

Analysis of Students' Misconceptions on Electrochemistry Material using the Four-Tier Diagnostic Test Instrument

**Novita Pebriani*¹, Iriani Bakti¹, Abdul Hamid¹, Rusmansyah¹,
Almubarak¹, Fadhlan Muchlas Abrori²**

¹Department of Chemistry Education, Faculty of Teacher Training and Education, Universitas Lambung Mangkurat, Banjarmasin, Indonesia.

²Linz School of Education, Johannes Kepler University, Linz, Austria

*Email: novitapebriani2002@gmail.com

Article History:

Received date: April 13 2024

Received in revised from: July 15 2024

Accepted date: October 7 2024

Available online: October 14 2024

Citation:

Pebriani, N., Bakti, I., Hamid, A., Rusmansyah, Almubarak & Abrori, F.M. 2024. Analysis of student misconceptions on electrochemical materials with four-tier diagnostic test instruments. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, 12(4):757-768

Abstract. This study was conducted to determine the percentage and causes of student misconceptions in electrochemistry using the Four-Tier diagnostic test instrument. The research was conducted using a quantitative-qualitative descriptive method. The data collection technique was done through written tests with four-tier diagnostic test instruments and non-tests through interviews. The research subjects were students of the 2021 batch of Chemistry Education at FKIP Lambung Mangkurat University Banjarmasin. The results showed that 34% of students experienced misconceptions. Students experienced misconceptions in electrochemistry and electromotive power (DGL) sub-matter by 25.27%; the thermodynamic aspect of electrochemistry experienced the smallest misconception of 7.69%; DGL and temperature by 12.09%; connecting the Nernst equation with pH measurements by 17.58%; concentration cells by 14.29%; electrolysis by 12.64%; and corrosion sub-matter by 10.44%. Misconceptions occur in electrochemical materials because students think that salt bridges play a role in accelerating reactions. Students were confused about determining the relationship between DGL and temperature; and they were less careful in determining whether a chemical reaction is spontaneous or not. In addition, students were less careful in determining the actions of the gilding process.

Keywords: misconception, Four-Tier, electrochemistry

Introduction

College students who are enrolled in academic institutions often encounter problems during the study process. As stated in the comprehensive Indonesian dictionary, problems are obstacles. In the context of education, a problem is defined as a factor that impedes students' comprehension of a particular subject matter. The constant occurrence of advanced coursework at the beginning of each semester is one of the factors that discourages numerous students from pursuing a college education.

Misconceptions are common problems or obstacles that students encounter. Suwanto (2013) explained that misconceptions can be considered incorrect understanding of concepts, incorrect use of concepts, incorrect classification of examples, and confusion of incorrect concepts. Misconceptions occur when the results of students' knowledge construction do not match the results of scientists' knowledge construction. A common

obstacle experienced by students is a misunderstanding of a concept when pursuing education in a college study program in the chemical education major. According to Adi and Karina (2019), concepts are abstract frameworks of the characteristics of objects, events, phenomena, or situations that are understood and facilitate communication between humans involving the thinking process (cognitive).

Electrochemistry is a subject that frequently presents obstacles. Early research revealed that some Chemistry Education Study Program students did not understand the electrochemical content they had studied, based on interviews and several tests utilizing the Four-Tier diagnostic test. Electrochemistry is one of the most difficult subjects for students to learn because they must overcome misconceptions about redox reactions, electric current, electrolytic cells, electrolysis, electrolytes, and galvanic cells (Tihar Ali et al., 2022). The focus of this research is electrochemistry. Electrochemistry advances are dependent on a greater fundamental knowledge of complicated reactions or occurrences at electrodes (Luo et al., 2022). Students and teachers agree that electrochemistry is the most difficult chemistry topic to learn. Both teachers and students have misunderstandings regarding electrochemistry. Furthermore, electrochemistry is a topic that is crucial in daily life, such as batteries, electroplating, corrosion, and so on (Oztay & Boz, 2022).

Teachers' low confidence in the knowledge content impedes electrochemistry teaching and learning in senior secondary schools, particularly at higher levels. This is evident in teacher expositions as well as in public resources such as textbooks. Misconceptions are influenced by the pattern of transition to college. University professors also assume that students comprehend electrochemistry principles taught in high school without confirming that such underlying knowledge is acquired before offering higher concepts (Turner et al., 2024). Teaching electrochemistry is challenging. Understanding electrochemical instruments and troubleshooting electrochemical cells necessitates a working knowledge of amplifiers and feedback circuits. To obtain knowledge of the link between thermodynamics and kinetics, students must be fluent in differential equations and multivariable calculus. As a result, most specialist courses in electrochemistry at the undergraduate level are based on the preceding assumptions. As a result, they are impossible to learn for any new college student (Kempler et al., 2021).

Students who experienced classificational misconceptions could not utilize the information contained in the questions and experienced misunderstandings related to the concept (Djam'an et al., 2022). Misconception diagnostic tools can also be created in the form of a four-tiered system (Irawan, 2021). The Four-Tier Misconception Diagnostic Test (FTDT) is a four-tiered test. FTDT is a multiple-choice question-and-answer item in the first tier (Tier-1). The level of student confidence in selecting responses in Tier 1 is at the second level (Tier-2). The expression of students' reasoning for selecting responses in Tier 1 is at the third level (Tier-3). Meanwhile, the fourth level (Tier-4) increases students' confidence in explaining the rationale in Tier 3. Jurnal (Bakti & Analita, 2020) explained that the Four-Tier Diagnostic Test instrument can be used as a substitute for interviews with consideration of a more effective and time-efficient process. Although the results of this study are quite valid and reliable, the researchers used the Four-Tier Diagnostic Test instrument and interviews to examine chemical education students' misconceptions about electrochemical materials. The FTDT minimizes guessing answers for accurate student assessments. It assesses students' understanding comprehensively by evaluating various levels. FTDT, based on modern test theory, offers a more advanced assessment tool. It helps identify misconceptions and areas lacking knowledge in students. Educators can tailor teaching strategies using FTDT for improved learning outcomes (Istiyono et al., 2023).

Methods

In this study, a four-tier diagnostic test instrument was used, where the four-tier pattern arrangement refers to the choice items in the first choice (A, B, C, and D), the second choice (sure and unsure), the third choice (A, B, C, and D) refers to the explanation of the answer to the question, and the fourth choice (sure and unsure) refers to the level of confidence in the third answer. This study used descriptive-form research design and quantitative-qualitative design techniques. According to Sugiyono (2015), quantitative techniques are approaches that measure insights into numbers and use statistics as a tool to analyze data. The steps in this study were: (1) putting together research tools using tests; (2) validating the tools that were made with validators, who were chemistry education lecturers; (3) making the results of the instrument validation tests better; (4) testing the reliability of the instrument; (5) giving four-level diagnostic tests to look for misconceptions after learning; and (6) using interviews with students to clear up misconceptions as a qualitative method.

Table 1. Four-Tier research object criteria

No	Level 1	Level 2	Level 3	Level 4	Conclusion
1	T	S	T	S	UC
2	T	S	T	US	NUC
3	T	US	T	S	NUC
4	T	US	T	US	NUC
5	T	S	F	S	FP
6	T	S	F	US	NUC
7	T	US	F	S	NUC
8	T	US	F	US	NUC
9	F	S	T	S	FN
10	F	S	T	US	NUC
11	F	US	T	S	NUC
12	F	US	T	US	NUC
13	F	S	F	S	M
14	F	S	F	S	NUC
15	F	US	F	S	NUC
16	F	US	F	US	NUC

(Murningsih, 2020)

Description:

T : True
F : False
S : Sure
US : Unsure

NUC : Not Understand the Concept
FP : False Positive
FN : False Negative
M : Misconception
UC : Understand the Concept

The research results that already had answer criteria were then calculated using the following formula.

$$\text{Misconceptions (\%)} = \left(\frac{\sum \text{leaners with misconceptions}}{\sum \text{number of leaners}} \right) \times 100 \quad (1)$$

After getting the results and receiving data in the form of numbers, the data was categorized as low, medium, and high based on Table 2.

Table 2. Percentage of misconception categories

Misconceptions (%)	Category
$0 < \text{misconception} \leq 30$	Low
$31 < \text{misconception} \leq 60$	Medium
$61 < \text{misconception} \leq 100$	High

(Murningsih, 2020).

Results and Discussion

The four-tier diagnostic test was utilized in this research to examine chemical education students' misconceptions about electrochemical materials. This study included two classes of Chemistry Education students from the 2021 cohort of FKIP ULM Banjarmasin, A1 and A2, with a total of 49 students. According to (Suyono et al., 2023) research, the equilibrium section had the largest percentage of students who experienced misconceptions due to the influence of catalysts. Most students demand a more in-depth understanding of each item. The arrangement of the difficulty level of these questions must be considered from the beginning of the instrument's preparation.

Based on the results of student answers, there were five categories: understanding the concept, not understanding the concept of misconceptions, positive misconceptions, and negative misconceptions. The average percentage of the degree of understanding of students can be clearly seen in Figures 1 and 2.

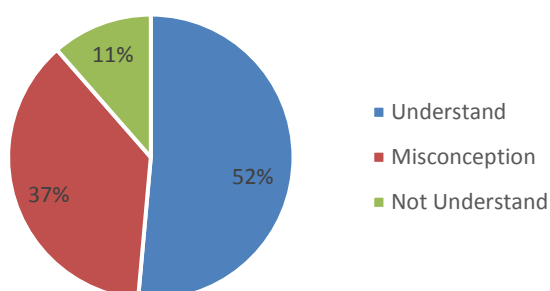


Figure 1. Average percentage of students' level of understanding

Figure 1 shows that the category of taking the concept dominated the level of student understanding, with an average percentage of 51% (high). The large percentage of students who understand the idea indicates that many students might respond properly at all four levels on the four-tier diagnostic test. The average

percentage of students who did not understand the subject was 12% (low), and students who had misconceptions showed that 37% (middle) of students could not answer correctly at all four levels on the Four-Tier diagnostic test.

After utilizing the criteria established by Annisa et al. (2019) for categorizing test results, Figure 2 shows a clear indication of the average percentage of students who have achieved a certain level of understanding.

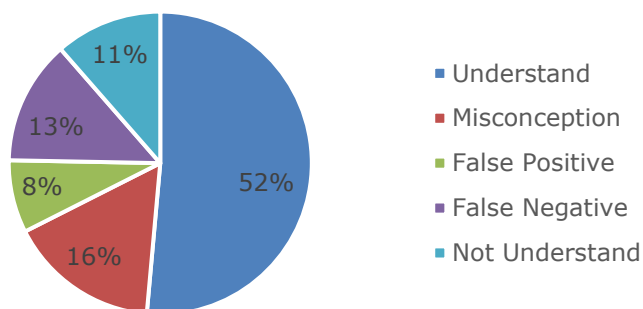


Figure 2. Percentage of the average level of student understanding based on the criteria for grouping test results

Figure 2 shows that the degree of student understanding based on the criteria for grouping test results, according to (Annisa et al., 2019) has been dominated by the category of understanding the concept with a percentage of 51% (high). The high percentage of concept understanding shows that there were still many students who could answer correctly at all four levels of the four-tier diagnostic test. The average percentage showing students who did not understand the concept was less, namely 11% (low); students who experienced misconceptions showed that some students could not answer correctly at all four levels on the Four-Tier diagnostic test, namely 17% (low); the average percentage showing students who were positively wrong was 8% (low); and the average percentage showing students who were negatively wrong was 13% (low).

According to (Rizki & Setyarsih, 2022), false positives are when students answer the first-level question correctly for the wrong reason, but the student believes the answer. In this situation, it could be said that the student lacks understanding of the concept (lack of understanding) or the student has the correct answer but the concept is wrong. In the wrong-correct-correct answer pattern, it can be said that negative misconception, also known as false negative, is a condition where students put forward the right reason for the wrong concept. One of the causes of negative misconceptions is the carelessness of students in choosing answers to the concept equations given (Dahlan & Kurniasari, 2022).

Ten items of four-tier multiple-choice questions were included on the examination, each of which represented a distinct electrochemical concept. Table 3 shows the results of the analysis.

Table 3. Percentage of student misconceptions

Study Material/ Subject Matter	Question No.	Knowledge Level	Indicator	Subject Matter Misconceptions (%)	Misconceptions Indicator (%)
Electrochemistry and Electromotive Power (EMF)	1	C2	Describe the role of salt bridges	25.27	13.19
	7	C4	Analyze reactions at different types of electrodes		12.09
Thermodynamic aspects of electrochemistry	8	C4	Examine the relationship between cell potential and Gibbs	7.69	7.69
EMF and Temperature	4	C3	Show the equation for the relationship between EMF and temperature	12.09	12.09
Connecting the Nernst equation with pH measurement	5	C3	Determine the Nernst equation in the standard state	17.58	6.59
	6	C4	Analyze potential Nernst equation with pH		10.99
Concentration cell	2	C3	Calculate the potential difference of cells in a battery	14.29	14.29
Electrolysis	3	C3	Calculate metal electrolysis time	12.64	0.55
	9	C4	Analyze the electrolysis process in metal plating		12.09
Corrosion	10	C4	Analyze corrosion events with the concepts of oxidation and reduction	10.44	10.44

It is depicted in Table 3 that the results of student misconceptions in question no. 2 have the highest level of misconception, namely 14.29% in the material for calculating the potential difference of cells in the battery. Students are expected to be able to calculate the potential difference between cells in the battery. In question number 2, students were given half a chemical reaction and asked to determine the potential difference between cells. In the reaction problem used, namely: $\text{Zn}^{2+}_{(\text{aq})} + 2\text{e} \rightarrow \text{Zn}_{(\text{s})}$ with an E° value of -0.763 V and $\text{Cl}_{2(\text{g})} + 2\text{e} \rightarrow 2\text{Cl}^{-}_{(\text{s})}$ with an E° value of +1.358 V, the two reactions were compared based on their potential differences. Both reactions were compared based on the potential difference; the reaction that has a higher potential value will be reduced; otherwise, if the potential value is small, the reaction will be oxidized. The reduction reaction is in the reactant, while the oxidation reaction is in the product. Metals with lower electrochemical potentials act as anodes and are susceptible to oxidative dissolution, while metals with higher electrochemical potentials act as cathodes and are protected from oxidation (Huang et al., 2021). Students who encountered misconceptions because they chose the answer -2.12V while the correct answer was 2.12V. The reduction potential of chlorine was higher, so Zn would be oxidized. Based on the results of interviews with students, they stated that when calculating the potential difference of cells in a battery, it was easy to answer because the problem, even though they had to calculate and remember the theory, was still classified as easy material. Students also stated that the material could be related to logic, so they were confident that they had answered correctly. However, students experience misconceptions about the material, which results in wrong answers.

Question number 1 had the second greatest level of misconception, with students being asked to explain the role of salt bridges, resulting in a 13.19% misconception proportion. Salt bridges balance electrolytes by supplying either positive or negative ions (Pauzi et al., 2019). Misconceptions occurred because the students thought that the role of salt bridges was to balance ions. Students were only concerned with the ions that travel, which did not explain the role of the salt bridge. In electrochemistry, a salt bridge is laboratory equipment that connects the oxidation and reduction of half cells of a voltaic cell to an electrochemical cell. The salt bridge maintains the internal circuit electrically neutral, preventing the cell from driving the reaction quickly to equilibrium. If there is no salt bridge, the solution in one half of the cell will accrue a negative charge as the reaction develops, while the solution in the other half of the cell will accumulate a positive charge, preventing further development and resulting in electricity (Gebrehiwot et al., 2023). According to the results of student interviews, it was easy to describe the role of the salt bridge because it employed theory and there was no calculation or technique. Therefore, it could be answered using logic. However, there were still students who had misconceptions regarding this subject. The misconception surrounding the salt bridge in electrochemistry is not due to the absence of an algorithm but rather stems from students' confusion about its function and purpose within electrochemical cells. The misconception is also influenced by teachers and textbooks, as students tend to over-generalize concepts and apply incorrect principles to different aspects of electrochemistry, including the salt bridge (Turner et al., 2024).

Question numbers 7, 4, and 9 all have the same percentage of misconceptions (12.09%). In problem 7, students were required to determine the standard potential difference between the reaction and the observed reaction. Students had the misunderstanding that because they believed $E = -0.34$ V, the reaction that happened was not spontaneous. An electrochemical potential is created when electrons are pushed from the anode (oxidation) to the cathode (reduction). A chemical reaction will occur if this potential is greater than the redox potential (Schotten et al., 2020). According

to the results of student interviews, determining reactions on various types of standard electrodes was not too difficult or easy to answer because the questions required theory, arithmetic, or algorithms. However, there were still students who had misconceptions regarding this subject. Individuals struggle to understand complex concepts related to standard potential differences, leading to misconceptions. Misleading information about standard potential differences through various sources can contribute to misconceptions (Gichangi et al., 2022).

Problem number 4 covered the submaterial of EMF and temperature. In this submaterial, students were expected to be able to show the equation of the relationship between EMF and temperature. Students were asked for an explanation of the measurement of electromotive force (EMF) and to determine the relationship equation between EMF and temperature. Students believed that the relationship between EMF and temperature is shown by the equation $E = E^\circ - \frac{0,0592 RT}{nF} \log Q$. Where E° red is the standard half-cell reduction potential value at the cathode and anode electrodes, R is the ideal gas constant, F is Faraday's constant, T is the temperature in kelvin, n is the number of electrons transferred, and the term logarithm refers to the concentration of redox reactants with their corresponding exponentials (Tan et al., 2020). The misconception that occurred in students was that they thought that $E = E^\circ - \frac{0,0592}{n} \log Q$ was the equation for the relationship between EMF and temperature. 0.0592 is an equation if the temperature is 250 °C, and the equation above is the result after the value of $2.303RT$, also called the Nernst equation. Based on the results of interviews with students, they stated that determining the relationship equation between EMF and temperature is difficult to answer because the problem used a formula in the theory. Students also stated that the material was forgotten or that they did not remember it anymore. But in reality, some students were still able to answer correctly without experiencing misconceptions. The misconception regarding the relationship between EMF and temperature in electrochemistry can arise from misunderstandings of thermodynamics, confusion with galvanic cells, limited knowledge of electrochemistry, the complexity of electrochemical concepts, inadequate teaching strategies, variability in student conceptions, and the need for conceptual clarity (Amponsah, 2020).

Problem 9 Students were given a gilding diagram and asked to figure out what steps needed to be completed to make the process work. Students who faced misconceptions assumed that gilding required the addition of an electric current source. Students were still unable to grasp that gilding requires changing the location of the spoon as a cathode and copper metal as an anode, rather than adding an electric current source. In order for the gilding process to take place, the gilding metal was used as the anode, and the metal to be gilded was the cathode. Following that, a DC electric current was introduced to the circuit to initiate the electrolysis process. The iron dissolves and copper is gilded on the surface of the substrate in an immersion gilding process in which the surface of the substrate is replaced by a nobler metal in solution, such as when an iron substrate is immersed in a copper sulphate solution (de Luna et al., 2020). According to the findings of student interviews, they indicated that assessing the electrolysis process in metal gilding was difficult to answer because the question used photos as a help, and some students even hesitated to answer. Students claimed that they had forgotten about the material. However, there were still students who did not have misconceptions regarding the subject matter.

In question number 6, students were asked to analyze the potential of the Nernst equation with pH, which had a miscalculation of 10.99%. The variables associated with pH-dependent equilibrium states can differ depending on the specific process. The

simplest reaction, for example, involves H^+ or OH^- and is merely regulated by the Nernst equilibrium factor (Yin et al., 2022)

. Based on the equation $E = E^\circ - \frac{0,0592}{n} \log Q$, this problem is determined by the equation $E_{cell} = E^\circ - 0,0592 \log \frac{[H_2]}{[H^+]}$ with $n = 1$ and $E^\circ = 0$, $[H_2] = 1$ and $[H^+] = 10^{-10}$, yielding -0.0592 . Students who had misconceptions thought $E^\circ = 1$, $[H_2] = 10^{-10}$ and $[H^+] = 1$. According to the findings of student interviews, evaluating the potential of the Nernst equation with pH is difficult to answer since the problem requires the use of formulae in theory and calculation. Students also indicated that they had forgotten or did not remember the subject. However, some students were still able to answer accurately without any misconceptions.

Question 10 includes corrosion submaterials, which obtained 10.44% incorrect answers. Students were supposed to analyse corrosion occurrences using the concepts of oxidation and reduction in this submaterial. In question 10, students were given a chemical process involving iron and oxygen and were asked to explain the oxidation conditions of iron in the anode and cathode sections. Corrosion is the process by which a metal is destroyed as a result of its reaction with the environment. Corrosion between metal surfaces and aqueous electrolyte solutions often happens by direct reactions between the environment and metals rather than chemical reactions (Ma et al., 2019). Students who had misconceptions thought the cathode cell potential was greater than the anode cell potential. Students were still unable to interpret corrosion events accurately through oxidation, as seen by the incorrect selection of student justifications. According to the findings of student interviews, analysing corrosion events using the concepts of oxidation and reduction was difficult to answer because the question used illustrations as an assistance. Students complained that the visuals used in number 10 were in English, making them difficult to grasp. Students also indicated that they had forgotten or did not remember the subject. However, some students were still able to answer accurately without any misconceptions.

Question number 8 focused on the thermodynamic features of electrochemistry, which obtained 7.69% incorrect answers. Students were expected to be able to assess the correlation between cell potential and Gibbs in this submaterial. Conditions under which cell reactions in electrochemical cells occur spontaneously. When cell reactions in electrochemistry occur spontaneously, the condition is $\Delta G^\circ < 0$, where negative Gibbs energy indicates that a chemical reaction occurs spontaneously. Positive Gibbs-free energy occurred spontaneously, according to students who experienced misconceptions. According to the findings of student interviews, analysing the relationship between cell potential and Gibbs standard was neither difficult nor easy to answer because the question employs theory; there was no calculation or procedure, so it may be answered using logic. However, there were still some students who had misconceptions regarding this subject.

In question 5, students were given the definition of the Nernst equation and asked to determine the Nernst equation in its standard state. The Nernst equation defined the quantitative correlation between the standard electrode potential, reactant activity, and the cell electrode's reversible potential. In electrochemistry, this is a specific example of chemical equilibrium (Liu et al., 2020). According to students, the Nernst equation in the standard state was $E = E^\circ - \frac{2,303 RT}{nF} \log Q$, whereas the right equation was $E = E^\circ - \frac{0,0592}{n} \log Q$. According to the findings of student interviews, determining the Nernst equation in the standard state was difficult to answer because the problem required the use of formulas from the theory. Students also indicated that they had forgotten or did not remember the subject. However, students were still able to answer correctly without encountering misconceptions, and only a few students did.

Meanwhile, question 3 has the lowest level of misunderstanding in the material for estimating the time of metal electrolysis, with a 0.55% misunderstanding. Students who faced misconceptions believed that the time required to precipitate all metals was 48,250 s and that the mole of Cu^{2+} was 1.2 moles, obtaining 96,500 s. In comparison, the time required to precipitate all copper metal (Cu) is 57900 s. The process of converting electrical energy into chemical energy is known as electrolysis. There will be a process of degrading chemical compounds from the solution and electrolyte during the electrolysis process. There is oxidation (which occurs at the anode) and reduction (which occurs at the cathode) in the electrolyte (Sihotang et al., 2021). According to the findings of student interviews, estimating the time of electrolysis of standard metals was not too difficult or easy to respond because the problem utilised a calculation or algorithm whose theory students knew. However, others said that the question in number 3 was answered last because students had forgotten about the content, and in fact, there were still students who had misconceptions about the subject.

Conclusion

The following conclusions are derived from the results of the research and subsequent discussion students had misconceptions with an average percentage, namely in the electrochemistry and electromotive power (EMF) sub-matter experiencing the largest misconception of 25.27%, the thermodynamic aspect of electrochemistry experiencing the smallest misconception of 7.69%, DGL and temperature of 12.09%, connecting the Nernst equation with pH measurements of 17.58%, concentration cells of 14.29%, electrolysis of 12.64%, and corrosion sub material of 10.44%. The factors leading to student misconceptions in electrochemistry are as follows, students assumed that the salt bridge serves to establish a correlation between the anode and cathode, facilitating an instantaneous response despite its lengthy period, students were still confused regarding the determination of the correlation equation between DGL and temperature, students demonstrated a decreased level of concentration when determining the spontaneity of a chemical reaction, students endured a lack of accuracy when identifying the steps involved in the gilding process.

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