electrochemistry lessons. In order to find out the performance of students in electrochemistry before the intervention, a pre-intervention achievement test was conducted for both Plab group and Vlab group. The total score was scaled to 100%.

The scores of the pre-intervention achievement and post-intervention achievement scores are listed in the table below;

Table 4: Distribution of pre-intervention and post- intervention score of the Plab group.

Score Obtained	Number of students **(pre-intervention)**	% number of students	Number of students **(post-intervention)**	% number of students
0-10	4	44	0	0
11-20	4	44	0	0
21-30	0	0	0	0
31- 40	0	0	3	33
41- 50	0	0	1	11
51- 60	1	11	3	33
61- 70	0	0	1	11
71-80	0	0	0	0
81-90	0	0	0	0
91-100	0	0	1	11
Total	9	99	9	99

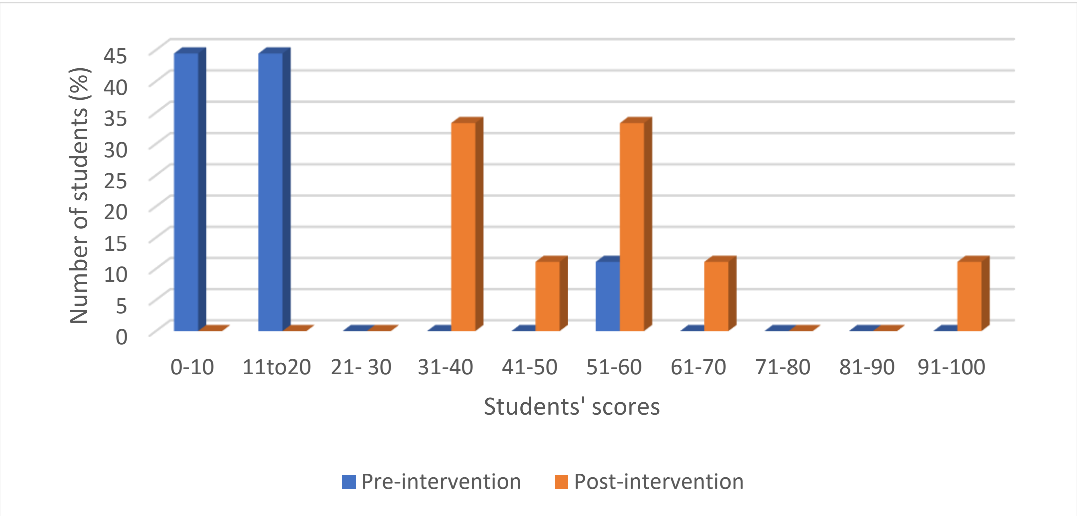


Figure 4: Bar chart showing test scores of students in Plab Group for pre-intervention and post-intervention

Discussion of Pre-intervention and Post-intervention Results of Plab Group

From Table 4 above, the pre-intervention results of the Plab group indicated that four (4) students representing 44% scored between zero (0) and ten (10) marks. Another four (4) students representing 44 % scored between eleven (11) and twenty (20) marks. No student scores the mark ranges, twenty-one (21) and thirty (30), thirty-one (31) and forty (40) and also forty-one (41) and fifty (50) representing 0% respectively. One student scored between fifty-one (51) and sixty (60) marks. No student representing 0% scored between sixty-one (61) and seventy (70), seventy-one and eighty, eighty-one and ninety, and finally 91 and 100 marks.

However, the post-intervention results of the same group indicated an improvement in students' performance. None of the students representing 0% scored between zero (0) and thirty (30) marks. three students representing 33% scored between thirty-one (31) and forty (40) marks. One student representing 11.1% scored between forty-one (41) and fifty (50) marks. Three students representing 33.3% scored between fifty-one (51) and sixty (60) marks. One student representing 11.1% scored between sixty-one (61) and seventy (70) marks. Between seventy-one and ninety marks, no student scored, representing 0%. However, one student representing 11.1% scored between ninety-one (91) and one hundred (100) marks.

The bar chart in figure 3, above showed the test scores of students in the Plab group for pre-intervention and post-intervention. The results showed that students performed well in the post-intervention as compared to the pre-intervention.

Research Question three: What is the effect of virtual laboratory resources on the students' performance in electrochemistry?

This research question focused on the effect of the virtual laboratory resources on the students' performance in electrochemistry lessons. In order to find out the performance of students in electrochemistry before the intervention, a pre-intervention achievement test was conducted for both Plab group and Vlab group. The total score was scaled to 100%.

Table 5: Distribution of pre-intervention and post-intervention scores of the Vlab group

Score Obtained	Number of students **(pre-intervention)**	% number of students	Number of students **(post-intervention)**	% number of students
0-10	5	50	0	0
11-20	2	20	0	0
21-30	1	10	0	0
31- 40	0	0	3	30
41- 50	2	20	3	30
51- 60	0	0	2	20
61- 70	0	0	0	0
71-80	0	0	1	10
81-90	0	0	1	10
91-100	0	0	0	0
Total	10	100	10	100

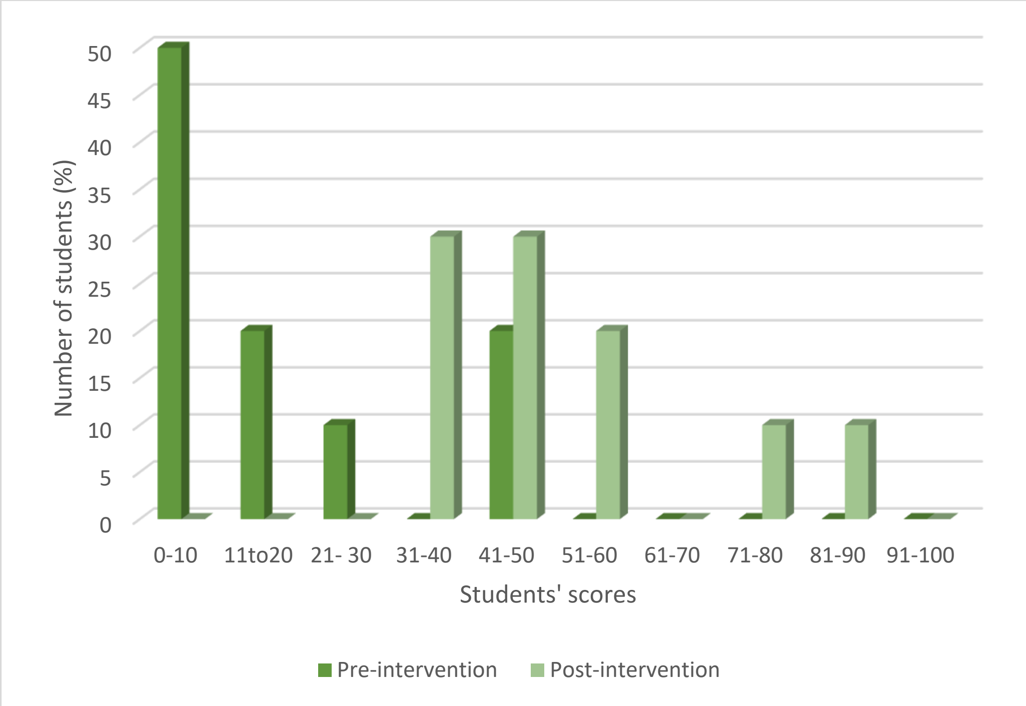


Figure 5: Bar Chart Showing Test Scores of Students in the Vlab Group for Pre-intervention and post-intervention

Discussion of Pre-intervention and Post-intervention Results of Vlab Group

From Table 5, the pre-test results of the vlab group indicated that five (5) students representing 50% scored between zero (0) and ten (10) marks. Two (2) students representing 20 % scored between eleven (11) and twenty (20) marks. One (1) student representing 10% scored between twenty-one (21) and thirty (30) marks. No (0) student representing 0% scored between thirty-one (31) and forty (40) marks. Two students representing 20% scored between forty-one (41) and fifty (50) marks.

However, the post-intervention scores of the same group indicated an improvement in students' performance. None of the students representing 0% scored between zero (0) and thirty (30) marks. Three students representing 30% scored between thirty-one (31) and forty (40) marks. Another three students representing 30% scored between forty-one (41) and fifty (50) marks. Two students representing 20% scored between fifty-one

(51) and sixty (60) marks. No student representing 0% scored between sixty-one (61) and seventy (70) marks and one student representing 10%, each, scored between seventy-one (71) and eighty (80), eighty-one (81) and ninety (90), respectively. Finally, no student scored between ninety-one (91) and one hundred (100). The bar chart in figure 3 above showed the scores of students in the vlab group for pre-intervention and post-intervention. The results showed that students performed better in the post-intervention as compared to the pre-intervention.

Ho1: **There is no significant difference in students' performance in electrochemistry between those utilizing physical laboratory resources and those using virtual laboratory resources.**

Table 6: Comparison of Mean and variance of Pre-intervention and Post-intervention scores for Plab and Vlab Groups

Group	Intervention	Mean	Variance	P-Value
Plab	Pre-Intervention	14.8	285.8472	0.886834[a]
Vlab	Pre-Intervention	15.984	346.95936	
Plab	Post-Intervention	55.5	404.74485	0.7089[b]
Vlab	Post-Intervention	52.281	283.5062	

a = Not significant; $p>0.05$ **b** = Not significant; $p>0.05$

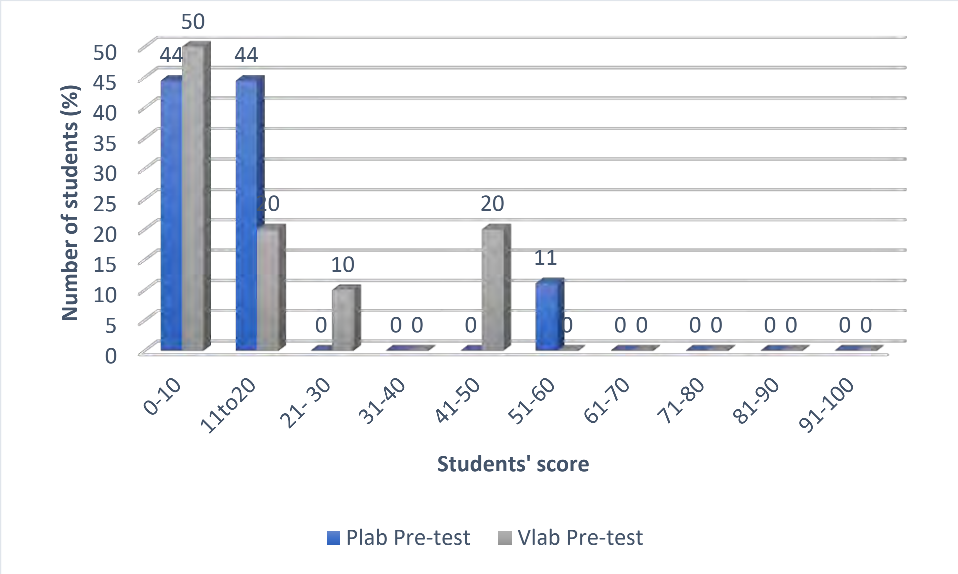


Figure 6: Distribution of Plab and Vlab group scores in the Pre-intervention

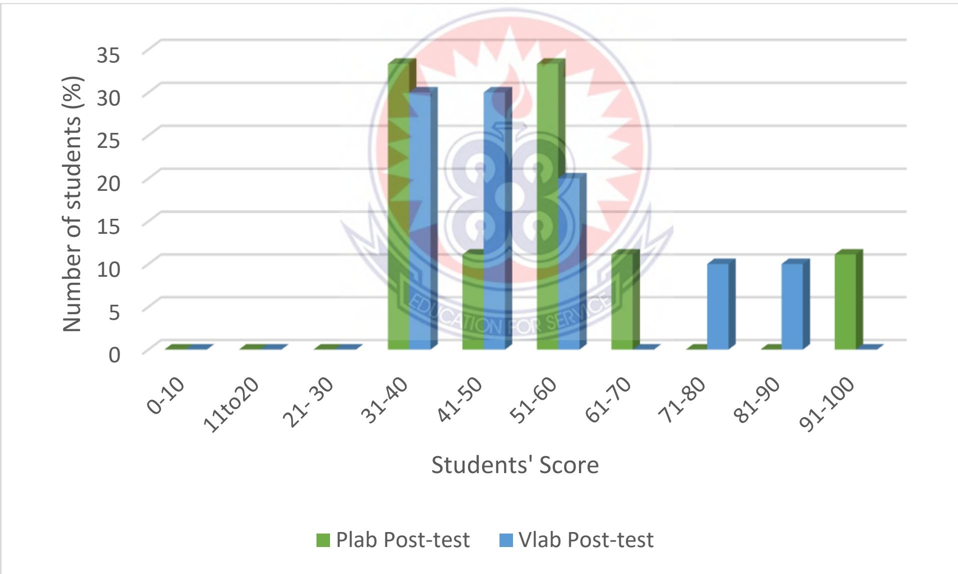


Figure 7: Distribution of Plab and Vlab group scores in the Post-intervention

From the Table 6 above, the mean for the Plab group in the pre-test was less than that of the Vlab group. However, the t-test analysis of pre-intervention mean score indicated that there was no statistically significant difference between the mean scores of both Plab and Vlab group in the pre-intervention of electrochemistry achievement assessment test ($p > 0.05$; $p = 0.887$). This showed that the two groups were statistically the same before the intervention. On the other hand, the post-intervention results showed that the mean test score of the Plab group (55.5) was slightly higher than that of the Vlab group (52.3). The t-test analysis of the post-intervention indicated that there was no significant difference in the means of both Plab and Vlab group ($p > 0.05$; $p = 0.71$). Hence the hypothesis that, there is no significant difference in students' performance in electrochemistry between those taught utilizing physical laboratory resources and those using virtual laboratory resources could not be rejected. In other words, the performance of the Plab group was not significantly different from the Vlab group. This implies that, both groups benefited immensely from the intervention which made them perform well in the post-intervention achievement test.

From the results of this study, it can be deduced that teaching electrochemistry through utilization of Physical laboratory and virtual laboratory resources has increased the understanding of electrochemical concepts.

Some of the related studies which confirm the results of this undertaken study are discussed.

The improvement of the performance in students utilizing physical lab resources are corroborated by Afyusisye and Gakuba (2022), who investigated the effect of the chemistry practical on the academic performance of Ward Secondary. They found out that, the use of physical lab has increased significantly the performance of high school students in chemistry. Physical chemistry practical has positive effect on the academic performance of students (Mwangi , 2016). The results were also correlated by Buhatwa (2014), who found the importance of laboratory practical in science subjects. The study results also are in line with Olubu (2015) who found that chemistry practical facilitate student understanding, which results in a good performance. The results are also in line with Pavešić (2008), who explains that the good achievement of students has been influenced by practical work. He adds that practical works promote positive attitudes of students towards learning chemistry. The results also agreed with the ones obtained by Shana and Abulibdeh (2020), which show the positive relationship between practical work and the academic achievement of students.

The findings in support of the use of physical labs are not different from those utilizing virtual labs. Yusuf and Afolabi (2010), observed that the use of computer assisted instruction, CAI, (otherwise known as Virtual laboratory resource) significantly increases the academic achievements of students. Furo (2015), also reported that the use of CAI in education contributed significantly to higher students' performance in schools. Safo, Ezenwa and Wushishi (2013) also reported Computer Assisted Instruction enhanced the achievement and retention in geometry. Adherr (2015) buttress the report that, students improve their test scores when exposed to computer assisted instructions.

The findings by Owusu , Monney , Appiah and Wilm (2010) however provided a contradictory report on the use of CAI by reporting that students, who were instructed by the conventional or other approaches performed better on the post-intervention than those instructed by the use of CAI. Bayraktar (2008) could also, not found any significant difference between the students exposed to CAI and those exposed to traditional method.

Ho2; There is no significant difference in the performance of male and female students taught electrochemistry, using virtual laboratory resources.

Table 7: Comparison of Mean and variance of Male and Female Post-intervention scores for Vlab Group

Gender	Mean	Variance	P-value
Male	52.6	388.3	0.959
Female	52.0	254	

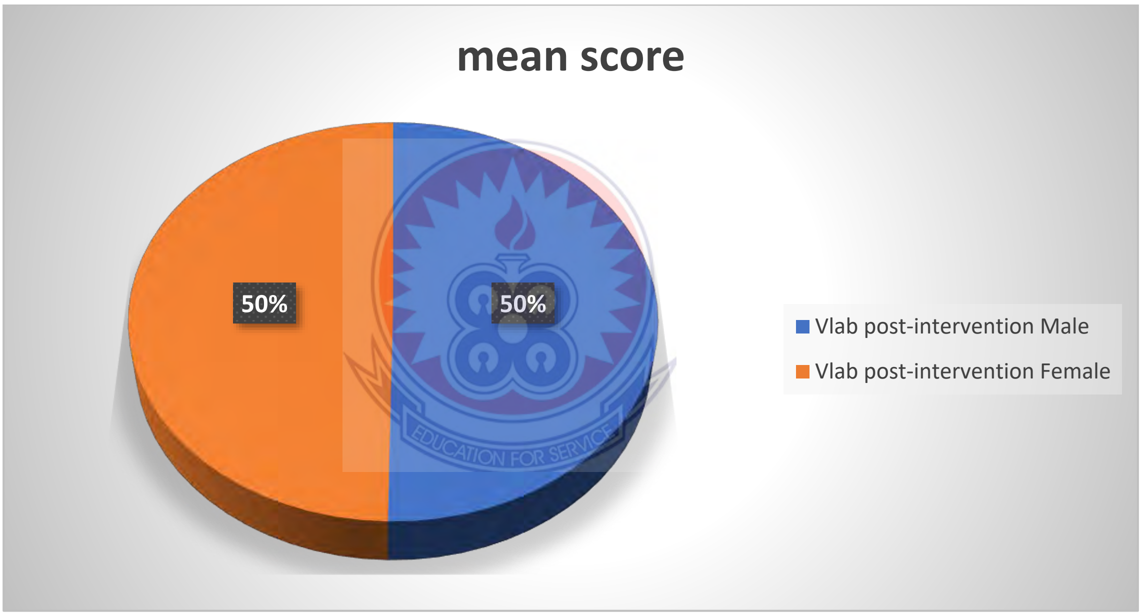


Figure 8: Comparison of Mean of Male and Female Post-intervention scores for Vlab Group

From table 7 and Figure 8. The post-test mean score for male and female in the Vlab group is almost equal, (52.6 for male and 52.0 for female). The p-value is 0.96 which is greater than 0.05 confidence interval. This implies that, there is no significant difference between the mean scores statistically. Therefore, the null hypothesis cannot be rejected. Male and female perform equally when taught using virtual lab. However few research reports gave contrary views.

Gunawan , Suranti, Nisrina, Herayanti, and Rahmatiah (2018), studied the effect of physics virtual labs on gender and creativity in high schools and found that the female students scored higher than their male counterparts. Radulović, Županec, Stojanović and Budić (2022) reports that virtual experiments contribute more to females' motivation to learn physics than applying real experiments. This is the case in the electrochemistry as well.

Contrary, Jolley , Wilson, and Kelso (2016) emphasized that, male students perform better than females when using virtual laboratories.

Ho3**: There is no significant difference in the performance of male and female students taught electrochemistry, using physical laboratory resources.**

Table 8: Comparison of Mean and variance of Male and Female Post-intervention scores for Plab Group

Gender	Mean	Variance	P-value
Male	66.8	371.2	0.054475
Female	41.5	129	

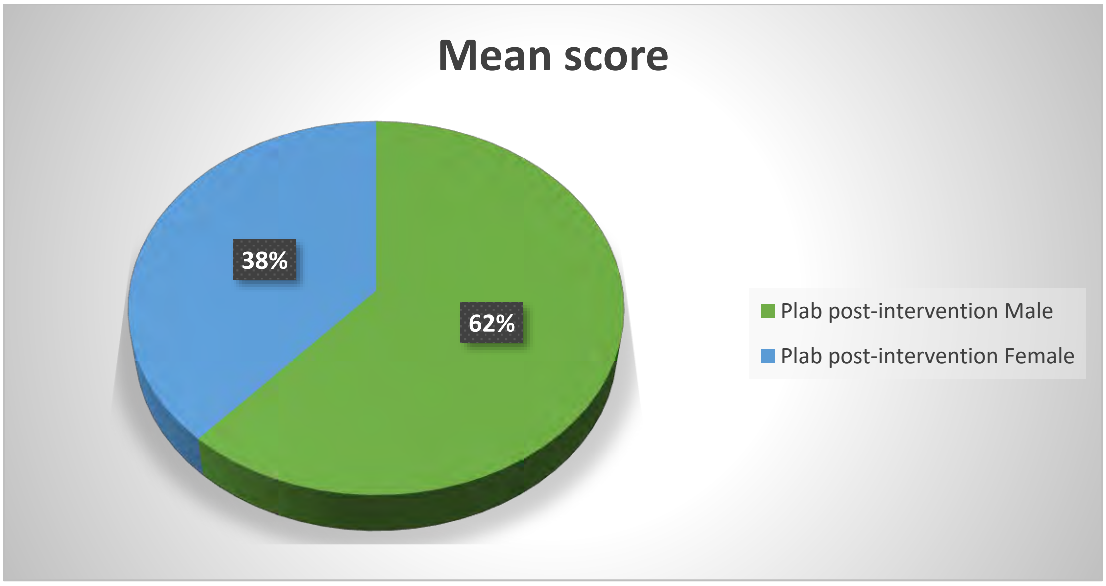


Figure 9: Comparison of Mean of Male and Female Post-intervention scores for Plab Group

From table 8 and Figure 9, The post-test mean score for male and female in the Plab group is not equal, (66.8 for male and 41.5 for female). It could be observed that, the male students perform better than the females when taught with physical lab. However, statistically, there is no significant difference between the performance of the two genders, since the p-value (0.054475) is slightly greater than 0.05, hence the null hypothesis cannot be rejected.

Also comparing fig.7 and 8, one would observe that the mean score for female students in the Vlab group is 50% and that of Plab group is 36%. It can be deduced that female students perform better when taught using virtual laboratory resources than physical laboratory resources. Ratamun and Osman (2018) reported that, female students showed an increase in attitude towards chemistry when they conduct experiments using the VLab. This is because the girls are comfortable with the approach and strategic learning that is integrated in the VLab. Female students feel safe conducting experiments using the VLab because the experiments conducted do not involve actual apparatus and chemicals. This causes them to be more convinced and actively involved in experiments. This finding is equivalent to the study of Keter, Wachanga and Anditi (2016) stating that computer-assisted experiments can change attitudes and motivate female students to learn chemistry. Holmes, Roll, and Bonn (2014) suggest that male students handle lab equipment significantly more often than female students during hands-on activities. This could be the reason why male students performed better than their female counterparts in the Plab group.

Research Question four: What are the students' perceptions of the use of physical and virtual laboratory resources for electrochemistry lessons?

This question was posed to solicit from the students their perceptions and opinions about the use of Plab and Vlab in development of basic experimental skills, arresting their interest/ motivation, and also their perceptions about the merit and demerits of the two approaches respectively. Questionnaires were administered to the two groups after they have respectively gone through interventions.

Discussions of response from student's questionnaire.

The following questions were posed in the questionnaire and their respective responses recorded for analysis for the both groups.

Question: Was the measurement and analysis of data easy for you?

This question was posed to find out the opinions of the respondents, the extent to which they could measure and analyze data using the two approaches respectively. The responses are presented in the table 9&10 and figure 9 &10 respectively below.

Table 9: Vlab Group's response on measurement and analysis of data

Responses	Frequency	Percentage (%)
Not easy	0	0
Barely easy	2	20
Easy	3	30
Very easy	3	30
Most easy	2	20
Total	10	100

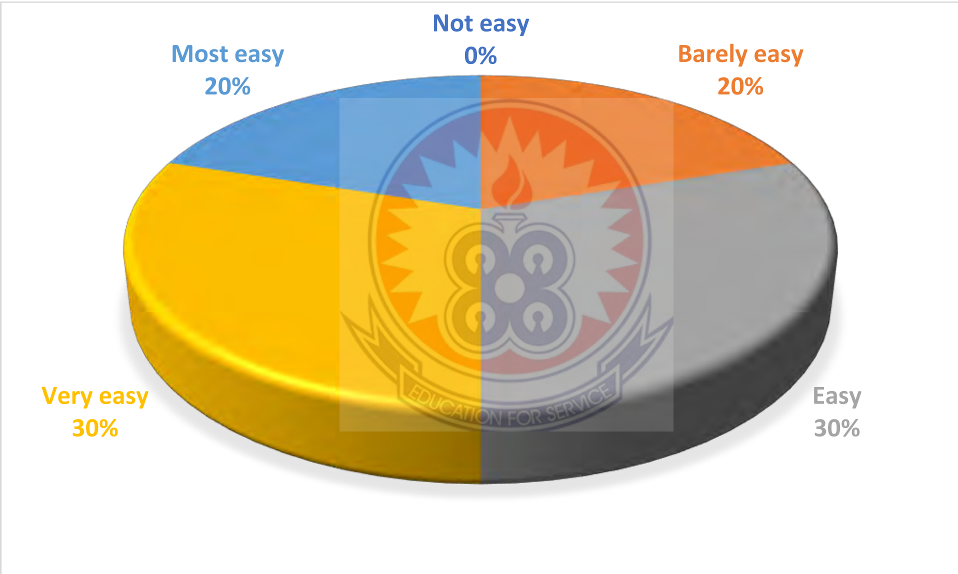


Figure 10: A Pie Chart Showing Vlab Group's response on measurement and analysis of data

Table 9 and fig.10 indicate respondents' response, 2 students out of 10, representing 20% responded most easy to the questions, 3 students representing 30% responded very easy, 3 students representing 30% responded easy, 2 students representing 20% responded barely easy while no students responded not easy. This means that majority of students were able to measure and analyze data obtained from virtual experiments with ease.

Table 10: Plab Group's response on measurement and analysis of data

Responses	Frequency	Percentage (%)
Not easy	0	0
Barely easy	0	0
Easy	4	44.4
Very easy	4	44.4
Most easy	1	11.1
Total	9	100

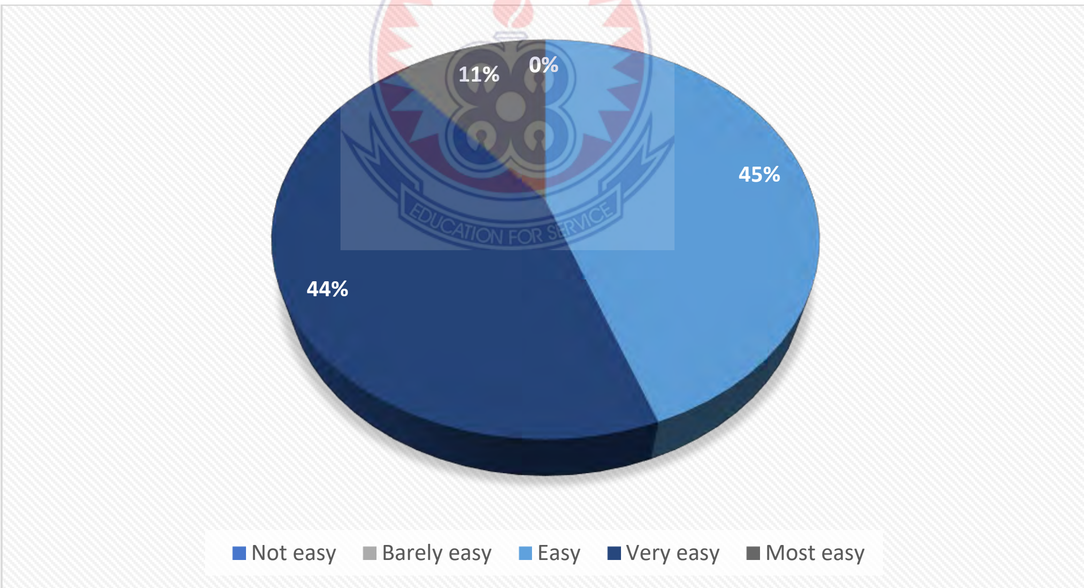


Figure 1: A Pie Chart Showing Plab Group's response on measurement and analysis of data

From the table 11 and figure 10, indicating respondents' response, 1 student out of 9, representing 11.1% responded most easy to the questions, 4 students representing 44.4% responded very easy, another 4 students representing 44.4% responded easy, while no student responded barely easy and not easy. This means that majority of students were able to measure and analyze data obtained from physical lab experiments with ease.

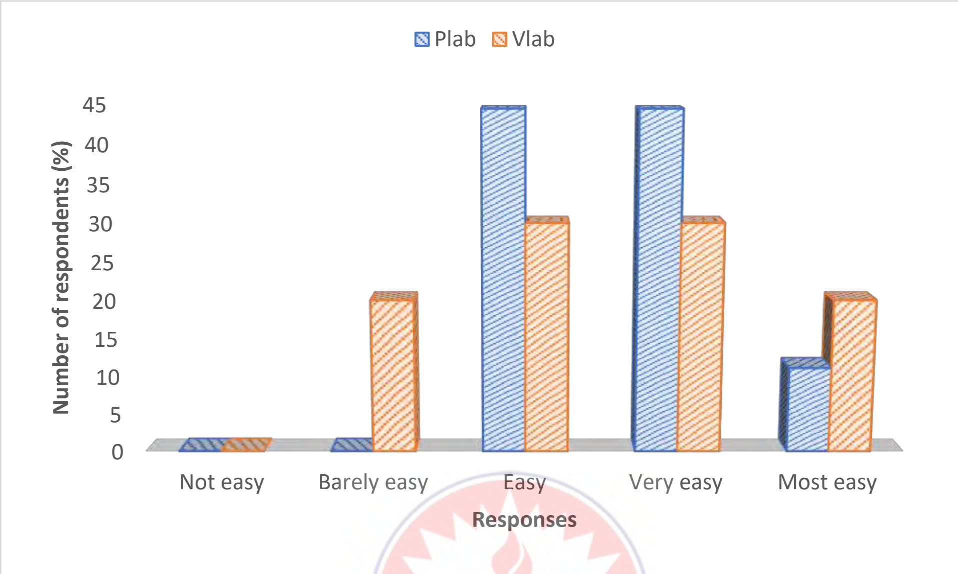


Figure 12: A Bar Chart Showing comparison of Vlab and Plab Groups' responses on measurement and analysis of data

From fig. 12 above, it can be deduced that the respondent from the two group can easily measure and analyze data from their respective lab experiments with ease.

Question: Were the results of the experiment easily interpreted?

This question was posed to find out the ease with which students could interpret the results of the experiments using the two approaches respectively. The responses are presented respectively below.

Table 11: Vlab Group's response on interpreting results of experiments

Responses	Frequency	Percentage (%)
Not easy	1	10
Barely easy	0	0
Easy	3	30
Very easy	4	40
Most easy	2	20
Total	10	100

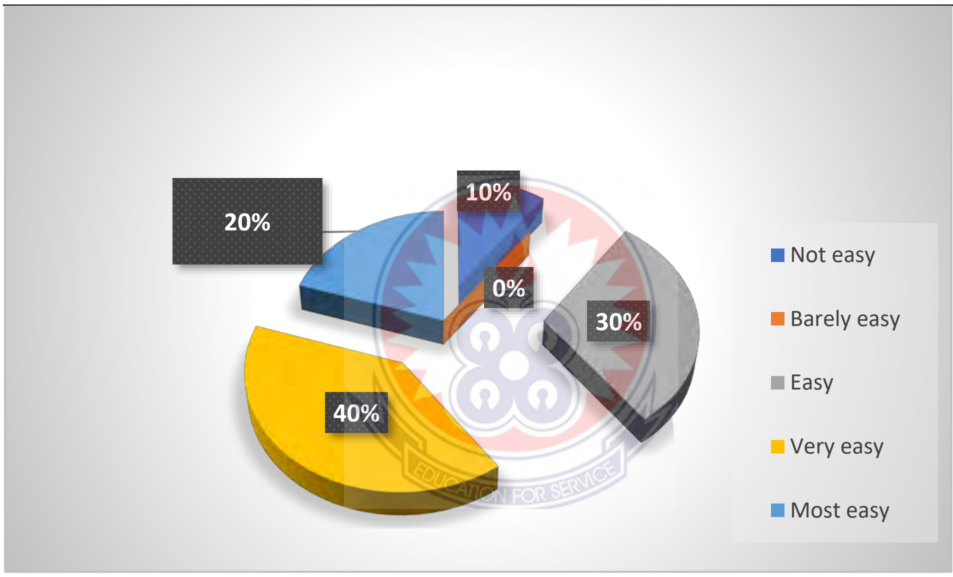


Figure 13: A Pie Chart Showing Vlab Group's response on interpreting results of experiments

From the table 11 and fig. 13 indicating respondents' response, 2 students out of 10, representing 20% responded most easy to the questions, 4 students representing 40% responded very easy, 3 students representing 30% responded easy, while no student responded barely easy and one student representing 10% responded not easy. This means that majority of students were able to interpret the results obtained from the virtual lab experiments with ease.

Table 12: Plab Group's response on interpreting results of experiments

Responses	Frequency	Percentage (%)
Not easy	0	0
Barely easy	0	0
Easy	3	33.3
Very easy	6	66.6
Most easy	0	0
Total	9	100

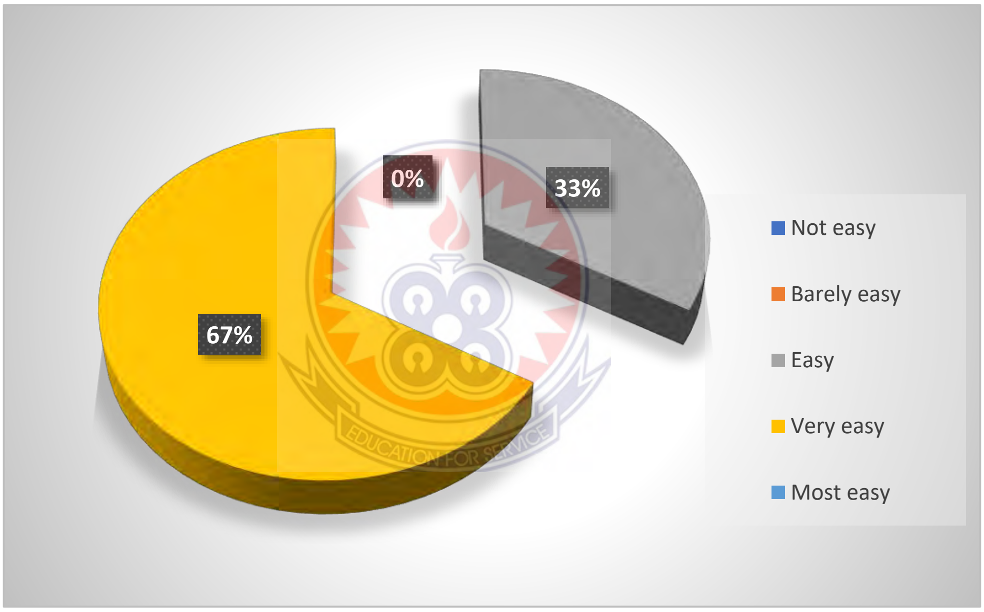


Figure 14: A Pie Chart Showing Plab Group's response on interpreting results of experiments

From Table 12 and Fig. 14 indicating respondents' response, 6 students out of 9, representing 67% responded very easy to the questions, 3 students representing 33% responded easy, while no student responded barely easy, not easy and most easy representing 0% each. This means that majority of students were able to interpret the results obtained from the physical lab experiments with ease.

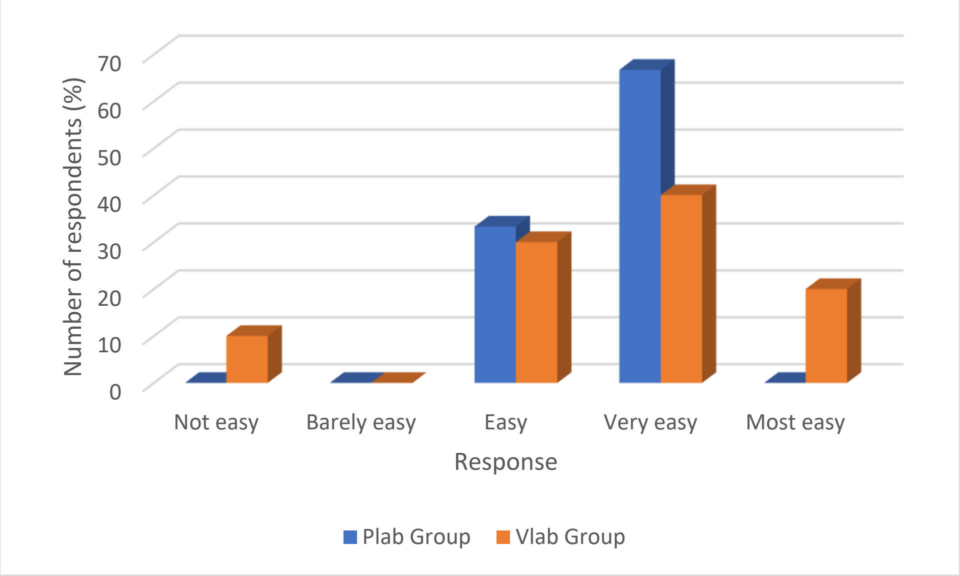


Figure 15: A Bar Chart Showing comparison of Vlab and Plab Groups' responses on interpreting results of experiments

From the bar chart above, it can be deduced that the respondent from the two group can easily interpret the results obtained from their respective lab experiments.

Question: Was the experiment/ process motivating enough?

This question was asked in order to evaluate the level of motivation or interest to learn derived from the two groups respectively. The responses are presented below.

Table 13: Plab Group's response on whether the experiment was motivating enough

Responses	Frequency	Percentage (%)
No	0	0
Can't say	1	11
Yes	8	89
Total	9	100

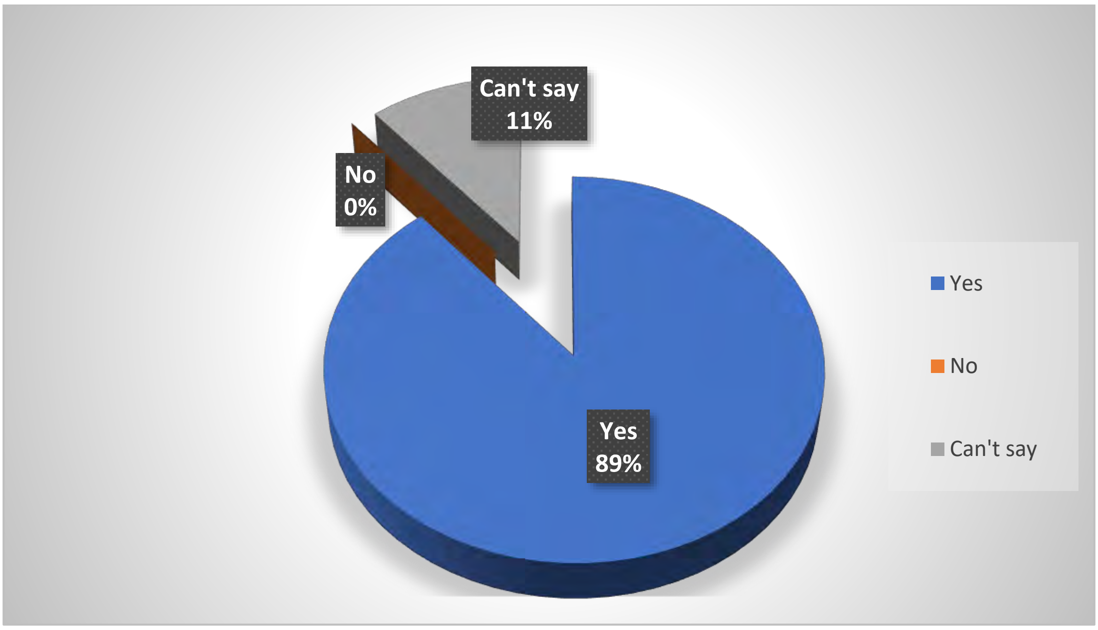


Figure 16: A Pie Chart Showing Plab Groups' responses on whether the experiment was motivating enough

It can be inferred from the pie chart in fig 16 that, overwhelming majority (89%) of the respondents answered yes, the physical lab experiment was motivating enough.

Table 14: Vlab Group's response on whether the experiment was motivating enough

Responses	Frequency	Percentage (%)
No	1	10
Can't say	2	20
Yes	7	70
Total	10	100

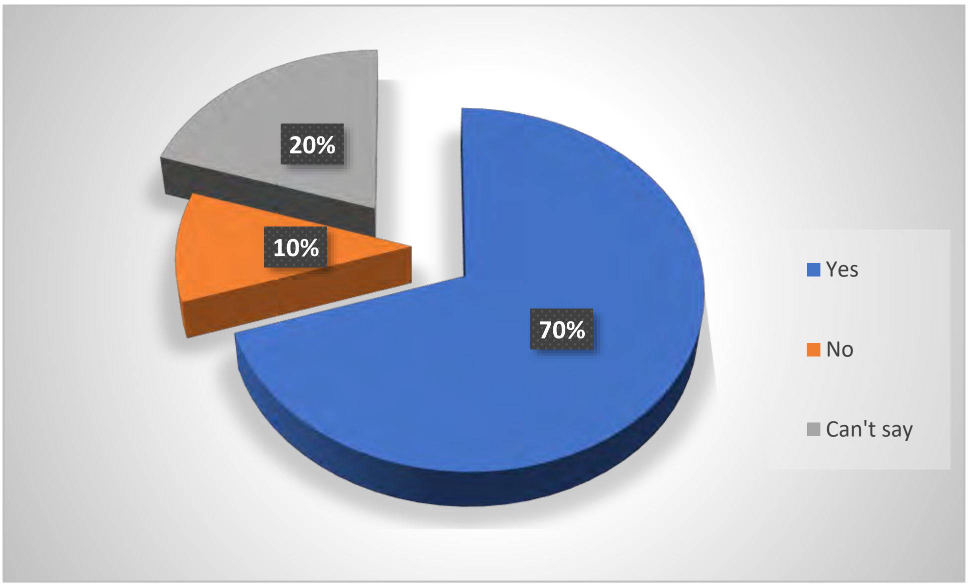


Figure 17: A Pie Chart Showing Plab Groups' responses on whether the experiment was motivating enough

It can also be deduced from table 14 and fig.17 that, the majority (70%) of the students say yes, the virtual experiment is motivating enough.

The findings of both Vlab and Plab groups agree largely with some existing reports. Chemistry practical increase motivation, and students' engagement and promote communication skills (Köller, Olufsen , Stojanovska , & Petrusevski, 2015).

Increasing, motivation and interest in students help them to love and learn chemistry (Hodson, 1990). Chemistry practical also helps students to develop a positive attitude and curiosity towards chemistry. This helps students to learn chemistry voluntarily which increases engagement and affects attitude, hence raising their performance (Afyusisye & Gakuba, 2022).

On the other hand, it has been shown that virtual laboratory applications contribute to students' meaningful learning by enabling the concretization of abstract subjects, and that these applications positively support students' interest, excitement and motivation towards the science course because they are found attractive. (Yildirim, 2021).

It concluded that the level of students' attitude towards chemistry is same when experiment is done in VLab or PLab (Ratamun & Osman, 2018).

Question: Do you believe that virtual laboratories can fully replace traditional hands-on (physical) laboratory experiments in electrochemistry lessons?

This question is asked to determine the opinion of students and how the Vlab group perceive the virtual laboratory in relation to physical laboratory. Below are the responses.

Table 15: Vlab Groups' responses on believe that virtual laboratories can fully replace traditional hands-on (physical) laboratory experiments in electrochemistry lessons

Responses	Frequency	Percentage (%)
No	6	60
Not sure	2	20
Yes	2	20
Total	10	100

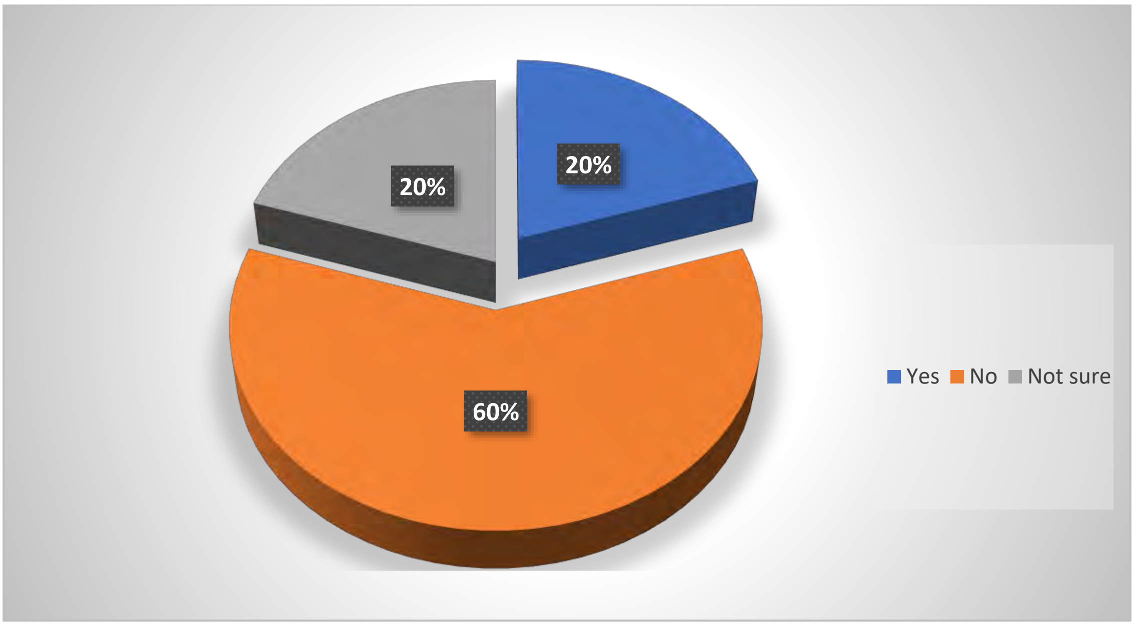


Figure 18: A Pie Chart Showing Vlab Groups' responses on believe that virtual laboratories can fully replace traditional hands-on (physical) laboratory experiments in electrochemistry education

In the pie chart above (Fig.18), only 20% of the respondence believed that virtual laboratories can fully replace traditional hands-on laboratory experiments in electrochemistry lessons. The majority constituting 80% do not believe so. When asked why not or not sure they expressed the following reasons:

"I believe having hands on experience with the proper precautions facilitates better learning for the students".

"Online labs are just a simulation of the real thing and do not provide real experience in the field. Once the time to do hands-on activity in the real world comes, students will be unprepared".

"I believe there are certain experiments that may be easier done virtually because it is more convenient, but there are experiments that may be better done in a traditional way. The traditional way can give students a hands-on experience wherein it allows them to see what really happens during the experiment, while the results of a virtual experiment may be inaccurate".

"I also think the procedures in virtual experiments are based on how it is done in a physical laboratory, but there might be limited procedures or resources depending on how the website or experiment as a whole is programmed".

"Both virtual and traditional are good and could work, but it depends on the situation (The students and teacher have classes online or the students and teacher have classes in a physical classroom), that is why I am not sure."

"Due to the lack of hand-on experience I think students still learn more when they see it in real life".

"Virtual laboratories do not impact students the same way as a physical one does. There is a cognitive marker we place on activities we do that require foresight, making the activity memorable while giving us an opportunity to see how the concepts we study in our books can be applied in real life. The application of these concepts in a more practical and real setting outweighs its cons and I thoroughly believe in the potential of participating in physical experiments rather than virtual". "Physical experiment is better than virtual experiment because in physical experiment, you do it yourself and it gives more understanding but in virtual you only look and experiment".

It could be inferred from the above responses that, virtual lab cannot replace the physical laboratory, despite its usefulness. However, it can be used to complement the physical laboratory. This assertion is corroborated by Adegoke and chukwunenye (2013). They examined the effect of computer simulated experiments on student's learning outcomes in practical physics. There were three groups: computer simulated experiment only, computer simulated experiment with hands-on experiments, and hands-on experiment. The results showed that the students who have studied by computer simulated and hands-on experiments are the best among three groups.

Question: In your opinion, should the use of the physical laboratory be continued in future electrochemistry courses?

This question is asked to determine the opinion of students and how the Plab group perceive the Physical laboratory. Below are the responses.

Table 16: Plab Groups' responses on should the use of physical laboratory be continued in future electrochemistry lessons

Responses	Frequency	Percentage (%)
No, alternative methods should be explored	0	0
No, it's not necessary	0	0
Yes, but with improvements	4	50
Yes, absolutely	4	50
Total	8	100

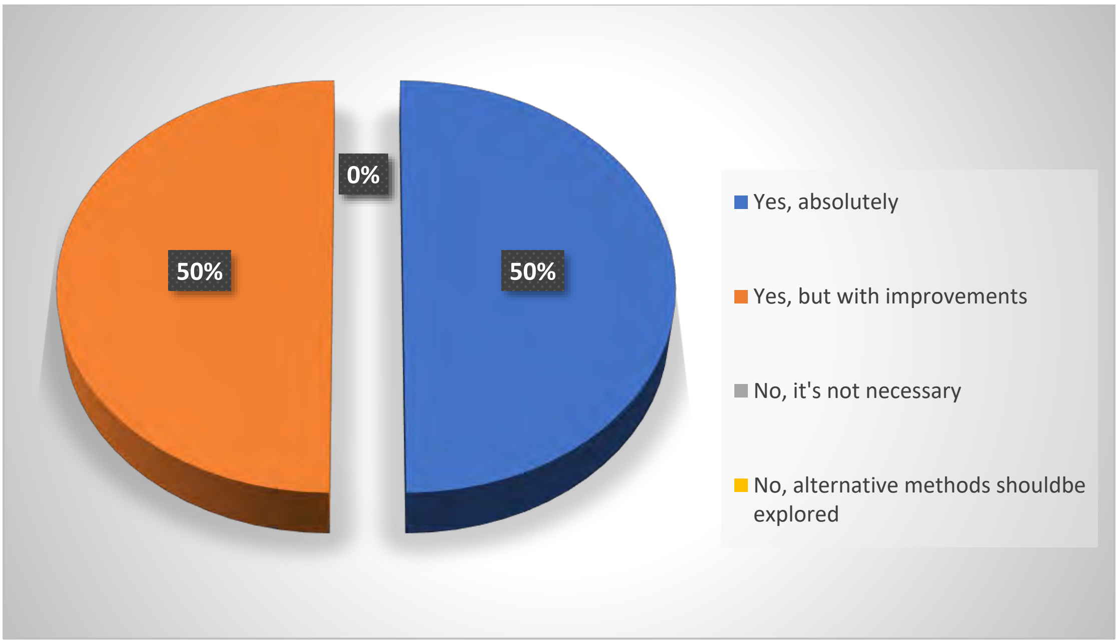


Figure 19: A Pie Chart Showing Plab Groups' responses on should the use of physical laboratory be continued in future electrochemistry lessons

The response was very emphatic, yes (fig.19 and table 16), only that 50% of the respondents think there should be improvement. This actually buttress the opinions of the Vlap group on the replacement of physical lab with the virtual laboratories.

Question: What are the disadvantages you see in using a physical laboratory for learning electrochemistry?

This question was asked the Plab group to determine some limitations of the use of physical laboratory. Their responses are represented below;

Table 12: Plab Groups' responses on the limitations and challenges of physical laboratory in electrochemistry lessons

Responses	Frequency	Percentage (%)
Not accessible anytime and anywhere, unless going to the lab	7	87.5
Not cost-effective compared to virtual labs	2	25
Less student engagement	3	37.5
Complex experiments cannot easily be undertaken	2	25.5
Student's safety cannot be guaranteed.	2	25.5

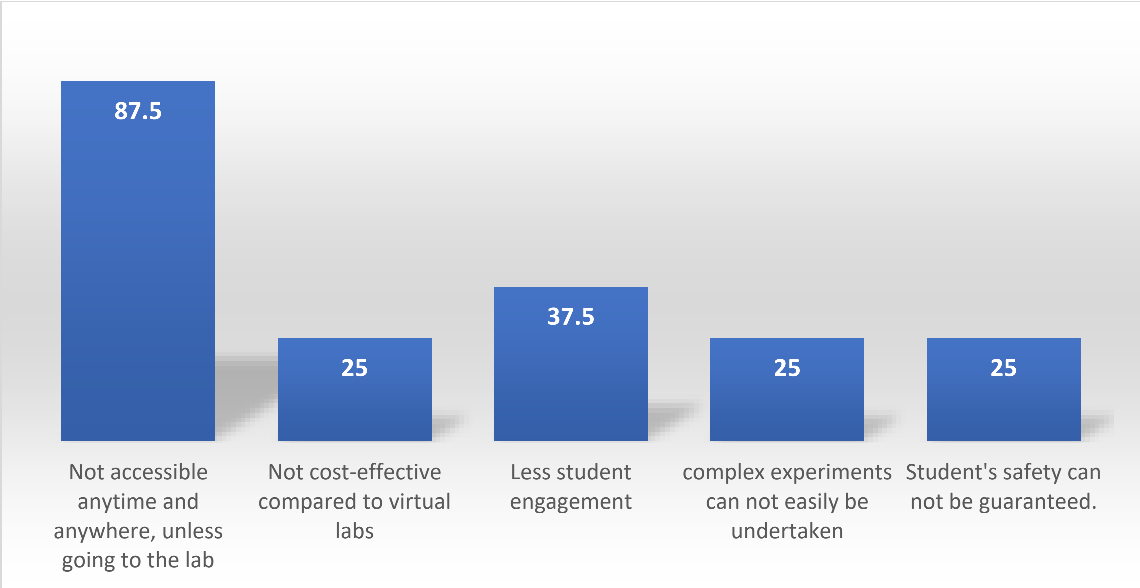


Figure 20: A Bar Chart Showing Plab Groups' responses on the limitations and challenges of physical laboratory in electrochemistry lessons

From the table 17 and figure 20 above, the respondents enumerated the challenges and limitations of physical laboratory as; not accessible anytime and anywhere, not cost-effective compared to virtual labs, less student engagement, complex experiments cannot easily be undertaken and finally student's safety cannot be guaranteed.

Question: What are the disadvantages or challenges you have encountered when using virtual laboratories for teaching electrochemistry?

This question is posed to Vlab group in order to solicit their opinions on the challenges they may encounter when using virtual labs. The responses are presented below;

Table 18: Vlab Groups' responses on the limitations and challenges of virtual laboratory in electrochemistry lessons

Responses	Frequency	Percentage (%)
Limited hands-on experience	8	80
Technical issues or connectivity problems	6	60
Lack of real-world context	6	60
Difficulty in simulating certain experiments	5	50
Inadequate guidance or instructions	4	40

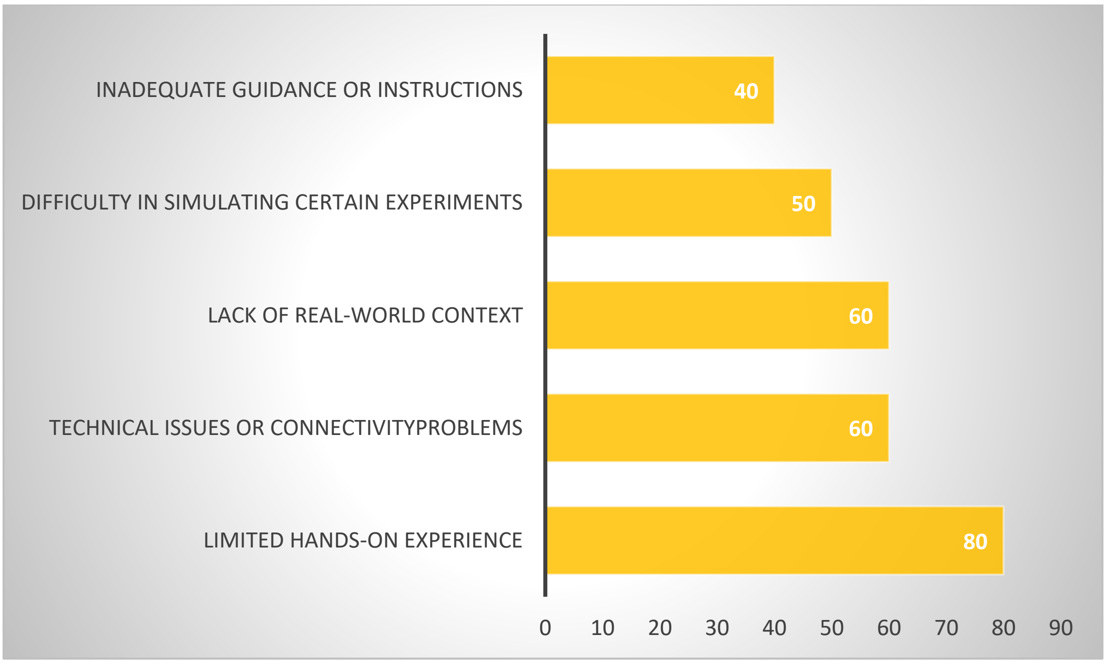


Figure 21: A Bar Chart Showing Vlab Groups' responses on the limitations and challenges of virtual laboratory in electrochemistry lessons

As shown in the table 18 and figure 21 above, inadequate guidance or instructions, difficult in simulating certain experiments, lack of real-world context, technical issues or connectivity problems and limited hands-on experience are the responses enumerated, being the challenges of the virtual experiments.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This chapter includes the summary of the findings and conclusion of the study. Also, the chapter looks at recommendations for stakeholders, suggestions for further research, and contributions of the study to chemistry educators.

5.2 Summary of the findings

The main reason for the conduct of this research was to compare the effectiveness of using virtual laboratory and physical laboratory resources on the performance of students in electrochemistry lessons. The study sought to evaluate the influence of traditional physical laboratory resources on students' performance in electrochemistry. That is to determine the extent to which hands-on practical experiences contribute to students' understanding of theoretical concepts and their ability to apply them in real-world scenarios. It also sought to examine the impact of virtual laboratory resources, including augmented reality tools, on students' performance in electrochemistry focusing on exploring the potential benefits and limitations of virtual laboratories in facilitating learning, practical skill development, and problem-solving abilities.

The following are the summary of the findings:

1. The finding from the study showed a positive improvement in the performance of students in electrochemistry when taught using physical and virtual laboratory resources respectively. The two groups benefited immensely from their respective interventions and there is no significant difference in their understanding of electrochemical concepts, leading to improved performance. This conclusion was based on the difference in the mean post-test scores of the

Plab and Vlab groups being 55.5 and 52.3 respectively with their p-value being 0.71 which is greater than 0.05 (Table 4 and Figure 5).

2. On gender comparison, male and female students perform equally when taught using virtual laboratory resources. The mean post-intervention score for male and female students are 52.6 and 52.0 respectively. Their p-value (0.96) is far greater than 0.05, (Table 5 and Figure 6). This implies that there is no significant difference between the mean scores statistically.
3. It is also observed that the male students perform better than their female colleagues when taught electrochemistry utilizing physical laboratory resources. This can be inferred from Table 6 and Figure 7, The post-test mean score for males and females in the Plab group is not equal, (66.8 for males and 41.5 for females). However, statistically, there is no significant difference between the performance of the two genders, since the p-value (0.054) is slightly greater than 0.05.
4. The majority of students were able to measure and analyze data obtained from both virtual and physical experiments respectively, with ease. (fig. 8 & fig,9).
5. This finding is not different from the ability to interpret experimental data. It can be deduced from Fig. 11, Fig.12, and Fig.13, that the respondent from the two groups can easily interpret the results obtained from their respective lab experiments.
6. The result presented in Figure 14 and Figure 15 indicates that students' motivation and interest to learn electrochemistry tremendously increase when any of the laboratory resources are used to teach them. It has been shown that physical and virtual laboratory applications contribute to students' meaningful learning by enabling the concretization of abstract subjects and that these

applications positively support students' interest, excitement, and motivation toward the science course because they are found attractive.

7. An overwhelming majority of the students do not believe that virtual laboratories can fully replace physical laboratories, though they acknowledge the usefulness of the Vlab. Some of the reasons they assigned are;

- "Online labs are just a simulation of the real thing and do not provide real experience in the field. Once the time to do hands-on activity in the real world comes, students will be unprepared".
- I believe there are certain experiments that may be easier done virtually because it is more convenient, but there are experiments that may be better done in a traditional way. The traditional way can give students a hands-on experience wherein it allows them to see what really happens during the experiment, while the results of a virtual experiment may be inaccurate.
- Etc.

It is clear that virtual labs cannot replace the physical laboratory, despite their usefulness, but should complement the physical lab.

8. The challenges and limitations of the physical laboratory are; not being accessible anytime and anywhere, not being cost-effective compared to virtual labs, less student engagement, complex experiments cannot easily be undertaken and finally student safety cannot be guaranteed.

9. Inadequate guidance or instructions, difficulty in simulating certain experiments, lack of real-world context, technical issues or connectivity problems, and limited hands-on experience are the responses enumerated, being the challenges of the virtual experiments.

5.3 Conclusion

In conclusion, it could be said that this study has opened the eyes of the researcher and in fact that of the stakeholders of chemistry to the enormous benefits that could be derived from the use of virtual and physical laboratory resources in teaching electrochemistry. The study revealed that the use of both the virtual and physical laboratory resources respectively improved the understanding of electrochemical concepts, which leads to increased performance of the students.

On gender comparison, male and female students perform equally when taught using virtual laboratory resources. In this study, it is observed that the male students perform better than their female colleagues when taught electrochemistry utilizing physical laboratory resources. However, statistically, there is no significant difference in the performance of the two genders. Also, female students perform better when taught using virtual lab than physical lab resources. The study, therefore, revealed that teaching electrochemistry by using both physical and virtual laboratory resources is an effective way to improve students' academic performance. The basic experimental skills such as measurement, data analysis and interpretation are enhanced when electrochemistry is taught by the use of both virtual and physical laboratory resources. The advantage of the utilization of virtual and physical laboratory resources in teaching electrochemistry creates and enhances students' motivation, interest, and achievement. This definitely can bring about more effective learning. The study also revealed that a virtual laboratory cannot replace the physical laboratory, despite its usefulness, but should complement the physical laboratory.

Some challenges and limitations for both virtual and physical laboratories were identified.

5.4 Recommendations

Based on the findings and the conclusions drawn from the study, the following recommendations have been made:

1. **Balanced Use of Physical and Virtual Labs:** Given that both physical and virtual laboratory resources showed positive effects on students' performance and interest, it is recommended to strike a balance between using both types of laboratories in teaching electrochemistry. This approach can cater for different learning preferences and provide a comprehensive learning experience.
2. **Gender-Neutral Teaching Strategies:** The finding that male and female students performed equally well when taught using virtual laboratory resources suggests that virtual labs can be effective in promoting gender equality in science education. Therefore, it is recommended to incorporate more virtual laboratory resources into science education to promote gender equity.
3. **Improving Female Participation in Physical Labs:** While there was a slight difference in the performance of male and female students in physical laboratory settings, though not statistically significant, it is however recommended that chemistry teachers should encourage female students' participation and performance in physical laboratories also, chemistry teachers and high schools may consider implementing strategies to enhance their experience and comfort in such environments.
4. **Emphasizing Data Analysis and Interpretation**: Given that the majority of students were able to measure, analyze, and interpret data from both virtual and physical experiments, it is recommended to focus

on developing students' data analysis and interpretation skills. This could be achieved through enhanced training and resources in these areas.

5. **Motivating and Attracting Students:** The results suggest that the use of laboratory resources significantly increases students' motivation and interest in learning electrochemistry. Therefore, it is recommended to continue incorporating laboratory resources into science education to keep students engaged and enthusiastic about the subject.
6. **Supplementing, Not Replacing, Physical Labs:** The majority of students do not believe that virtual laboratories can fully replace physical laboratories. Thus, it is recommended to continue using physical laboratories for experiments that require hands-on experience and use virtual labs to supplement the learning process. High schools can design curricula that strike a balance between the two types of labs.
7. **Addressing Challenges and Limitations:** Both physical and virtual labs have their respective challenges and limitations. Educators and institutions may work on addressing these challenges, such as making physical labs more accessible and improving the guidance and instructions for virtual labs. This could lead to a more seamless and effective learning experience.

These recommendations can help inform educational institutions and instructors on how to make the most of both physical and virtual laboratory resources while addressing the specific needs and preferences of students in electrochemistry education.

5.5 Suggestions for Further Research

Based on the findings and limitations of the study, the following suggestions have been made for further research:

1. It would be appropriate if this study is replicated in other schools in other regions of the country with much larger sample size and with different research design such as experimental and quasi-experimental, if possible, to assess the comparative effectiveness of virtual laboratory and physical laboratory in nurturing students' attitude towards electrochemistry and come out with stronger conclusions.
2. Conduct comparative studies across different educational levels, such as junior high school and senior high schools, to investigate whether the effectiveness of physical and virtual laboratories varies depending on the student's level of education. This can help identify potential age-related or developmental factors that influence the impact of each approach.
3. Investigate how teacher expertise, pedagogical practices, and instructional strategies can maximize the benefits of each laboratory approach for students' cognitive achievement and process skill development.

These suggestions aim to expand the current knowledge and provide a deeper understanding of the comparative effects of physical and virtual laboratories on students' cognitive achievement and process skill development in electrochemistry.

5.6 Contributions of the Study to Chemistry Education

The study ultimately contributes to the improvement of education in the field of electrochemistry. The findings may guide educators, curriculum developers, and policymakers in making informed decisions regarding the integration of laboratory resources to enhance teaching and learning experiences in electrochemistry.

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APPENDICES

Appendix A

Questionnaire on the use of Physical Laboratory Resources in Electrochemistry lessons

Dear Participant,

Thank you for your interest in the research study. I kindly request your participation by completing the following questionnaire. Your responses will provide valuable insights and contribute to the advancement of knowledge in the field of electrochemistry education. Please take a few moments to carefully answer the questions to the best of your ability. Your participation is entirely voluntary, and all information provided will be kept strictly confidential. I appreciate your time and contribution, which will help us gain a deeper understanding of the topic at hand.

Thank you in advance for your participation.

Please indicate your Gender

Male ☐ **Female** ☐

Please indicate your agreement with the following statements

1. What are the main benefits of using a physical laboratory in electrochemistry lessons? (Select all that apply)

☐ Hands-on experience with experimental setups

☐ Practical application of theoretical concepts

☐ Opportunity to troubleshoot experimental issues

☐ Better understanding of experimental techniques and procedures

☐ Improved retention of knowledge

2. How do you feel about performing experiments in the laboratory?

☐ Very positive

☐ Positive

☐ Neutral

☐ Negative

☐ Very negative

b. Was the experiment/ process motivating enough?

☐ Yes

☐ No

☐ Can't say

c. How well did the physical laboratory activities enhance your understanding of electrochemistry concepts?

☐ Significantly enhanced

☐ Moderately enhanced

☐ Slightly enhanced

☐ Did not enhance

d. Did the physical laboratory activities help you develop practical skills related to electrochemistry experiments?

☐ Yes, to a great extent

☐ Yes, to some extent

☐ No, not really

☐ No, not at all

e. Was the measurement and analysis of data easy for you?

☐ Excellent

☐ Very good

☐ Good

☐ Average

☐ Poor

f. Were the results of the experiment easily interpreted?

☐ Excellent

☐ Very good

☐ Good

☐ Average

☐ Poor

g. What are the disadvantages you see in using a physical laboratory for learning electrochemistry? (Select all that apply)

☐ Not accessible anytime and anywhere, unless going to the lab.

☐ Not cost-effective compared to virtual labs

☐ Less student engagement

☐ complex experiments cannot easily be undertaken

☐ Student's safety cannot be guaranteed.

☐ Other (please specify)

……………………………………………………………………................

h. Have you encountered any challenges or difficulties while conducting experiments in the laboratory? If yes, please describe them briefly………………………………………………………………………

………………………………………………………………………………

i. In your opinion, should the use of the physical laboratory be continued in future electrochemistry lessons?

- [ ] Yes, absolutely
- [ ] Yes, but with improvements
- [ ] No, it's not necessary
- [ ] No, alternative methods should be explored

j. Any additional comments or suggestions regarding the use of the physical laboratory in electrochemistry lessons? (Open-ended)

……………………………………………………………………………

……………………………………………………………………………

………………

Thank you for taking the time to complete this questionnaire! Your feedback is greatly appreciated.

.

Appendix B

Questionnaire on the use of Virtual Laboratory Resources in Electrochemistry lessons

Dear Participant,

Thank you for your interest in the research study. I kindly request your participation by completing the following questionnaire. Your responses will provide valuable insights and contribute to the advancement of knowledge in the field of electrochemistry education. Please take a few moments to carefully answer the questions to the best of your ability. Your participation is entirely voluntary, and all information provided will be kept strictly confidential. I appreciate your time and contribution, which will help us gain a deeper understanding of the topic at hand.

Thank you in advance for your participation.

Please indicate your Gender

Male ☐ Female ☐

Please indicate your agreement with the following statements

1. How do you rate the online performance of the experiments?

☐ Excellent

☐ Very good

☐ Good

☐ Average

☐ Poor

2. To what degree was the actual laboratory environment simulated?

☐ Excellent

☐ very good

☐ good

☐ average

☐ poor

3. Was the measurement and analysis of data easy for you?

☐ Excellent

☐ Very good

☐ Good

☐ Average

☐ Poor

4. Were the results of the experiment easily interpreted?

☐ Excellent

☐ Very good

☐ Good

☐ Average

☐ Poor

5. A clear understanding of experiment and related topics was

☐ Excellent

☐ very good

☐ good

☐ average

☐ poor

6. How helpful do you feel the system is?

☐ very helpful

☐ helpful

☐ barely helpful

☐ not helpful

7. Did you feel confident enough while performing the experiment?

- [ ] Yes
- [ ] No
- [ ] can't say

8. Was the experiment/ process motivating enough?

- [ ] Yes
- [ ] No
- [ ] Can't say

9. Did you get the feel of a real laboratory while performing the experiment virtually?

- [ ] Yes
- [ ] No
- [ ] Can't say

10. What are the advantages you see in using a virtual laboratory for learning electrochemistry? (Select all that apply)

- [ ] Accessible anytime and anywhere.
- [ ] Cost-effective compared to physical labs
- [ ] More student engagement
- [ ] complex experiments easily undertaken
- [ ] Student's safety can be guaranteed.
- [ ] Other (please specify)

11. Did you experience any problem?

- [ ] Yes
- [ ] No

12. What are the disadvantages you see in using a virtual laboratory for learning electrochemistry? (Select all that apply)

- [ ] Limited hands-on experience
- [ ] Technical issues or connectivity problems
- [ ] Lack of real-world context
- [ ] Difficulty in simulating certain experiments
- [ ] Inadequate guidance or instructions
- [ ] Other (please specify)

13. Do you believe that virtual laboratories can fully replace traditional hands-on (physical) laboratory experiments in electrochemistry education?

- [ ] Yes
- [ ] No
- [ ] Not sure

14. If you answered "No" or "Not sure" to the previous question, please provide reasons for your opinion

…………………………………………………………………………….
…….

15. Do you think performing experiments through virtual laboratories were more challenging than the Physical lab experiments?

- [ ] Yes
- [ ] No

16. Specify any problems/ difficulties you faced while performing the experiments?

…………………………………………………………………………….

……………………………………………………………………………

17. Describe some interesting things about the experiments

……………………………………………………………………………

……………………………………………………………………………

18. Do you think doing experiments through virtual lab gives scope for more innovative and creative research work?

☐ Yes

☐ No

19. Would you recommend the use of virtual laboratories in electrochemistry lessons to other students?

☐ Yes

☐ No

☐ Not sure

20. Please share any additional comments or suggestions regarding the use of virtual laboratories in electrochemistry lessons.

……………………………………………………………………………

Thank you for taking the time to complete this questionnaire! Your feedback is greatly appreciated.

Appendix C

Pre-Intervention (Achievement Test)

Introduction

The items below are designed to find out your previous knowledge in electrochemistry. It is done for research purposes only; thus, your answers will be treated confidentially. Thank you very much as you participate in this research.

Students Number (Provided by researcher) ……………………………

Duration: 20 Min.

Answer all questions. (15 marks)

1. Which of the following is the correct definition of oxidation? **(1mark)**

   a) Loss of electrons b) Gain of electrons c) Loss of protons d) Gain of protons

0. Which of the following reactions is a redox reaction? **(1mark)**

   a) $NaCl + H_2O \rightarrow NaOH + HCl$

   b) $CaO + CO_2 \rightarrow CaCO_3$

   c) $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

   d) $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

0. Which of the following is a correct representation of an electrochemical cell? **(1mark)**

   a) $H_2O(l) + 2e^- \rightarrow H_2(g)$

   b) $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+(}aq) + Cu(s)$

   c) Mg(s) + 2HCl(aq) → MgCl2(aq) + H2(g)

   d) NaCl(aq) + AgNO3(aq) → NaNO3(aq) + AgCl(s)

0. Which of the following substances will be produced at the cathode during the electrolysis of molten NaCl? **(1mark)**

a) Cl_2 gas

b) H_2 gas

c) Na metal

d) O_2 gas

0. The following reactions are spontaneous as written. **(1mark)**

$Fe(s) + Cd^{2+}(aq) \rightarrow Fe^{2+}(aq)$

$+ Cd(s)$

$Cd(s) + Sn^{2+}(aq) \rightarrow Cd^{2+}(aq)$

$+ Sn(s)$

$Sn(s) + Pb^{2+}(aq) \rightarrow Sn^{2+}(aq) +$

$Pb(s)$

Which of the following pairs will react spontaneously?

I. Sn(

s)

$+Fe^{2+}(aq)$

II. Cd(

s)

$+Pb^{2+}(aq)$

III. Fe(s)

$+ Pb^{2+}(aq)$

A. I only B. II only C. III only D. II and III only

6. Electrolysis is the decomposition of some compounds using electricity.

a) Circle all the substances in the list that can be decomposed by electrolysis.

(2 marks)

solid ionic compounds **molten ionic compounds**

ionic compounds in solution **gases** **solid covalent compounds**

molten covalent compounds **covalent compounds in solution**

b) What do these substances have in common that allows them to be electrolyzed? **(1 mark)**

………………………………………………………………………………………

7. Define in terms of electron transfer,

.Oxidizing agent;

…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

ii. Reducing agent

…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

……………………………………………………………………………

……………………………………………………………………………

……………………………………… **(2marks)**

8. i) What is the role of salt bridge in an electrochemical cell?

………………………………………………………………………………………

………………………………………………………………………………………

2marks

ii) What type of ions must flow into the cathode? Give a reason for your

………………………………………………………………………………………

………………………………………………………………………………………

3marks

Appendix D

Post-Intervention Achievement Test

This Test consists of two **SECTIONS, A&B**.

Section A

For each question, choose the answer you consider to be the best and write CAPITAL LETTERS in the answer sheet provided.

Section B

Answer all questions in the answer booklet provided

The maximum mark for this Test is **[53 marks]**

Duration: 1 hr, 30min

Students Number (Provided by researcher):……………………………

Section A (20 Marks): Answer all questions

1. Which of the following are redox reactions?

   I. $2Mg + O_2 \rightarrow 2MgO$

   II. $2FeCl_2 + Cl_2 \rightarrow 2FeCl_3$

   III. $4HCl + O_2 \rightarrow 2Cl_2 + 2H_2O$

   IV. $2PbO + C \rightarrow 2Pb + CO_2$

A. I, II, III, IV

B. I, II, III

C. II, III

D. II, III, IV

2. Which of the following **is/are** oxidation reactions?

   I. $Zn(s) \rightarrow Zn^{2+}(aq)$

II. $Fe^{2+}(aq)$ → $Fe^{3+}(aq)$

III. $2Cl^{-}(aq)$ → $Cl_2(g)$

IV. $4OH^{-}(aq)$ → $H_2O(l) + O_2(g)$

A. I, II, III, IV

B. I, II, III

C. II, III

D. II, III, IV

3. The reaction $Cl_2(g) + 2e^-$ → $2Cl^{-}(aq)$ represent the

A. Ionization potential of chlorine

B. Electron affinity of chlorine

C. Enthalpy of dissociation of chlorine

D. Standard reduction potential of chlorine

4. Which of the following device(s) function(s) on redox reactions?

I. Electric generator

II. Electric motor

III. Car battery

IV. Dry cells

A. I only

B. I and II

C. III and IV

D. I, III and IV

5. Which of the following species in the reaction below is an electron donor?

$Cr_2O_7^{2-}(aq) + 5H_3O^+ + 3H_2SO_3(aq)$ → $2Cr^{3+}(aq) + 9H_2O(l) + 3HSO_4^-$

A. $Cr_2O_7^{2-}(aq)$

B. $H_3O^+(aq)$

C. $H_2SO_3(aq)$

D. $Cr^{3+}(aq)$

6. The reaction $Cl_2(g) + 2I^-(aq) \rightarrow 2Cl^-(aq) + I_2(s)$ can be described as

A. Displacement of chlorine by iodine

B. Reduction of chlorine by iodide

C. Reduction of iodine by chlorine

D. Reduction of chlorine by iodine

7. The reaction $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$ takes place when

I. Copper and zinc are added to aqueous solution of zinc tetraoxosulphate (VI)

II. Zinc is added to an aqueous solution of copper(II)tetraoxosulphate(VI)

III. Aqueous solutions of copper (II) tetraoxosulphate (VI) and zinc tetraoxosulphate(VI) are mixed

IV. A Daniel cell delivers electric current

A. II only

B. II and III

C. II and IV

D. I and IV

8. Consider the standard reduction potentials:

Zn2+/Zn, -0.76V; Fe2+/Fe, -0.44V; Sn2+/Sn, -0.14V.

Which of the following comments is **not** valid?

A. Zn is the strongest reducing agent

B. Sn^{2+} is the strongest oxidising agent

C. Zn will displace Fe^{2+} from solution

D. Sn will displace Fe^{2+} from solution

9. Which of the following is **not** a redox reaction?

A. $CuSO_4 + H_2S \rightarrow CuS + H_2SO_4$

B. $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

C. $FeCl_3 + H_2S \rightarrow FeCl_2 + 2HCl + S$

D. $2H_2S + SO_2 \rightarrow 2H_2O + 3S$

10. Which element is reduced in the reaction

$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$

A. Hydrogen

B. Iron

C. Manganese

D. Oxygen

11. Which is the oxidizing agent in the following reaction?

$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$

A. $C_2O_4^{2-}$

B. H^+

C. Mn^{2+}

D. MnO_4^-

12. In which of the following reactions does oxidation occur?

I. $Mg^{2+} + 2e- \rightarrow Mg$

II. $Na \rightarrow Na^+ + e-$

III. $H_3O^+ + OH^- \rightarrow 2H_2O$

IV. $CuSO_4 + Zn \rightarrow ZnSO_4 + Cu$

A. I and II

B. II and IV

C. II, III and IV

D. I, II, and III

13. Consider the following E values: Fe^{3+}/Fe, -0.05V; Zn^{2+}/Zn, -0.76V. The electrochemical cell which produces an emf of 0.71V from these two electrodes is represented by

A. $Zn/Zn^{2+}// Fe^{3+/}Fe$

B. $Zn^{2+}/Zn//Fe^{3+}/Fe$

C. $Fe/Fe^{3+}//Zn/Zn^{2+}$

D. $Fe/Fe^{3+}//Zn^{2+}/Zn$

14. The function of the salt bridge in an electrochemical cell is to

A. Maintain electrical neutrality

B. Maintain the concentration of the electrolyte

C. Increase the rate of reaction

D. Maintain high voltage

15. Which of the statements below describes an oxidation process?

A. The removal of oxygen from a compound

B. The addition of hydrogen to a compound

C. The acceptance of electron(s) by a substance

D. The removal of electron(s) from a substance

16. The reducing agent in the reaction;

$2AI(s) + Fe_2O_3 \rightarrow Al_2O_3(s) + 2Fe(s)$ is

A. Al

B. Fe

C. Al_2O_3

D. Fe_2O_3

17. The arrangement of two different metals in aqueous solutions of their salts to produce electric current is known as

A. Electrolytic cell

B. Chemical couple

C. Metallic couple

D. Voltaic cell

18. Which of the following information can be deduced from the cell $Pb/Pb^{2+}//Cu^{2+}/Cu$?

A. The concentration of the ions in solution

B. The anode of the cell

C. The electrolyte in the salt bridge

D. The emf of the cell

19. If iron and magnesium rods are used as electrodes in an electrochemical cell,

A. There will be no need for a salt bridge

B. The electrons will remain in the electrolyte

C. The electrons will flow from magnesium to iron

D. The electron will flow from iron to magnesium

20. In a galvanic cell, the electrode at which oxidation takes place is referred to as

A. Cathode

B. Electrolyte

C. Salt bridge

D. Anode

Section B (33 marks)

Answer all questions.

1. (a) Consider the redox reaction represented by the following equation

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

i) State the change in oxidation number of

α) magnesium **[1mk]**

β) hydrogen **[1mk]**

ii) Which species is being

α) oxidised? **[1mk]**

β) reduced? **[1mk]**

iii) Identify the oxidizing agent. **[1mk]**

b. State the property exhibited by nitrogen (IV) oxide (NO_2) in each of the following equations:

i) $4Cu + 2NO_2 \rightarrow 4CuO + N_2$; **[1mk]**

ii) $H_2O + 2NO_2 \rightarrow HNO_3 + HNO_2$ **[1mk]**

c. Define reduction in terms of electron transfer. **[2mk]**

d. Consider the reaction represented by

$CUO(s) + CO(g) \rightarrow Cu(s) + CO_2(g)$

α) Name the reducing agent. **[1mk]**

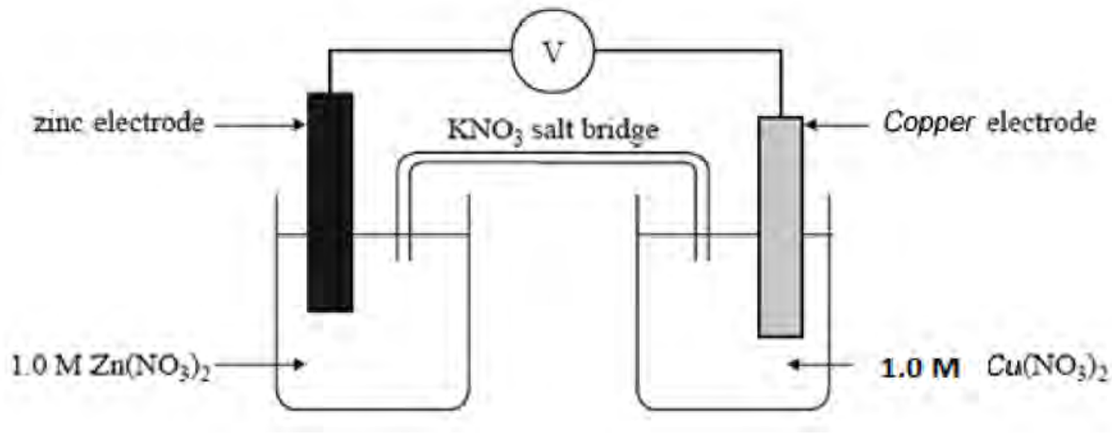
β) State one other reducing agent that can be used. **[1mk]**

e. Determine the oxidation number of

α) chromium in $K_2Cr_2O_7$ **[2mk]**

β) vanadium in V_2O_5 **[2mk]**

2.



a) Above is a galvanic cell. Label the following

i) Direction of electron flow **(1mark)**

ii) The anode **(1mark)**

iii) The cathode **(1mark)**

iv) Direction of anion movement **(1mark)**

v) The polarity of the electrodes **(1mark)**

b)

i) Indicate the maximum theoretical voltage that can be generated by the cell and describe the conditions under which this voltage is achievable. **(1mark)**

ii) What happens to the concentration of zinc ions in the solution surrounding the zinc electrode? **(1mark)**

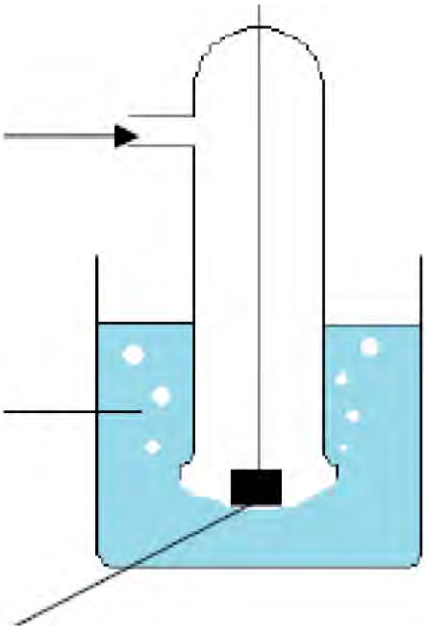
iii) Write the equation for the reaction taking place at the anode and for the reaction taking place at the cathode. **(1mark)**

iv) Write the overall equation **(1mark)**

c) Standard electrode potentials are measured by connecting a half cell containing the equilibrium, the potential of which is to be measured to a standard hydrogen electrode at 298 K.

i) Label the diagram below showing the standard hydrogen electrode. **(3 marks)**

ii) Complete the diagram to show the complete cell you would use if you wished to measure $\mathbf{E^0}$ for a zinc electrode. **(4 marks)**



d) Cells can be represented in shorthand form using a series of standard conventions.

i) Match up the symbol to its meaning when used to represent an electrochemical cell;

/	Shows a salt bridge
//	Indicates a phase boundary **(1 mark**)

iii) For each half cell, the species in the highest oxidation state in the redox equilibrium is written next to the salt bridge. Use this convention to complete the shorthand representation of the cells produced when half cells containing each of the equilibria below are connected to a standard hydrogen electrode.

$Fe^{2+}(aq) + 2\ e^- \rightleftharpoons Fe(s)$; $\quad Pt \mid H_2(g) \mid H^+(aq) \parallel$

(1 mark)

$MnO_4^-(aq) + 1\ e^- \rightleftharpoons MnO_4^{2-}(aq)$; $\quad Pt \mid H_2(g) \mid H^+(aq) \parallel$ **(1mark)**

Appendix E

Sample of Physical Lab Report

Galvanic Cells and Activity Series

Learning outcomes:

At the end of the experiment, students should be able to:

Arrange Al, Zn, Mg, Fe and Cu in an electrochemical (activity) Series

Procedure

(i) Clean the metal with sand paper/abrasive cloth

(ii) Fill a 50mL beaker with 35mL of 0.1M CuSO4(aq) and the other beaker with 35mL of 0.1M ZnSO4(aq).

(iii) Set up the apparatus as shown

(iv) Record the cell potential (E^{θ}_{cell})

Repeat step 1-4 by replacing Zn2+/Zn half-cell with Mg, Al, Fe strip in 0.1M of their respective electrolyte, respectively.

(v) MgSO4(aq), Fe/Fe2+. Al/Al3+ Etc.

(vi) Calculate the standard Reduction Potential

- Using : $E^{\theta}_{cell} = E^{\theta}_{half-cell\ reduction} - E^{\theta}_{half-cell\ oxidation}$ ($E_{cell} = E_{right\ cell} - E_{left\ cell}$)
- Take the standard reduction potential of cu to be $\boldsymbol{E^{o} = +0.34}$ **V**

(vii) Arrange the metals in descending order of strength as reducing agents.

[Arrange starting from the least (most negative) value to the highest (most positive) value. The most negative value (standard reduction potential) is the most reducing agent]

Results Sheet

No	Electrode pair	Ecell/volt	Ered/volt

Electrochemical series

Most Reducing agent

↓

Least Reducing agent

Appendix F

Sample of Virtual Lab Report

Galvanic Cells and Activity Series

Learning outcomes:

At the end of the experiment, students should be able to:

Arrange Al, Zn, Mg, Fe and Cu in an electrochemical (activity) Series

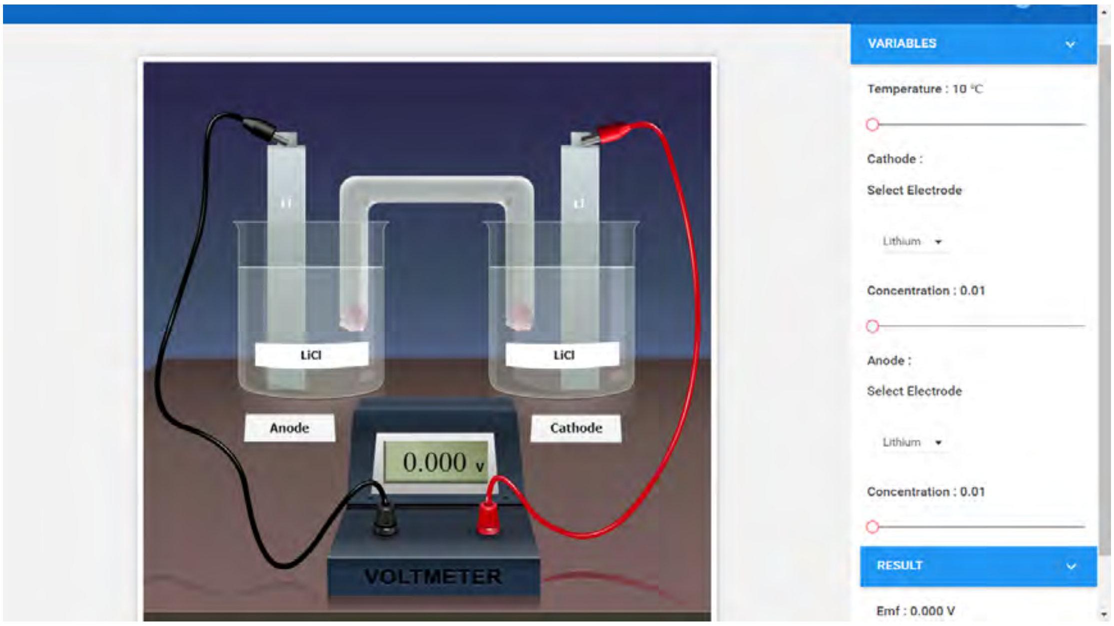
Website: Click on anyone for your experiment

https://vlab.amrita.edu/index.php?sub=2&brch=190&sim=361&cnt

https://teachchemistry.org/classroom-resources/galvanic-voltaic-cells-2

Materials Required:

1. Beaker
2. Voltmeter
3. Salt bridge
4. Electrode Used - Li, K, Ba, Ca, Na, Mg, Al, Mn, Zn, Cr, Fe, Cd, Ti, Co, Ni, Sn, Pb, Cu, Ag, Au, 2H
5. Electrolyte Used -LiCl, KCl, $BaCl_2$, $CaCl_2$, NaCl, $MgSO_4$, $Al(NO_3)_3$, $MnSO_4$, $ZnSO_4$, $Cr(NO_3)_3$, $FeSO_4$, $CdSO_4$, $TiNO_3$, $CoSO_4$, N iSO$_4$, $SnSO_4$, $PbNO_3$, $CuSO_4$, $AgNO_3$, $AuNO_3$, HCl



Procedure:

1. Set the temperature to 25°C
2. Select copper as the cathode from the list.
3. Select zinc as the anode from the list.
4. Select concentration of their respective electrolyte, to be 0.1M
5. Record the voltage of the cell.

6. Repeat step 1-5 by replacing Zn2+/Zn half-cell with Mg, Al, Fe strip in 0.1M of their respective electrolyte Mg, Al, Fe strip in 0.1M of their respective electrolyte

7. Calculate the standard Reduction Potential (

- Using : $E^{\theta}_{cell} = E^{\theta}_{half-cell\ reduction} - E^{\theta}_{half-cell\ oxidation}$($E_{cell} = E_{right\ cell} - E_{left\ cell}$)

- Take the standard reduction potential of cu to be ***E*º = +0.34 V**

(viii) Arrange the metals in descending order of strength as reducing agents.

[Arrange starting from the least (most negative) value to the highest (most positive) value. The most negative value (standard reduction potential) is the most reducing agent].

Results Sheet

No	Electrode pair	Ecell/volt	Ered/volt

Electrochemical series

Most Reducing agent

Least Reducing agent

Appendix G

Single Displacement Reactions – Physical Laboratory

Objectives:

- To perform and observe the results of a variety of single displacement reactions,
- To become familiar with some of the observable signs of these reactions,
- To identify the products formed in each of these reactions,
- To write balanced chemical equations for each single displacement reaction studied.

Procedure

Materials and Equipment

Solids: Copper metal, zinc metal, Iron metal and Lead metal

Solutions: 0.1M hydrochloric acid, all other solutions are 0.1 M and include silver nitrate, lead (II) nitrate, iron (III) chloride, copper (II) nitrate, zinc nitrate, copper (II) sulphate,

Equipment: 6 large test tubes, 8 small test tubes, plastic test tube rack (or large beaker)

Safety

Be especially cautious when using the solutions, most especially HCl(aq) can burn your skin. Also be aware that skin discoloration will result from contact with $AgNO_3$(aq). If you feel any tingling sensations or see any colour changes on your skin, flush with water immediately for a minimum of 15 minutes. Inform your instructor of any chemical contact as soon as possible.

Perform the following reactions and record your observations for each on the report form. Note that some reactions take longer than others. Thus, if results are not obtained immediately, give the reaction some time. ***All waste is to be disposed of in the plastic container in the hood!***

1. Zinc metal + hydrochloric acid
2. Lead metal + aqueous copper(II) sulfate
3. Copper metal + aqueous silver nitrate
4. Iron metal + aqueous zinc nitrate
5. Zinc metal + aqueous iron (II) nitatrate
6. Copper metal + aqueous lead (II)nitrate
7. Zinc metal + aqueous lead(II) nitrate

When finished, complete your lab report by writing the balanced molecular and ionic equations for each reaction studied. If no reaction is observed indicate NR as the product of that particular reaction.

Results

1. Zinc metal + hydrochloric acid

Observations: Product Names & States (if none, why not?):

Balanced Equation:

Molecular

Ionic

Appendix H

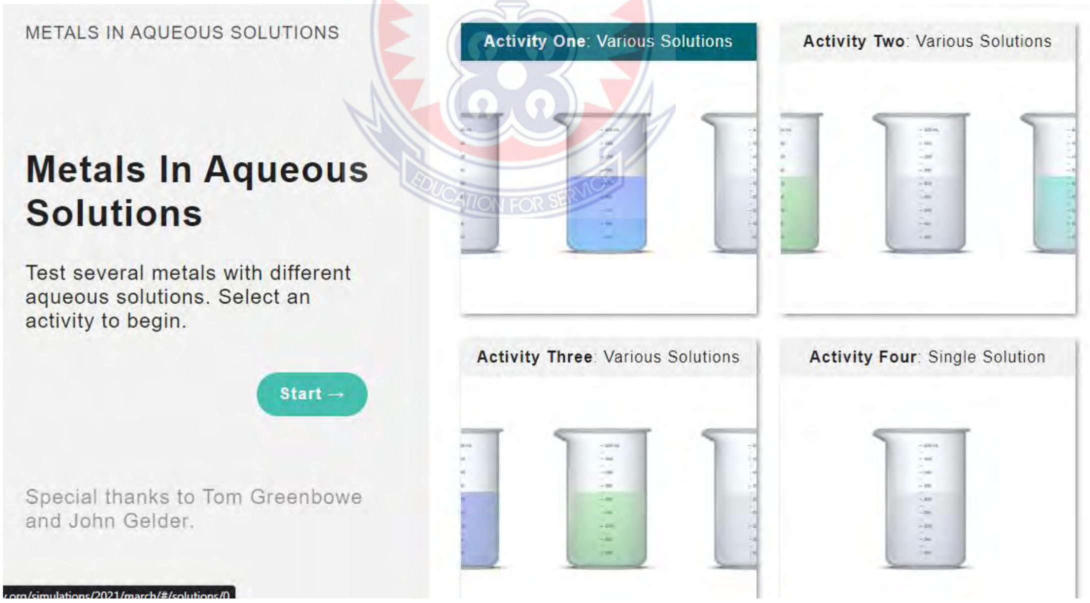
Single Displacement Reactions – Virtual Laboratory

Objectives:

- To perform and observe the results of a variety of single displacement reactions,
- To become familiar with some of the observable signs of these reactions,
- To identify the products formed in each of these reactions,
- To write balanced chemical equations for each single displacement reaction studied.

Log onto the website provided and follow the instructions.

https://teachchemistry.org/classroom-resources/metals-in-aqueous-solutions-simulation



Perform the following reactions and record your observations for each on the report form. Note that some reactions take longer than others. Thus, if results are not obtained immediately, give the reaction some time.

a). Zinc metal + hydrochloric acid

b). Lead metal + aqueous copper(II) sulfate c). Copper metal + aqueous silver nitrate

d). Iron metal + aqueous zinc nitrate

e). Zinc metal + aqueous iron (II) nitatrate

f). Copper metal + aqueous lead (II)nitrate

g). Zinc metal + aqueous lead(II) nitrate

When finished, complete your lab report by writing the balanced molecular and ionic equations for each reaction studied. If no reaction is observed indicate NR as the product of that particular reaction.

Results

2. Zinc metal + hydrochloric acid

Observations: Product Names & States (if none, why not?):

Balanced Equation:

Molecular

Ionic

Appendix I

Galvanic Cell Lab Report

In this experiment you will construct a series of galvanic cells using metals and metal salt solutions. Each cell will consist of two half cells, each containing a metal electrode and its corresponding ion in solution (i.e. a piece of copper in a Cu^{2+} solution). Pairs of half -cells will be connected together by a salt bridge which will supply inert cations and anions to each of the half cells, providing a pathway for ion flow (see diagram below).

Materials:

Plab Group

Voltmeter or multimeter with alligator clip wires

One 12---well reaction plate

Filter paper (for salt bridge) soaked in 1M KCl

Small beakers for KCl

Plastic forceps (for handling the salt bridge)

1---2 cm metal strips of Zn, Mg, Cu, and Sn

15 drops of each of the following 1M solutions: ZnSO4, MgSO4, CuSO4, and SnCl2

Vlab Group

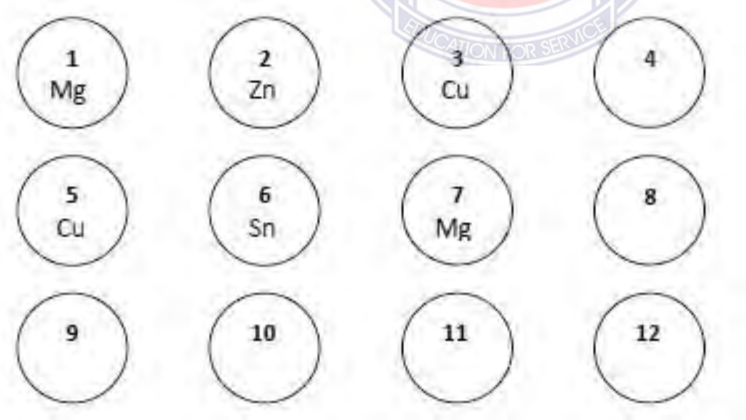
https://teachchemistry.org/classroom-resources/galvanic-voltaic-cells-2

https://vlab.amrita.edu/index.php?sub=2&brch=190&sim=361&cnt=4

Procedure:

Fill the wells you will use with 15 drops of the appropriate metal ion solution.

(Recommended arrangement below)



2. Identify each of the four metals you will use in the experiment.

3. Clean each of the metal strips with sandpaper and place the on a piece of paper which identifies the metal

4. Make a salt bridge by soaking a 2cm strip of filter paper in the KCl solution Use the forceps. (Make separate salt bridges for each cell.)

5. Select the two wells to be tested (See student worksheet), and place the salt bridge so that it is immersed in both solutions.

6. Attach the alligator clips from the multi---meter to the metal strips of the corresponding solutions.

7. Immerse the metal electrodes into their metal ion solutions and record the voltage.

Vlab Group

Log on to the website below and follow the instructions;

https://teachchemistry.org/classroom-resources/galvanic-voltaic-cells-2

https://vlab.amrita.edu/index.php?sub=2&brch=190&sim=361&cnt=4

Data

Cell	**Anode (Black -)**	**Cathode (Red +)**	**Volts**
A	**Mg**	**Zn**	
B	**Zn**	**Cu**	
C	**Mg**	**Cu**	
D	**Zn**	**Sn**	
E	**Mg**	**Sn**	
F	**Sn**	**Zn**	
G	**Sn**	**Cu**	
H	**Zn**	**Mg**	

Questions:

1. Why is the salt bridge necessary?
2. Explain cells F and H.
3. Draw a diagram for cell C. Indicate the direction of the flow of the electron.
4. Write the anode and cathode reactions, hence the overall equation
5. Briefly explain what happens in the anode and cathode respectively.