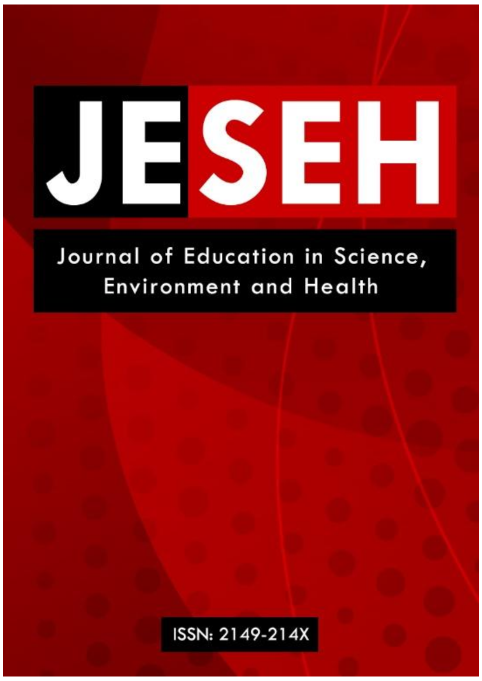

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Abstract

The purpose of this study was to develop a valid and reliable measurement tool that can be used to identify pre-service teachers' misconceptions about electrochemistry. The Electrochemistry Concept Test (ECT) developed for this purpose consists of a total of 12 questions, each containing four tiers. The Electrochemistry Concept Test (ECT) was applied to a total of 307 science teacher candidates from 10 different universities in seven regions of Türkiye. The data were analyzed using Excel, SPSS, and Factor programs. A four-factor structure with 12 questions was determined using EFA, and the KMO value of the test was calculated as 0,682, indicating that this four-factor structure explained 48% of the total variance. As a result of the reliability analyses, the KR-20 reliability coefficient for the scientific knowledge score obtained from correct answers was calculated as .819, and the KR-20 reliability coefficient for the misconception score obtained from wrong answers was calculated as 0,702. The item analyses revealed that the difficulty and discriminative indices of the test were at an intermediate level. Positive and negative wrong values were calculated for content validity. The validity and reliability analyses confirm that the developed test is a valid and reliable measurement tool. As a result of the analysis of the data collected in the study, it was determined that the pre-service teachers had misconceptions above 10% for each question related to electrochemistry - activity, reduction–oxidation, galvanic cell reactions, and cell potential - and that their scientific knowledge was not at a sufficient level. As a result of the study, a total of 37 misconceptions related to the topic of electrochemistry were identified, among which 9 misconceptions with a prevalence of over 10% were determined, thereby contributing new misconception statements to existing literature. In conclusion, a valid and reliable measurement tool has been developed that researchers can use to determine pre-service teachers' misconceptions and achievement levels in electrochemistry.

Introduction

Concepts are abstract units of thought that are understood by the human mind. They exist alongside concrete examples from the real world, as well as abstract concepts such as love and affection, whose meanings vary from person to person. In concept teaching, students' prior knowledge, misconceptions, and experiences can significantly impact their subsequent learning and negatively affect the acquisition of new knowledge. Conceptual misconceptions are mental definitions and designs related to elements in individuals' mental processes that differ from scientifically accepted truths (Yakışan et al., 2007). According to existing studies in the literature, one reason for failure in chemistry is that chemistry topics often contain abstract and complex concepts. This makes chemistry difficult for students to understand. Since electrochemistry involves more abstract concepts, students find it challenging to understand this subject. Many studies have reported that students have numerous misconceptions about electrochemistry, which is one of the important topics in chemistry education (Sanger & Greenbowe, 1997a; Sanger & Greenbowe, 1997b; Garnett & Treagust, 1992a; Garnett & Treagust, 1992b; Birss & Truax, 1990; Garnett & Treagust, 1990; Sanger & Greenbowe, 1999; Geban et al., 1999; Morgil et al., 2002; Yılmaz et al., 2002; Şen et al., 2017; Yılmaz, 2012; O'Grady-Morris, 2008; Özkaya, 2000; Erdoğmuş, 2009; Ercan, 2009).

Books & teachers are among the primary sources of information that students can access directly. Gaps in teachers' knowledge or their misunderstandings can cause misconceptions in students. For this reason, it is essential to identify and address pre-service teachers' lack of knowledge and misconceptions in electrochemistry. Methods such as interviews, open-ended questions, multiple-choice tests, and various test formats, including two-tier, three-tier, and four-tier tests, are used to identify misconceptions held by individuals. Interviews and open-ended questions, which are frequently used to identify students' misconceptions, offer the opportunity to examine participants' thoughts in depth, but they also have some limitations (Lee & Schneider, 2015; Karaarslan & Çetin, 2018). Marshall & Rossman (2006) state that the main disadvantages of these methods are that they are carried out with a limited number of participants, the data may be subject to subjective influences due to the researcher's direct involvement in the process, the application process is time-consuming, and the analysis of the data obtained is relatively more complex and time-consuming.

Multiple-choice tests, on the other hand, can be considered a more efficient and practical measurement tool compared to other data collection methods due to their ability to reach a broad sample, be administered in a short time, and be easily scored (Haladyna, 1997). However, it is often impossible to distinguish whether student responses obtained in such tests are due to lack of knowledge, simple wrongs, chance, or external factors such as copying. Two-tier tests, which aim to minimize the disadvantages of multiple-choice tests while retaining their advantages, enable more in-depth analysis of the misconceptions that students may hold (Karataş et al., 2003). However, two-tier tests are also insufficient in determining whether the answer stems from a lack of knowledge or a misconception.

According to Kaltakçı (2012), three-tier tests were developed by incorporating a third tier into the test, which aims to assess the level of confidence in the answers provided in the first two tiers, thereby overcoming the limitations of two-tier tests. The primary advantage of three-tier tests over two-tier and multiple-choice tests is that they enable researchers to identify the causes of students' misconceptions and assess the degree of their confidence in their answers. Additionally, these tests offer an opportunity to determine whether wrong answers result from misconceptions or a lack of knowledge. However, in three-tier tests, students' confidence levels regarding their answers are asked for both tiers together. This makes it difficult to determine whether the student's confidence or lack thereof, as expressed in the third tier, is related to the answer given in the first tier, the justification provided in the second tier, or both. Four-tier tests were developed to overcome the limitations of three-tier tests.

In four-tier tests, the first tier represents the content tier, describing the knowledge level of the respondents. The second tier questions the level of certainty about the content tier and thus forms the confidence tier. The third tier, which forms the reason tier, includes the justification for the answer given to the main question. The fourth tier is the confidence tier, which questions the confidence level of the answer given to the reason tier (Kaltakçı, 2012). If the student is "not confident" at any tier of their answer, i.e., if there is doubt at any tier, then it is concluded that there is a "lack of knowledge". Table 1 compares the possible outcomes of students' decisions on four-tier tests (Kaltakçı-Gürel et al., 2015).

Table 1. Comparison of decisions from four tier tests

1. Tier	2. Tier	3. Tier	4. Tier	Decision of four-tier test decision
True	Confident	True	Confident	SK
True	Confident	False	Confident	FP
False	Confident	True	Confident	FN
False	Confident	False	Confident	M
True	Confident	True	Not Confident	LK1
True	Not Confident	True	Confident	LK2
True	Not Confident	True	Not Confident	LK3
True	Confident	False	Not Confident	LK4
True	Not Confident	False	Confident	LK5
True	Not Confident	False	Not Confident	LK6
True	Confident	True	Not Confident	LK7
False	Not Confident	True	Confident	LK8
False	Not Confident	True	Not Confident	LK9
False	Confident	False	Not Confident	LK10
False	Not Confident	False	Confident	LK11
False	Not Confident	False	Not Confident	LK12

SK: Scientific Knowledge, LK: Lack of Knowledge, M: Misconception, FN: False Negative, FP: False Positive

Four-tier diagnostic tests provide more comprehensive information than two- and three-tier tests because they can separately reveal which option participants chose, why they chose it, and how confident they are in both their choice and their reasoning. In this study, a four-tier concept misconception diagnostic test developed by the researcher was used as a measurement tool to identify misconceptions in electrochemistry among pre-service science teachers.

Problem Statement

Printed materials and teachers are among the primary sources of information for students. Teachers' lack of knowledge or misunderstandings can lead to misconceptions among students. For this reason, it is important to identify and eliminate pre-service teachers' misconceptions and knowledge levels in electrochemistry. This study aims to develop a valid and reliable measurement tool to identify misconceptions of pre-service science teachers regarding electrochemistry. In this context, a four-tier diagnostic test was developed to identify misconceptions. It is believed that this diagnostic test can be used to identify pre-service teachers' misconceptions about electrochemistry and the reasons behind these misconceptions. Additionally, this research is of great importance in guiding future studies aimed at addressing these misconceptions. In light of this information, the following sub-problems were addressed in the study:

1. Is the test developed to identify misconceptions of pre-service science teachers about electrochemistry a valid measurement tool?
2. Is the test developed to identify pre-service science teachers' misconceptions about electrochemistry a reliable measurement tool?
3. What are the factor-based values of pre-service science teachers' misconceptions about electrochemistry, their scientific knowledge levels and their lack of knowledge?

Method

Research Design

In this study, a concept test was developed to identify pre-service teachers' misconceptions about electrochemistry, and a quantitative test development and validation was employed as the preferred quantitative research method. Quantitative research is defined as the process of collecting data using scientific research principles and expressing the results in numerical data or symbols to understand a phenomenon or problem better, or to contribute to the solution of an existing problem (Büyüköztürk, 2013).

The primary objective of survey designs is to generate various statistical results about events and situations using quantitative data collected from large sample groups. In this way, the relevant phenomena or situations are described (Creswell, 2009). Especially in cross-sectional survey designs, the variables under study are evaluated with a single measurement (Büyüköztürk, 2013). For these reasons, the survey design was selected as an appropriate method for the test development process aimed at identifying misconceptions related to electrochemistry.

Data Collection

The target population of this study was comprised of pre-service science teachers from universities across Türkiye. The accessible population consisted of pre-service science teachers studying at 10 different universities in Türkiye, and the sample consisted of 307 pre-service science teachers. Due to various reasons, including transportation difficulties, application challenges, and cost, it was not feasible to apply the study to the entire population; therefore, a sample was created. In the sample selection process, 10% of the accessible population, at least 10 times the number of items in the measurement tool, or the sample size obtained from the G-Power analysis was considered (Pallant, 2020). Accordingly, the study aimed to reach participants that are at least 10 times the number of items included in the test and as a result a sample of 307 participants was selected. Since the sample determination process is a fundamental element in survey research, this study employed a rigorous process to ensure representativeness of the target population. The study sample was created by selecting participants from universities in all seven regions of Türkiye. To enhance the reliability coefficient of the test results, a heterogeneous sample was selected, comprising pre-service teachers from all grade levels.

Of the pre-service teachers who voluntarily participated in the study, 246 (80,13%) were female and 61 (19,87%) were male. In terms of class level, 123 (40,07%) pre-service teachers were in the first grade, 114 (37,13%) were in the second grade, 32 (10,42%) were in the third grade, and 38 (12,38%) were in the fourth grade. Demographic data regarding gender distribution and grade level are presented in Table 2. Data for this study were gathered during the spring semester of the 2023–2024 academic year through the Electrochemistry Concept Test, which was developed by the researcher and administered at designated universities.

Table 2. Gender distribution and class levels

Gender	Number	Percentage %
Female (F)	246	80,13%
Male (M)	61	19,87%
Total	307	100%
Class Level		
1st grade	123	40,07%
2nd grade	114	37,13%
3rd grade	32	10,42%
4th grade	38	12,38%
Total	307	100%

During the test development process, open-ended questions were prepared by combining the observations of teachers and instructors in theoretical and practical lessons, the answers given by students on their exam papers, and findings related to misconceptions about electrochemistry in the literatüre and a pool of questions was created. Three subject matter experts reviewed the item pool, and 17 questions were selected that were considered to contain all possible misconceptions on the subject. The selected questions were read to five pre-service teachers who were not included in the study to obtain information about the questions' visual, linguistic, and comprehension levels, and feedback was obtained on the suitability of the test. The researcher applied these questions to 64 pre-service science teachers. The researcher analyzed the data from their responses and identified misconceptions. After this tier, the answers given by the pre-service teachers on their exam papers and the findings related to misconceptions in the literature on electrochemistry were combined. The test was converted into a multiple-choice format. The test consisted of three tiers: the first tier contained a three-choice knowledge question (content), the second tier contained the confidence level of the answer given to the knowledge question, the third tier asked for the reason (justification) for the knowledge question, and the fourth tier consisted of a confidence question indicating whether the candidate was confident in their justification. With the addition of confidence tier to the knowledge tier and justification tier to the reasoning tier, the test was converted into a four-tier concept test. The four-tier draft test was sent to three subject matter experts for content and face validity, and the necessary revisions were made based on their feedback, resulting in the final version with 12 questions. The Electrochemistry Concept Test (ECT) consists of 12 questions, each divided into four tiers. The Electrochemistry Concept Test (ECT) was administered to a total of 307 pre-service science teachers from 10 different universities across 7 regions of Türkiye during the spring semester of 2023-2024.

Data Analysis

The validity and reliability analyses of the developed Electrochemistry Concept Test (ECT) were performed using Excel, SPSS, and Factor software packages. During the data analysis process, the data were assigned separate scores based on possible results, including scientific knowledge, misconceptions, false positives, and false negatives. In the calculations, correct answers were coded as "1" and wrong answers as "0" for all questions. In tiers where the level of confidence was questioned, the "I am sure" option was coded as "1" and the "I am not sure" option as "0".

When calculating scientific knowledge scores, data with a 1-1-1-1 coding, where all tiers were answered correctly, were included. In concept misconception scoring, a 0-1-0-1 coding was used for cases where participants gave wrong answers in the first and third tiers, but were confident in both confidence levels. In cases of false positive (answer correct, justification wrong), the calculation was made based on the 1-1-0-1 coding, where the answer was correct in the first tier, wrong in the third tier, and confident in both confidence levels. False negative (answer wrong, justification correct) scores were calculated based on the 0-1-1-1 coding, where the answer was wrong in the first tier, correct in the third tier, and confidence was expressed in both confidence levels. All other possibilities were coded as missing information.

Reliability Analysis of the Test

The developed Electrochemistry Concept Test (ECT) can be used to identify students' misconceptions and determine their level of scientific knowledge. In this context, the reliability scores of the four-tier test can be calculated using two different methods:

Reliability 1: Scientific Knowledge Reliability

The first type of reliability coefficient for the ECT was calculated based on students' correct answers in the first and third tiers and their "I am sure" responses in the second and fourth tiers (1-1-1-1) scoring, resulting in the KR-20 reliability coefficient for the test. In the literature, a reliability coefficient of 0,70 or higher is generally considered sufficient for data reliability (Fraenkel & Wallen, 2006). However, it is also stated that this coefficient may be below 0,70 in concept misconception tests (Eryılmaz, 2010; Kaltakçı, 2012, p.118).

Reliability 2: Concept Misconception Reliability

The second type of reliability coefficient of the ECT was calculated based on questions where students answered "I am sure" in the second and fourth tiers and answered wrong in both the first and third tiers (0-1-0-1). This coefficient determined the test's ability to reveal misconceptions. The KR-20 reliability coefficient was calculated to determine the test's ability to identify conceptual misconceptions. If the reliability coefficient of the developed test was 0,70 or above, it indicated that the test was reliable.

Validity Analysis of the Test

Not all reliable data may be valid. For this reason, the validity of the test was determined using data obtained from four different methods (Taban & Kiray, 2022).

Validity-1: Factor Analysis

One of the most basic statistical methods used to collect evidence of construct validity is factor analysis (Cronbach, 1984; Pedhazur & Pedhazur Schmelkin, 1991; Turgut, 1980; Urbina, 2004). Factor analysis is structured on the relationships between test items and can be applied in two different types: exploratory and confirmatory. The test items were grouped according to misconceptions, and factor analysis was performed according to the total scores obtained. In this study, the suitability of the data obtained from the ECT for factor analysis was examined using Bartlett's sphericity test and the Kaiser-Meyer-Olkin (KMO) test. Information regarding the exploratory factor analysis data of the four-tier conception test is presented in a table. As a result of the item analyses, the difficulty and discriminative indices of the test were calculated.

Validity-2: Correlation Between Correct Answer Scores and Confidence Scores

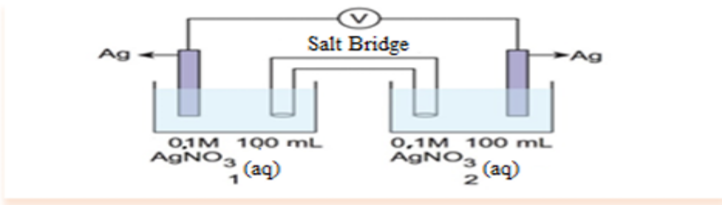
Three different correlation coefficients were calculated to examine the correlation between the correct answers and the confidence scores of the teacher candidates. These were the correlation coefficients between the first and second tier scores, between the third and fourth tier scores, and between the first and third tier scores and the second and fourth tier scores.

Validity 3: False Positive and False Negative

In terms of content validity, the possibilities of lack of knowledge, false negative and false positive were examined, and expert opinions were consulted. For the validity of concept misconception tests, it has been stated that the averages of false positive and false negative should be below 10% (Hestenes & Halloun, 1995).

Validity 4: Expert Opinion

Expert opinions were obtained from teachers and instructors in the field of chemistry education during the development of open-ended questions. The four-tier draft test was sent to three subject matter experts for content and face validity, and necessary revisions were made based on the experts' feedback, resulting in the final version shown in Figure 1.



$$Ag^{+}_{(aq)} + e^{-} \rightarrow Ag_{(s)} \quad E^{\circ} = +0{,}80\,V$$

11.1. If a small amount of 0.1M $AgNO_3$ solution is added to the battery setup shown in the figure, how does the battery voltage change compared to its initial state?

a) Increases
b) Decreases
c) Remains unchanged

11.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No,I am not sure

11.3. Why did you select the above option?

a) If a substance is added to reversible battery reactions, the battery voltage increases.
b) If $AgNO_3$ solution is added to the first container, the concentration of the solution will increase, causing a concentration difference and increasing the battery voltage.
c) If a coarse $AgNO_3$ solution is added, the volume of the solution increases, causing a concentration difference between the cells and reducing the battery voltage.
d) If a substance is added to reversible battery reactions, the battery voltage decreases.
e) If a coarse $AgNO_3$ solution is added, the concentration does not change, so the battery voltage remains unchanged.
f) In batteries made up of the same electrodes, the battery voltage is constant and does not change.

11.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

Figure 1. The four-tier electrochemistry concept test question sample

Findings and Discussion

Results of the Exploratory Factor Analysis (EFA) for the Electrochemistry Concept Test

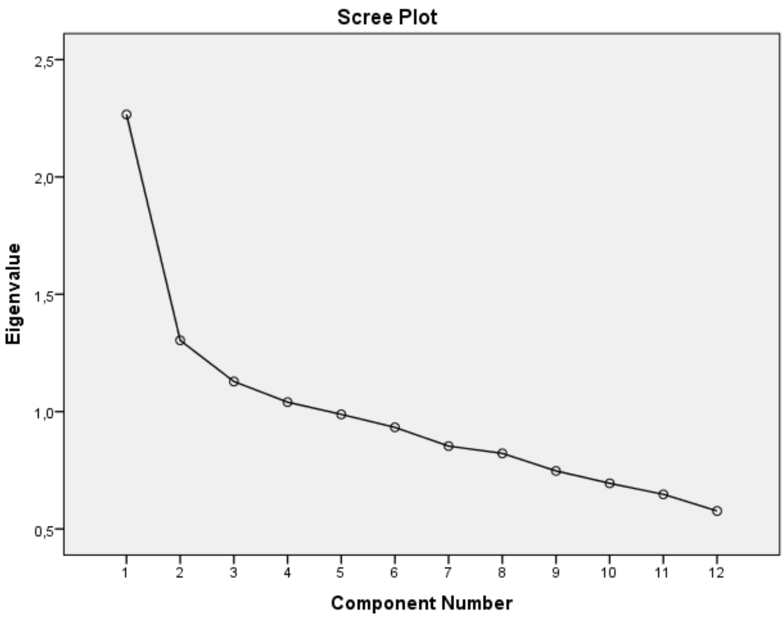


Figure 2. Slope accumulation graph

According to the EFA results based on concept misconception results, the KMO value was 0,682, indicating that the sample size was sufficient for factor analysis. According to Bartlett's sphericity test, the correlation matrix obtained for EFA is not a unit matrix, thus it was suitable for factor analysis (X^2 = 251.310, df = 66, p = .000). Figure 2 shows the slope accumulation graph from the EFA results, which measure misconceptions in the electrochemistry concept test. Upon examination of the graph, it can be seen that it begins to flatten from the fifth point onwards, indicating that the test had four factors.

The factor loadings and the total variance explained are presented in Table 3. According to the factor analysis results, the effect factor value of all items was greater than 1. If the total variance value of a test developed in the fields of education, measurement-evaluation, or science education is 40% or higher, the test is generally considered adequate (Tabachnick & Fidell, 2007). However, the higher this ratio is, the stronger the construct validity of the scale is interpreted to be.

Table 3. ECT factor load table

Test Questions	Factor 1	Factor 2	Factor 3	Factor 4
Question 6	0,738			
Question 1	0,627			
Question 7	0,578			
Question 9	0,446			
Question 11		0,751		
Question 12		0,726		
Question 5			0,725	
Question 8			0,629	
Question 4			0,529	
Question 3				0,821
Question 10				0,648
Question 2				0,318
Eigenvalue	2,266	1,304	1,128	1,04
Explained Variance	18,884	10,864	9,402	8,669
Explained Total Variance	47,819			
Overall Scale Reliability	0,702			

As a result of the EFA conducted on the concept of success test misconception, eigenvalues ranging from 1,04 to 2,266 were obtained, and four factors greater than 1 were identified. The first factor included 4 items (1, 6, 7, 9) and explained variance of 18,884; the second factor included 2 items (11, 12) and explained variance of 10,684; the third factor included 3 items (4, 5, and 8) and explained variance of 9,402; and the fourth factor included 3 items (2, 3, and 10) and explained variance of 8,669. In the success test, the total variance explained by all four factors was determined to be 47,819%. The factor loadings for the first factor ranged from 0,446 to 0,738; for the second factor, they ranged from 0,721 to 0,756; for the third factor, they ranged from 0,529 to 0,725; and for the fourth factor, they ranged from 0,318 to 0,821. All factor loadings were greater than 0,30. As a result, a four-factor structure was identified in the Electrochemistry Concept Test based on the EFA results, which were examined according to concept misconceptions.The correlations between the scores of the first and second tiers, between the third and fourth tiers, and between the first and third tiers and the second and fourth tiers are presented in Table 4.

Table 4. Correlation values

		Second Tier Scores
First Tier Scores	r	,301
	p	0
		Fourth Tier Scores
Third Tier Scores	r	,214
	p	0
		Second and Fourth Tier Scores
First and Third Tier Scores	r	,485
	p	0

Büyüköztürk (2013) states that a correlation coefficient of 1,00 indicates a perfect positive relationship between two variables, while a coefficient of -1,00 indicates a perfect negative relationship. If the coefficient is 0,00, this indicates that there is no relationship between the variables. Although there is no definitive consensus regarding the magnitude of the correlation coefficient, according to the generally accepted classification, a relationship is considered strong if the absolute value of the coefficient is between 0,70 and 1,00, moderate if it is between 0,30 and 0,70, and weak if it is between 0,00 and 0,30. Baykul (2010) states that a correlation coefficient of $r < 0,40$ indicates a weak relationship. A low positive correlation was found between the first and second tier scores (r=,301, p<,05). A low level of positive correlation was found between the third and fourth tier scores (r=,214, p<,05). A moderate level of positive correlation was found between the first and third tier scores and the second and fourth tier scores (r=,485, p<,05).

As a result of the reliability analyses, the KR-20 reliability coefficient for the scientific knowledge score obtained from correct answers was calculated as ,819, and the KR-20 reliability coefficient for the misconception score obtained from wrong answers was calculated as ,702. As a result of the item analyses, it was determined that the test's difficulty and discrimination indices were at a moderate level. In terms of data reliability, a reliability coefficient of 0,70 or higher indicates that the test is reliable (Fraenkel & Wallen, 1993, p.149). Kiray and Şimşek (2021) state that a reliability coefficient of 0,50 or higher in four-tier tests indicates that the test can be considered reliable. For the validity of concept misconception diagnosis tests, it has been stated that the averages of false positive and false negative answers should be below 10% (Hestenes & Halloun, 1995). In the analyses conducted with the data obtained from teacher candidates within the scope of the study, the calculated average of false positive answers was found to be 4,78%, and the average of false negative answers was found to be 1,89%. Both values are below 10%.

Findings Regarding Misconceptions

Tablo 5. Classification of teacher candidates' understanding of electrochemistry

Item Number	**1**	**6**	**7**	**9**	**Mean**	**11**	**12**	**Mean**	**4**	**5**	**8**	**Mean**	**2**	**3**	**10**	**Mean**
Content Grouping	**Cell Reactions**				**Factor 1**	**Cell Potential**		**Factor 2**	**Activity**			**Factor 3**	**Oxidation-Reduction**			**Factor 4**
% First Tier	40,4	43,4	50,6	30,6	**41,2**	26,3	35,4	**30,8**	27,3	42,3	39,2	**36,2**	47,0	28,6	28,6	**34,7**
% First Two Tiers	26,6	30,8	31,3	15,5	**26,1**	8,9	10,3	**9,6**	11,0	27,8	24,5	**21,1**	36,0	15,4	16,8	**22,7**
% First Three Tiers	11,6	20,1	23,7	12,5	**17,0**	6,9	6,3	**6,6**	7,2	17,5	15,4	**13,3**	19,6	8,9	5,6	**11,3**
% Four Tiers Together	9,7	16,3	21,4	11,1	**14,7**	3,8	5,6	**4,7**	5,9	15,5	14,1	**11,8**	18,3	7,6	4,5	**10,1**
% Scientific Knowledge	9,7	16,3	21,4	11,1	**14,7**	3,8	5,6	**4,7**	5,9	15,5	14,1	**11,8**	18,3	7,6	4,5	**10,1**
% Misconception	22,0	15,5	20,3	18,2	**19,0**	17,0	15,0	**16,0**	32,7	25,5	20,6	**26,2**	14,4	19,4	37,6	**23,8**
% All Lack of Knowledge	45,8	56,1	51,0	68,2	**55,3**	75,9	75,8	**75,8**	57,6	49,5	54,1	**53,7**	50,4	64,9	45,5	**53,6**
% False Positive	13,4	7,5	7,2	2,3	**7,6**	3,1	3,0	**3,0**	3,0	7,2	7,0	**5,7**	12,3	4,8	9,4	**8,8**
% False Negative	9,2	4,7	0,1	0,3	**3,6**	0,1	0,7	**0,4**	0,8	2,4	4,2	**2,5**	4,6	3,2	3,0	**3,6**
% Lack of Knowledge 1	1,8	3,8	2,3	1,4	**2,3**	1,0	07	**0,8**	1,3	2,0	1,3	**1,5**	1,3	1,3	0,8	**1,1**
% Lack of Knowledge 2	2,8	0,8	2,0	1,3	**1,7**	1,4	1,1	**1,3**	1,5	0,7	0,4	**0,9**	1,7	0,8	1,7	**1,4**
% Lack of Knowledge 3	3,8	3,2	10,1	7,9	**6,3**	8,9	15,2	**12,0**	9,4	7,9	7,7	**8,4**	4,1	4,5	4,2	**4,3**
% Lack of Knowledge 4	1,7	3,2	0,4	2,0	**1,5**	1,0	1,0	**1,0**	0,8	3,1	2,1	**2,0**	4,1	1,7	2,0	**2,6**
% Lack of Knowledge 5	3,2	1,0	1,0	0,6	**1,4**	0,4	1,3	**0,8**	0,3	0,3	0,6	**0,4**	1,3	0,6	2,1	**1,3**
% Lack of Knowledge 6	4,0	7,5	6,2	5,3	**5,7**	6,8	7,5	**7,1**	5,1	5,6	6,0	**5,5**	4,1	7,3	3,8	**5,1**
% Lack of Knowledge 7	0,3	2,2	0,0	0,3	**0,7**	0,3	0,1	**0,2**	0,1	0,4	1,1	**0,6**	0,8	0,4	0,8	**0,7**
% Lack of Knowledge 8	3,8	0,3	0,1	0,0	**1,1**	0,1	0,4	**0,3**	0,1	0,1	0,6	**0,3**	0,4	1,1	0,6	**0,7**
% Lack of Knowledge 9	3,5	6,5	0,6	1,3	**3,0**	1,8	1,5	**1,7**	1,8	3,8	7,0	**4,2**	4,1	3,8	2,1	**3,3**
% Lack of Knowledge 10	3,4	3,2	3,0	4,1	**3,4**	5,2	3,5	**4,4**	5,6	3,1	4,2	**4,3**	6,6	7,2	5,3	**6,4**
% Lack of Knowledge 11	5,1	3,7	3,0	5,1	**4,2**	5,3	3,1	**4,2**	3,7	2,9	4,1	**3,5**	5,0	5,2	4,6	**4,9**
% Lack of Knowledge 12	12,4	20,1	22,4	40,3	**23,9**	43,7	40,3	**42,0**	27,8	19,6	19,0	**22,1**	17,0	31,0	17,3	**21,8**

The developed electrochemistry concept test was administered to 710 pre-service science teachers. The percentages for the categories of the first tier, first two tiers, first three tiers, all four tiers combined, scientific knowledge, misconception, False Positive, False Negative, and lack of knowledge—related to the four sub-dimensions of the 12-item test, namely activity, oxidation–reduction, cell reactions, and cell potential—are presented at both the item and factor levels in Table 5.

When the responses of the pre-service science teachers to the first item of the test presented in Table 5 were analyzed, the percentage of correct responses to the first-tier question was found to be 40.4%. In other words, if the first item had been a single-tier question, it would have been concluded that approximately 60% of the pre-service teachers held misconceptions based solely on their incorrect responses. However, the four-tier test demonstrates that not all incorrect responses necessarily indicate the presence of a misconception. These individuals may instead exhibit misconceptions, False Positive responses, False Negative responses, or a lack of scientific knowledge. The percentage of participants who answered all four tiers of the first item correctly and with confidence was 9.7%, indicating that only 9.7% of the pre-service teachers possessed scientific knowledge regarding this concept. Of the remaining 90.3%, only 22% were identified as having misconceptions. Furthermore, 45.8% exhibited a lack of knowledge, 13.4% demonstrated False Positive responses, and 9.2% demonstrated False Negative responses.

A total of 37 misconception statements were identified from the four-tier diagnostic misconception test developed for the topic of electrochemistry. Items measuring the same misconception were grouped together and reorganized into a single statement. The table clearly indicates which misconceptions are identified based on specific response patterns to each item. The electrochemistry-related misconceptions of pre-service science teachers and their corresponding percentages obtained from the four-tier diagnostic test are presented in Table 6.

Table 6. Misconception statements about electrochemistry and percentages

Mis-conception	Perc. (%)	Misconception statements	Answer
M1	%11,8	All chemical reactions occur through the transfer of electrons.	1.1.a 1.3.a 1.1.a 1.3.b 1.1.a 1.3.e 1.1.a 1.3.c
M2	%8,3	A species that gains electrons is reduced, whereas a species that loses electrons is oxidized.	2.1.b 2.3.d
M3	%0,1	All chemical reactions are redox reactions.	1.1.c 1.3.a
M4	%3,9	A species that gains electrons is oxidized, while a species that loses electrons is reduced.	2.1.b 2.3.a 2.1.b 2.3.c
M5	%0,4	In a chemical reaction, both species involved in electron transfer exhibit both oxidation and reduction behavior.	2.1.c 2.3.b
M6	%10,1	Metalloids react only with strong acids.	3.1.a 3.3.a 3.1.a 3.3.b
M7	%5,6	Metalloids react only with aqua regia.	3.1.a 3.3.c
M8	%2,4	Metalloids react only with oxygen-rich acids and bases.	3.1.b 3.3.d
M9	%0,1	Metalloids react only with oxygen-poor acids and bases.	3.1.b 3.3.e
M10	%7,7	The interaction of metalloids with an HClO solution results in the formation of O_2 gas.	4.1.a 4.3.a 4.1.a 4.3.d
M11	%24,2	The interaction of metalloids with an HClO solution results in the formation of H_2 gas.	4.1.c 4.3.b 4.1.c 4.3.e
M12	%21,5	If the activity of an ion in a solution is greater than that of the immersed metal, the metal rod undergoes corrosion.	5.1.b 5.3.b 5.1.b 5.3.f 5.1.b 5.3.a
M13	%1,2	The corrosion tendencies of metals are the reverse of their positions in the activity series.	5.1.c 5.3.d
M14	%9,1	In an electrochemical cell, the sum of the standard oxidation potentials of the electrodes gives the standard cell potential.	6.1.a 6.3.c
M15	%1,2	In an electrochemical cell, the difference between the standard cell potentials of the anode and the cathode gives the standard cell potential.	6.1.a 6.3.d
M16	%2,5	The electrode with the higher reduction potential is the anode.	6.1.b 6.3.a
M17	%1,5	The electrode with the lower oxidation potential is the anode.	6.1.b 6.3.e

M18	%14,8	The mass of the electrode with the lower oxidation potential decreases over time.	7.1.a 7.3.a
M19	%1,8	While the mass of the anode electrode increases over time, the mass of the cathode electrode decreases over time.	7.1.a 7.3.b
M20	%3,3	Hydrogen gas is released because hydrogen has a greater tendency to be reduced than copper.	7.1.c 7.3.c 7.1.c 7.3.d
M21	%14,9	The schematic representation of an electrochemical cell is written according to the net cell reaction.	8.1.a 8.1.b
M22	%1,8	The schematic representation of an electrochemical cell is written according to the anode half-cell reaction.	8.1.a 8.3.a
M23	%0,4	The schematic representation of an electrochemical cell is written according to the cathode half-cell reaction.	8.1.b 8.3.c
M24	%1,9	In the schematic representation of an electrochemical cell, the cathode half-cell reaction is written to the left of the salt bridge and the anode half-cell reaction to the right.	8.1.b 8.3.e
M25	%1,7	In reversible cell reactions, an increase in temperature affects the cell potential because it changes the volume.	9.1.b 9.3.c
M26	%10,2	In cell reactions, as temperature increases, the kinetic energy of particles increases; therefore, the cell potential increases.	9.1.b 9.3.b
M27	%5,6	Cell reactions are reversible (bidirectional); therefore, they are not affected by temperature changes.	9.1.c 9.3.a
M28	%5,9	In an electrochemical cell, the container on the left is always the anode and the container on the right is the cathode.	10.1.a 10.3.a
M29	%3,8	In an electrochemical cell, the direction of electric current is from the anode to the cathode.	10.1.a 10.3.c
M30	%20,8	In a galvanic cell, electrons move through the salt bridge.	10.1.c 10.3.d
M31	%0,7	In the electrolyte solution, anions migrate toward the cathode and cations toward the anode.	10.1.a 10.3.e
M32	%11,4	In reversible cell reactions, adding the same solution at the same concentration increases the cell potential.	11.1.a 11.3.a 11.1.a 11.3.b
M33	%3,8	Adding the same solution at the same concentration to an electrolytic cell increases the solution volume; therefore, the cell potential decreases.	11.1.b 11.3.c
M34	%0,2	The addition of substances to electrochemical cell reactions decreases the cell potential.	11.1.b 11.3.d
M35	%4,9	In electrochemical cells composed of identical electrodes, the cell potential is constant and does not change.	12.1.c 12.3.e
M36	%6,1	In a concentration cell, the addition of a second substance that affects the solution concentration to the reaction vessel does not affect the cell potential.	12.1.b 12.3.c
M37	%2,7	As the amount of solid AgCl increases due to precipitation in the vessel while the volume of the $AgNO_3$ solution decreases, the cell potential decreases	12.1.b 12.3.d

Tablo 7. Percentage table of misconceptions

N=710	**M 1**	**M 2**	**M 3**	**M 4**	**M 5**	**M 6**	**M 7**	**M 8**	**M 9**	**M 10**
Mean	84	59	1	28	3	72	40	17	1	55
%	11,83	8,31	0,14	3,94	0,42	10,14	5,63	2,39	0,14	7,75
N=710	**M 11**	**M 12**	**M 13**	**M 14**	**M 15**	**M 16**	**M 17**	**M 18**	**M 19**	**M 20**
Mean	172	153	9	65	9	18	11	105	13	24
%	24,23	21,55	1,27	9,15	1,27	2,54	1,55	14,79	1,83	3,38
N=710	**M 21**	**M 22**	**M 23**	**M 24**	**M 25**	**M 26**	**M 27**	**M 28**	**M 29**	**M 30**
Mean	106	13	3	14	12	73	40	42	27	148
%	14,93	1,83	0,42	1,97	1,69	10,28	5,63	5,92	3,80	20,85
N=710	**M 31**	**M 32**	**M 33**	**M 34**	**M 35**	**M 36**	**M 37**			
Mean	5	81	27	2	35	43	19			
%	0,70	11,41	3,80	0,28	4,93	6,06	2,68			

In Table 7, the mean values and percentages of the identified misconception statements are presented. The graphical representation of the misconception percentages given in Table 7 is shown in Figure 3. An examination of Table 7 and Figure 3 reveals that 9 misconceptions were observed at a rate of 10% or higher among pre-service science teachers. These misconceptions are listed below:

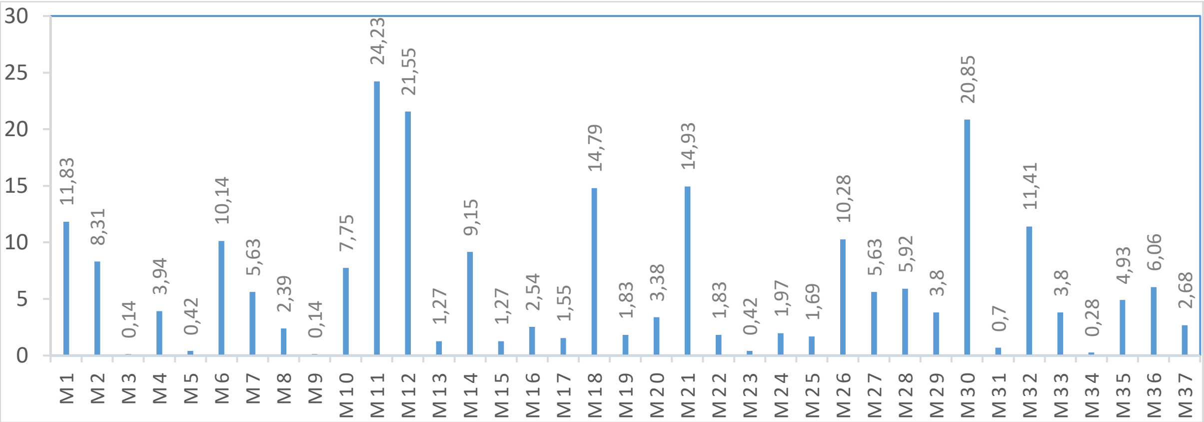


Figure 3. Percentages of misconceptions

M1 (%11,83): All chemical reactions occur through the transfer of electrons.
M6 (%10,14): Metalloids react only with strong acids.
M11 (%24,23): The interaction of metalloids with an HClO solution results in the formation of H_2 gas.
M12 (%21,55): If the activity of an ion in a solution is greater than that of the immersed metal, the metal rod undergoes corrosion.
M18 (%14,79): The mass of the electrode with the lower oxidation potential decreases over time.
M21 (%14,93): The schematic representation of an electrochemical cell is written according to the net cell reaction.
M26 (%10,28): In cell reactions, as temperature increases, the kinetic energy of particles increases; therefore, the cell potential increases.
M30 (%20,85): In a galvanic cell, electrons move through the salt bridge.
M32 (%11,41): In reversible cell reactions, adding the same solution at the same concentration increases the cell potential.

When the literature was reviewed, although there are studies indicating that various methods have been used to identify misconceptions, it was observed that in recent years the most commonly used approach in this field is the multi-tier diagnostic test. Among these tests, four-tier diagnostic tests are preferred more frequently because of their potential to reveal the causes of individuals' misunderstandings (Dewi et al., 2020; Kiray & Şimşek, 2021; Kural, 2021; Ranggu et al., 2023; Yan & Subramaniam, 2018). Four-tier tests, with respect to determining false positive, false negative, lack of knowledge, misconceptions, and levels of scientific knowledge, yield more effective results compared to other methods such as to two- or three-tier tests. However, in the existing literature there is no four-tier diagnostic test specifically addressing misconceptions in electrochemistry. In this context, the four-tier Electrochemistry Concept Test developed in this study can be regarded as a suitable instrument for addressing the identified gap in the literatre. Additionally, using the developed test, experimental studies can be designed, and the effectiveness of different teaching methods, techniques, or tools on misconceptions can be determined.

Conclusions and Recommendations

The purpose of this study was to develop a valid and reliable measurement tool for identifying pre-service science teachers' misconceptions about electrochemistry. To this end, a four-tier misconception diagnosis test was developed. The positive and negative wrong answer rates of the developed test were calculated to be below 10%. Correlation analysis, determine the validity of the four-tier diagnostic test, was applied. A moderate and significant positive correlation was observed between the first and third tier scores and the second and fourth tier scores ($r = ,485$, $p < ,05$). The developed four-tier misconception diagnosis test consisted of four sub-dimensions, as determined by the factor analysis results. The sub-dimensions of this four-tier test, which consisted of a total of 12 items, were supported by exploratory factor analysis. According to the factor analysis results, items 1, 6, 7, and 9 in the test are consistent with the first sub-dimension; items 11 and 12 are consistent with the second sub-dimension; items 4, 5, and 8 are consistent with the third sub-dimension; and items 2, 3, and 10 are consistent with the fourth sub-dimension. Within the scope of reliability analysis, two different reliability coefficients were calculated. These coefficients were KR-20 reliability coefficients calculated for the scientific knowledge and misconception scores. Both coefficients indicated that the test is a reliable measurement tool. The findings obtained from the analyses revealed that the developed electrochemistry misconception diagnostic test is a valid and reliable measurement tool for assessing pre-service science teachers' misconceptions and scientific knowledge in electrochemistry. This diagnostic test was applied to pre-service science teachers. It is recommended that validity and reliability studies fort his test to be repeated for research conducted with different study groups. Four-tier diagnostic tests are preferred over two-tier and three-tier tests because they can reveal the causes of individuals' misconceptions more effectively. Four-tier diagnostic tests are more effective than other methods and two- and three-tier tests in terms of determining false positive, false negative, lack of knowledge, misconceptions, and scientific knowledge.

Although various studies have been conducted on identifying misconceptions related to electrochemistry in the literature, no four-tier diagnostic test has been identified. In this context, it is believed that the four-tier electrochemistry misconception diagnostic test developed in this study can fill this gap in the literature. Thanks to the developed test, the areas where pre-service teachers' misconceptions in electrochemistry are concentrated can be identified, their causes analyzed, and corrective measures implemented. Additionally, experimental studies can be designed using the developed test to evaluate the impact of methods or tools on misconceptions.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors

* The research was conducted by scientific ethical rules. Furthermore, we declare that we accept all ethical and legal consequences that may arise from any violation of this statement and that we are responsible for these consequences. Ethical approval was obtained from the Hacettepe University Ethics Committee, as per the decision dated 10 February 2023 and numbered E-35853172-300-00002683846.

Conflict of Interest

* There is no conflict of interest among the authors regarding this study.

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ELECTROCHEMISTRY CONCEPT TEST

Dear Students,

This study aims to determine the misconceptions of pre-service science teachers about electrochemistry. Please read each item below carefully and answer accordingly. Your honest answers are crucial for the scientific validity of this study. I sincerely thank you for your contributions to my doctoral research through your sincere answers.

Best regards, Fatma ŞENER

Gender: Female: ☐ Male: ☐
Grade: 1☐ 2☐ 3☐ 4☐

I. $NaOH_{(aq)} + HCl_{(aq)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)} + H_2O_{(s)}$
II. $CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$
III. $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$

1.1. Which of the above reactions are redox reactions?

a) I and II
b) II and III
c) All of them

1.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

1.3. Why did you choose the above option?

a) All chemical reactions involve the exchange of electrons, therefore they are redox reactions.
b) Combustion reactions and acid-base reactions involving electron transfer are redox reactions.
c) Reactions involving particles that reduce by gaining electrons and oxidize by losing electrons are redox reactions.
d) Reactions involving particles that reduce by gaining electrons and oxidize by losing electrons are redox reactions.
e) Combustion reactions involving reduction and oxidation, and neutralization reactions involving oppositely charged ions are redox reactions.

1.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

2.1. Which of the following statements about this reaction are correct?

$\mathbf{H_{2(g)} + Cl_{2(g)} \rightarrow 2HCl_{(g)}}$

I H_2 is a reducing agent
II.Cl_2 is an oxidizing agent
III.It is a synthesis reaction

a) I and III b) II and III c) All of them

2.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

2.3. Why did you select the above option?

a) In the formation reaction, Cl_2 gains electrons and is oxidized to its anion, while H_2 loses electrons and is reduced to its cation.
b) In the formation reaction, there is an exchange of electrons between the H_2 and Cl_2 molecules, so both exhibit reduction and oxidation properties.
c) In the formation reaction, Cl_2 donates an electron and is reduced to an ion, while oxidizing the substance opposite to it, thus exhibiting oxidizing properties.
d) When the HCl molecule, a new type of molecule, is formed between the H_2 and Cl_2 molecules, H_2 exhibits reducing properties because it gains an electron.
e) In the formation reaction, H_2 exhibits reducing properties because it oxidizes the substance opposite to it by losing an electron.

2.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

3.1. Merve, a senior science teacher, wonders if the ring her fiancé bought her is really silver (Ag). To find out, she decides to go to the chemistry lab and conduct an experiment using what she learned in chemistry class. Which concentrated solutions do you think Merve should use?

I. Salt acid (HCl)
II. Caustic soda (NaOH)
III. Nitric acid (HNO_3)

a).I and III
b) II and III
c) Only III

3.2. Are you sure about your answer to the previous question?

a).Yes, I am sure
b).No, I am not sure

3.3. Why did you select the above option?

a).Silver is a semi-noble metallic element, so it reacts with all acids.
b).Silver is a semi-noble metallic element, so it only reacts with strong acids.
c).Because silver is a semi-noble metallic element, it reacts only with aqua regia (HCl + $3HNO_3$).
d).Because silver is a semi-noble metallic element, it reacts only with strong acids and bases rich in oxygen.
e).Because silver is a semi-noble metallic element, it reacts only with strong acids and bases poor in oxygen.
f).Silver is a semi-noble metallic element, so it only reacts with strong acids rich in oxygen.

3.4. Are you sure about your answer to the previous question?

a).Yes, I am sure

b).No, I am not sure

4.1. Mete Han, a senior student studying to become a science teacher, is disappointed when he cannot find a glass beaker to hold the concentrated HClO solution he needs for his chemistry lab experiment. He immediately looks around. Seeing the shiny, sterile bags on the shelf in front of him, he is delighted to find some copper containers that have not yet been removed from their packaging. He takes one of them and adds the concentrated HClO solution to it. Which of the following statements about the situation he observes in the container is correct?

a).O_2 gas is observed coming out of the copper container.
b).No change is observed in the copper container.
c).H_2 gas is observed coming out of the copper container.

4.2. Are you sure about your answer to the previous question?

a).Yes, I am sure
b).No, I am not sure

4.3. Why did you choose the above option?

a).HClO is an oxygenic acid solution, so it reacts with the semi-noble metallic copper container to form salt, water, and O_2 gas.
b).HClO is an oxygenic acid solution, so it reacts with the semi-noble metallic copper container to form salt, water, and H_2 gas.
c) Although HClO is an oxygen-containing acid solution, it is a weak acid, so it does not react with the semi-noble metallic copper container.
d).HClO is a strong base solution, so it reacts with the semi-noble metallic copper container to form salt, water, and O_2 gas.
e).Since HClO is a strong base solution, it reacts with the semi-noble metallic copper container, forming salt, water, and H_2 gas.
f).Since HClO is a base solution, it does not react with the semi-noble metallic copper container.

4.4. Are you sure about your answer to the previous question?

a).Yes, I am sure
b).No, I am not sure

5.1. The activity order of metals X, Y, and Z is X>Y>Z. According to this, which of the metals X, Y, and Z immersed in the following solutions will corrode?

$Y^+Solution$	$Z^+Solution$	$Z^+Solution$

a) X and Y
b) Only Z
c) All of them

5.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

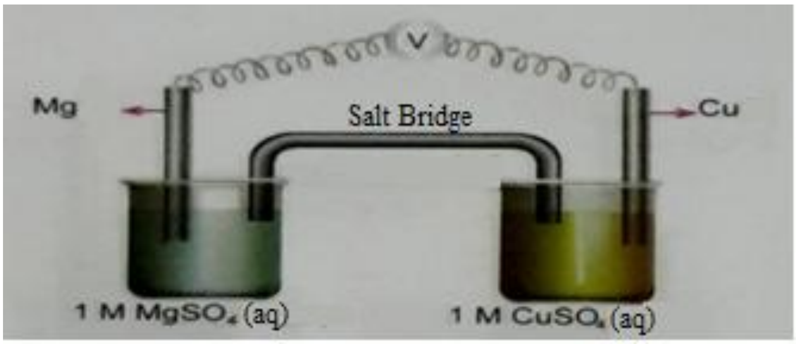
5.3. Why did you select the above option?

a) The activity of the solution containing ions is greater than the activity of the immersed Z metal, so the metal rod corrodes over time.
b) The solution containing ions is less active than the Z metal immersed in it, so the metal rod corrodes over time.
c) The most active X metal corrodes the most, followed by the less active Y metal, and the least active Z metal corrodes the least.
d) Since the corrosion activity order is the exact opposite, the Z metal corrodes the most, followed by the Y metal, and the X metal corrodes the least.
e) Since the activity of the solution containing ions in the container is lower than the activity of the X and Y metals immersed in it, the metal rods corrode over time.
f) The solution containing the ions in the container has a higher activity than the X and Y metals immersed in it, so the metal rods corrode over time.

5.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

Answer questions 6 and 7 based on the Mg-Cu battery shown in the figure.



$$Mg_{(s)} \rightarrow Mg^{2+}_{(aq)} + 2e^- \quad E^\circ = +2,37\ V$$
$$H_{2(g)} \rightarrow 2H^{+}_{(aq)} + 2e^- \quad E^\circ = 0,00\ V$$
$$Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2e^- \quad E^\circ = -0,34\ V$$

6.1. Which of the following statements about the Mg – Cu battery setup shown in the figure is correct?

a) The battery potential is +2.03 volts
b) The Cu electrode is the anode
c) The Mg electrode is the anode

6.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

6.3. Why did you select the above option?

a) The electrode with the higher reduction potential is the anode.

b) The electrode with the lower reduction potential is the anode.
c) The sum of the standard oxidation potentials of the electrodes gives the cell potential.
d) The difference between the standard cell potentials of the anode and cathode gives the cell potential.
e) The electrode with the smaller oxidation potential is the anode.

6.4. Are you sure about your answer to the previous question?

a) Yes,I am sure
b) No, I am not sure

7.1. Which of the following statements about the **Mg – Cu** battery shown in the figure is correct?

a) The mass of the Cu electrode decreases over time.
b) The mass of the Cu electrode increases over time.
c) The mass of the Cu electrode remains unchanged.

7.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

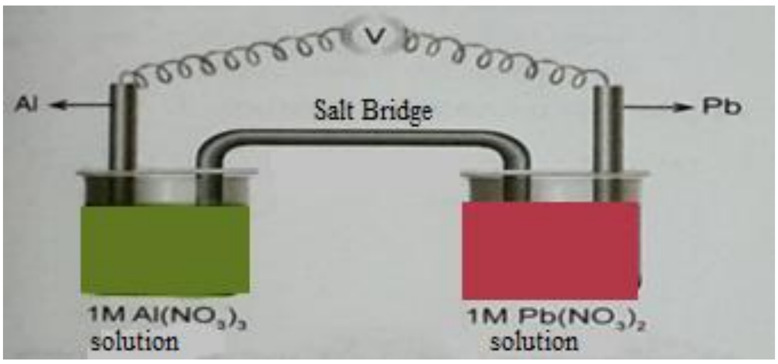
7.3. Why did you select the above option?

a) Since there will be corrosion at the anode and deposition at the cathode, the mass of the Cu electrode decreases over time.
b) Since there will be an increase at the anode and a decrease at the cathode, the mass of the Cu electrode decreases over time.
c) As the mass of the anode increases, the mass of the cathode remains constant, and H_2 gas is observed to exit the cathode chamber.
d) As the mass of the anode decreases, the mass of the cathode remains constant, and H_2 gas is observed to exit the cathode chamber.
e) Since there will be corrosion at the anode and deposition at the cathode, the mass of the Cu electrode increases over time.
f) Since there will be an increase at the anode and a decrease at the cathode, the mass of the Cu electrode increases over time.

7.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

Answer questions 8 and 9 based on the Al-Pb battery shown in the figure.



$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^{-} \quad E^{\circ} = +1,66\ V$$
$$Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2e^{-} \quad E^{\circ} = +0,12\ V$$

8.1st According to the battery arrangement shown in the figure, which of the following is the schematic representation of the battery?

$a).\ Al_{(S)}/Pb^{+2}_{(1M)}//Al^{+3}_{(1M)}/Pb_{(S)}$
$b)\ Pb_{(S)}/Pb^{+2}_{(1M)}//Al^{+3}_{(1M)}/Al_{(S)}$
$c).\ Al_{(S)}/Al^{+3}_{(1M)}//Pb^{+2}_{(1M)}/Pb_{(S)}$

8.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

8.3. Why did you select the above option?

a) The schematic representation of the battery is written according to the anode half-cell reaction.
b) The schematic representation of the battery is written according to the net cell reaction. The reactants are written to the left of the salt bridge (//) and the products are written to the right.
c) The schematic representation of the battery is written according to the cathode half-cell reaction.
d) In the schematic representation of the battery, the anode is written to the left of the salt bridge (//) and the cathode half-cell reaction is written to the right.
e) In the schematic representation of the battery, the cathode is written on the left side of the salt bridge (//) and the anode half-cell reaction is written on the right side.

8.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

9.1. In the battery circuit shown in the figure, how does the voltage of the battery change when the temperature increases?

a) The voltage decreases
b) The voltage increases
c) The voltage remains unchanged

9.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

9.3. Why did you select the above option?

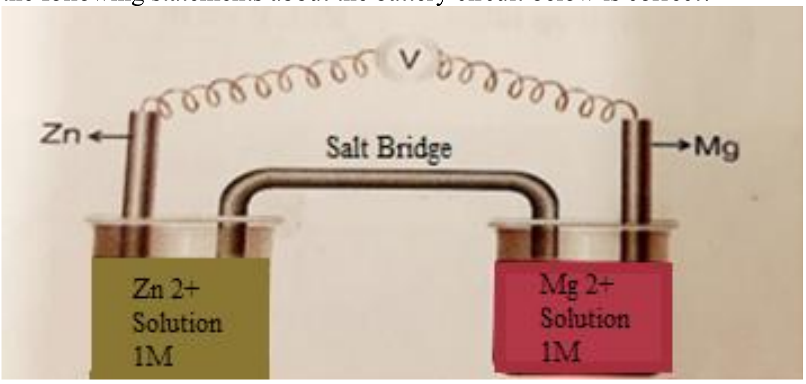
a) Battery reactions are reversible (two-way), so an increase or decrease in temperature does not affect the battery voltage.
b) As temperature increases, the kinetic energy of the particles increases, so the reaction rate increases and the battery voltage increases.
c) As temperature increases, the volume of the electrolyte solution decreases while its concentration increases, causing the battery voltage to increase.

d) As temperature increases, the volume of the electrolyte solution decreases, causing the battery voltage to decrease.
e) Since battery reactions are exothermic reactions, the battery voltage decreases as temperature increases.

9.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

10.1. Which of the following statements about the battery circuit below is correct?



$$Zn^{2+}_{(aq)} + 2e^- \rightarrow Zn_{(s)} \quad E^\circ = -0,76\,V$$
$$Mg^{+2}_{(aq)} + 2e^- \rightarrow Mg_{(S)} \quad E^\circ = -2,37\,V$$

a) The Zn electrode is the anode.
b) The direction of the electric current is from the positively charged electrode to the negatively charged electrode.
c) Electrons move through the salt bridge.

10.2. Are you sure about your answer to the previous question?

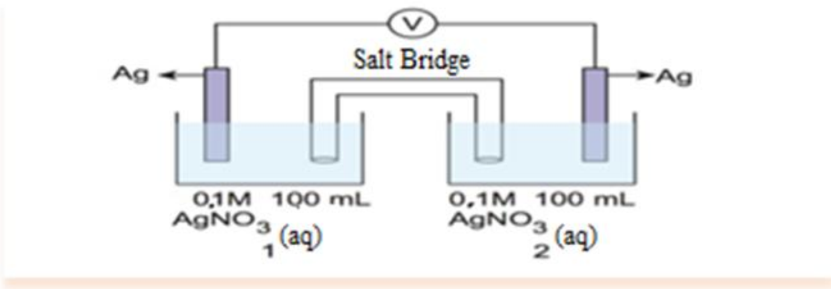
a) Yes, I am sure
b) No, I am not sure

10.3. Why did you select the above option?

a) In a battery circuit, the left container is always the anode and the right container is always the cathode, so the Zn electrode is the anode.
b) In a battery, the direction of electric current is opposite to the direction of electron movement.
c) In a battery, the direction of electric current is from the anode to the cathode.
d) In the battery, the movement of electrons is from the negatively charged anode to the positively charged cathode through the salt bridge.
e) In the solution, anions migrate toward the cathode and cations toward the anode.

10.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure



$$Ag^{+}_{(aq)} + e^{-} \rightarrow Ag_{(s)} \quad E^{\circ} = +0,80\ V$$

11.1. If a small amount of 0.1M $AgNO_3$ solution is added to the battery setup shown in the figure, how does the battery voltage change compared to its initial state?

a) Increases
b) Decreases
c) Remains unchanged

11.2. Are you sure about your answer to the previous question?

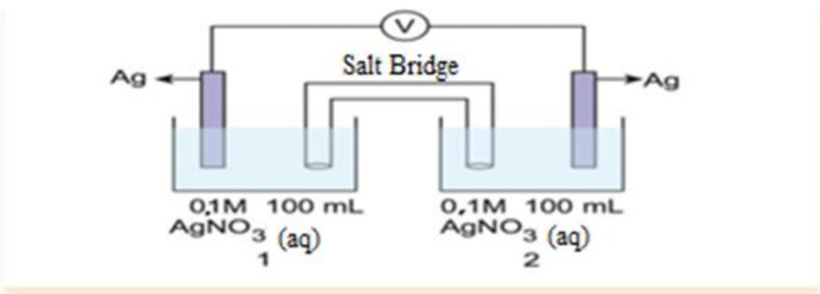
a) Yes, I am sure
b) No, I am not sure

11.3. Why did you select the above option?

a) If a substance is added to reversible battery reactions, the battery voltage increases.
b) If $AgNO_3$ solution is added to the first container, the concentration of the solution will increase, causing a concentration difference and increasing the battery voltage.
c) If a coarse $AgNO_3$ solution is added, the volume of the solution increases, causing a concentration difference between the cells and reducing the battery voltage.
d) If a substance is added to reversible battery reactions, the battery voltage decreases.
e) If a coarse $AgNO_3$ solution is added, the concentration does not change, so the battery voltage remains unchanged.
f) In batteries made up of the same electrodes, the battery voltage is constant and does not change.

11.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure



$$Ag^{+}_{(aq)} + e^{-} \rightarrow Ag_{(s)} \quad E^{\circ} = +0,80\ V$$

12.1. If a small amount of NaCl salt is added to the battery setup shown in the figure, how does the battery voltage change compared to the initial state?

a) Increases
b) Decreases
c) Remains unchanged

12.2. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure

12.3. Why did you select the above option?

a) Sedimentation occurs in the container, causing the [Ag+] concentration to decrease and the battery voltage to increase.
b) If a substance is added to reversible battery reactions, the battery voltage increases.
c) Precipitation occurs in the container, causing the [Ag+] concentration to decrease, which reduces the cell voltage.
d) Due to precipitation in the container, the amount of AgCl increases while the volume of the $AgNO_3$ solution decreases, causing the cell voltage to decrease.
e) Since the anode and cathode are made of the same electrodes, the cell voltage remains constant and does not change.

12.4. Are you sure about your answer to the previous question?

a) Yes, I am sure
b) No, I am not sure