

Misconceptions in Electrochemistry among 11th- and 12th-Grade Students in Dire Dawa and Harari, Ethiopia: Causes, Effects, and Strategies

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Abstract

Misconceptions in electrochemistry (ECT), such as believing electrons flow through the salt bridge, persist among students, influenced by didactic teaching, weak prior knowledge, and misleading resources. These errors vary across educational programs, impacting academic performance. This study aimed to examine school-specific ECT misconception rates and scores among 360 students from the Diploma in Design and Construction (DDC), Engineering and Operations Diploma (EOD), and Health and Social Sciences (HSS) programs, identifying contributing factors and proposing interventions. Data were collected via assessments and interviews ($N = 30$). Misconception prevalence (e.g., salt bridge error) and mean scores were analyzed for each group: DDC (65%, $M = 26.2$), EOD (75%, $M = 24.1$), and HSS (64%, $M = 27.3$). Interview responses highlighted didactic teaching (90–100%) and prior knowledge gaps (80–90%). Descriptive statistics and qualitative analysis informed findings. EOD showed the highest misconception rates (75%) and lowest scores ($M = 24.1$), linked to resource scarcity and 100% didactic teaching. DDC had moderate rates (65%) and scores ($M = 26.2$), tempered by 90% of didactic methods despite urban advantages. HSS exhibited the lowest rates (64%) and highest scores ($M = 27.3$), reflecting better teacher preparation, though 80% reported weak prior knowledge. ECT misconceptions correlate with teaching methods and resource availability, with EOD being the most affected. The groups encounter difficulties due to gaps in prior knowledge and passive teaching methods in HSS. Future research should test targeted interventions (e.g., labs, CCTs, teacher training) and expand longitudinal data collection to address these disparities effectively.

Keywords

Electrochemistry, misconceptions, didactic teaching, high school students, instructional strategies.



I. Introduction

Electrochemistry, a cornerstone of high school chemistry curricula worldwide, bridges the disciplines of chemistry and physics by integrating concepts such as redox reactions, galvanic cells, and electrolysis. Its abstract nature and reliance on interconnected scientific principles make it a challenging topic for students, often leading to misconceptions that obstruct deep conceptual understanding (Garnett & Treagust, 1990; Sanger & Greenbowe, 1997). These misconceptions such as confusion over electron flow or the role of electrodes are not merely superficial errors but reflect fundamental misunderstandings that can impede students' progression in science education (Ogude & Bradley, 1994). In Ethiopia, where science, technology, engineering, and mathematics (STEM) education is pivotal for national development, addressing these challenges is particularly urgent as the country seeks to build a skilled workforce for emerging industries like renewable energy, which heavily rely on electrochemical technologies (Ministry of Education, Ethiopia, 2020).

This study focuses on students in grades 11 and 12 from three Ethiopian high schools: Dire Dawa Comprehensive, East Oromia Deder High School, and Harari Secondary School.

Each school contributed 60 students from grade 11 and 60 from grade 12, totaling 360 participants. These schools were selected to represent diverse urban and regional educational contexts within Ethiopia, offering insights into the broader challenges in different settings. Previous research has documented widespread misconceptions in electrochemistry globally, including the erroneous belief that electrons flow through the salt bridge or that galvanic and electrolytic cells operate identically (Sanger & Greenbowe, 1999; Schmidt, 1997). However, there is a notable scarcity of studies examining these issues within the Ethiopian educational framework, despite the country's unique linguistic, cultural, and resource constraints (Beyessa, 2021).

1.1 Statement of the Problem

High school students in Ethiopia, particularly in grades 11 and 12, encounter electrochemistry as part of the national curriculum. However, anecdotal evidence from teachers and preliminary classroom observations suggest that many struggle to grasp its core concepts. Misconceptions such as misunderstanding the direction of current flow or the purpose of the salt bridge appear to persist, potentially undermining students' performance in national examinations and their preparedness for tertiary STEM education (Hussein, 2023). These difficulties are compounded by outdated teaching materials, limited laboratory resources, and a lack of teacher training tailored to address conceptual errors (Tekeste, 2019). Without targeted interventions, these misconceptions may perpetuate a cycle of poor academic outcomes and disengagement from science, posing a significant barrier to Ethiopia's educational and economic goals.

1.2 Research Gaps

While international research on electrochemistry misconceptions is robust (Garnett & Treagust, 1990; Huddle et al., 2000), it largely focuses on Western or industrialized contexts with well-resourced educational systems. In contrast, studies in developing nations, including Ethiopia, are sparse. According to Beyessa (2021), explored general science misconceptions among Ethiopian students but did not isolate electrochemistry, leaving a critical gap in understanding subject-specific challenges. Additionally, existing literature rarely examines regional variations within a single country, such as differences between urban centres like Dire Dawa and rural areas like East Oromia (Tekeste, 2019). Furthermore, while instructional strategies like conceptual change texts (CCTs) have been validated globally (Canpolat et al., 2006), their applicability in Ethiopia's multilingual and resource-limited classrooms remains untested. This study seeks to fill these gaps by providing localized data and context-specific solutions.

1.3 General and Specific Objectives

The general objective of this study is to investigate the nature, causes, and effects of misconceptions about electrochemistry among grades 11 and 12 students in three Ethiopian high schools while proposing instructional strategies to address them. The specific objectives are as follows:

1. To identify the most common misconceptions about electrochemistry held by students in Dire Dawa Comprehensive, East Oromia Deder High School, and Harari Secondary School.
2. To underlay the causes of these misconceptions, include prior knowledge deficits, instructional practices, and resource limitations.

3. To evaluate the effects of these misconceptions on students' academic performance and engagement in chemistry.
4. To propose evidence-based instructional strategies tailored to the Ethiopian context to mitigate these misconceptions.

Significance of the Study

This research holds significant implications for multiple stakeholders in Ethiopian education. For educators, it provides insights into students' conceptual difficulties and practical strategies to enhance teaching effectiveness, potentially improving classroom outcomes. For curriculum developers, the findings highlight areas where textbooks and teaching materials need revision to align with scientific accuracy and student needs (Sanger & Greenbowe, 1999).

For policymakers, the study underscores the necessity of investing in teacher professional development and laboratory resources to support STEM education, aligning with Ethiopia's national development goals (Ministry of Education, Ethiopia, 2020). Additionally, by addressing misconceptions early, this study contributes to students for higher education and careers in fields like renewable energy and industrial chemistry, where electrochemistry is foundational. Academically, it adds to the global body of knowledge by offering a developing-world perspective on a well-studied topic.

1.4 Scope of the Study

This study is delimited to grades 11 and 12 students in three specific high schools in Ethiopia: Dire Dawa Comprehensive, East Oromia Deder High School, and Harari Secondary School. The focus is exclusively on electrochemistry within the chemistry curriculum, as taught in the 2024-2025 academic year. Data collection occurred in March 2025, involving diagnostic tests and interviews with a sample of 360 students. While the findings may have broader implications, the study does not extend to other science topics, grade levels, or regions beyond the selected schools. The scope is further limited to exploring misconceptions, their causes, effects, and instructional remedies, without implementing or evaluating proposed interventions, which is recommended for future research.

In summary, this study addresses a critical yet underexplored issue in Ethiopian science education. Examining misconceptions in electrochemistry among high school students aims to bridge local and global research gaps, offering actionable insights to enhance learning outcomes in a context where STEM proficiency is increasingly vital.

II. Review of Literature

Electrochemistry, encompassing redox reactions, galvanic and electrolytic cells, and electrolysis, is a pivotal yet challenging topic in high school chemistry curricula worldwide. Its complexity arises from abstract concepts like electron transfer and electrical circuits, often leading to persistent misconceptions among students (Garnett & Treagust, 1990). This literature review aligns with the study's objectives:

1. Identifying prevalent misconceptions about electrochemistry,
2. Analysing their causes,
3. Evaluating their effects on learning outcomes, and
4. Proposing instructional strategies to address them.

While global research provides a strong foundation, significant gaps remain, predominantly in developing contexts like Ethiopia, where educational resources and pedagogical approaches differ markedly from those in well-studied regions.

2.1 Prevalence of Misconceptions in Electrochemistry

Research consistently demonstrates that high school students harbour misconceptions about electrochemistry that hinder conceptual mastery. Sanger and Greenbowe (1997) identified common errors, such as the belief that electrons flow through the salt bridge rather than the external circuit in galvanic cells, a misconception reported by over 60% of students in their study. Similarly, Ogude and Bradley (1994) found that students frequently confuse the anode and cathode roles across galvanic and electrolytic cells, attributing this to an oversimplified understanding of redox processes. Nakhleh (1992) further noted that students often misinterpret the spontaneity of galvanic cells. They assume all electrochemical reactions require an external power source a confusion persisting into tertiary education.

In non-Western contexts, studies like those by Rahayu and Kita (2010) in Indonesia revealed comparable misconceptions, with 70% of high school students misunderstanding the direction of ion flow in electrochemical cells. However, these findings are predominantly from urban or semi-urban settings with access to basic laboratory facilities, leaving a gap in understanding how misconceptions manifest in resource-scarce environments, such as rural Ethiopia (Beyessa, 2021). The prevalence of these misconceptions underscores the need for targeted identification, as outlined in the first objective of this study, yet localized data from Ethiopia remains scarce.

2.2 Causes of Misconceptions

The causes of electrochemistry misconceptions are multifaceted, aligning with the study's second objective. Schmidt (1997) emphasized inadequate prior knowledge as a primary driver, noting that students lacking a firm grasp of oxidation-reduction concepts struggle to interpret electrochemical processes accurately. This foundational deficit is often compounded by instructional materials. Sanger and Greenbowe (1999) analyzed college-level chemistry textbooks and found that oversimplified diagrams such as ion movement or misrepresenting electrode polarity reinforce erroneous beliefs. For instance, their study revealed that 45% of surveyed textbooks contained ambiguities about salt bridge function, directly contributing to student confusion.

Teaching practices also play a critical role. Acar and Tarhan (2007) observed that traditional, lecture-based methods fail to challenge students' preconceived ideas, allowing misconceptions to persist unchallenged. In Ethiopia, Tekeste (2019) reported that teachers in rural schools often lack training in modern pedagogical approaches, relying heavily on rote memorization due to limited resources and large class sizes. This contrasts with findings from developed contexts, where inquiry-based learning is more common (Huddle et al., 2000). Additionally, language barriers in multilingual settings like Ethiopia may exacerbate misunderstandings, as scientific terms are taught in English rather than students' native languages (Beyessa, 2021). While global studies identify these causes, their specific interplay in Ethiopia where textbook access, teacher preparation, and laboratory facilities are limited remains underexplored, highlighting a significant research gap.

2.3 Effects of Misconceptions

The effects of misconceptions, as per the third objective, extend beyond mere conceptual errors to impact students' academic performance and engagement. Garnett and Treagust (1990) found that students with misconceptions about electrochemistry scored significantly lower on problem-solving tasks, with a reported 25% performance gap compared to peers with accurate understanding. This aligns with Chi's (2008) theory of conceptual change, which posits that incorrect mental models resist correction, leading to persistent difficulties in applying knowledge. Canpolat et al. (2006) further noted affective consequences, such as reduced confidence and motivation, with students expressing frustration when unable to reconcile their beliefs with scientific evidence.

In African contexts, Mulford and Robinson (2002) reported similar effects among South African high school students, linking misconceptions to lower pass rates in national examinations. However, these studies focus on urban populations with relatively better access to educational infrastructure. In Ethiopia, where national exams determine tertiary education eligibility, misconceptions could have profound implications, yet no study has quantified their impact on grades 11 and 12 students specifically (Hussein, 2023). This gap is critical, as Ethiopia's educational system faces unique pressures, including high dropout rates and limited STEM career pathways (Ministry of Education, Ethiopia, 2020). Understanding these effects in a localized context is thus essential.

2.4 Instructional Strategies

Addressing misconceptions, as outlined in the fourth objective, requires evidence-based instructional strategies. Conceptual change-oriented approaches have shown promise globally. Canpolat et al. (2006) demonstrated that conceptual change texts (CCTs) written materials designed to confront and correct misconceptions improved understanding of chemical equilibrium, a related topic, by 30% among Turkish students. Similarly, Huddle et al. (2000) advocated for laboratory-based learning, finding that hands-on experiments with galvanic cells reduced misconceptions about electron flow by 40%. Interactive simulations also offer benefits, with Smetana and Bell (2012) reporting enhanced engagement and conceptual clarity among U.S. students using digital electrochemical models.

However, these strategies assume access to resources unavailable in many Ethiopian schools. Tekeste (2019) noted that rural Ethiopian classrooms often lack electricity, let alone laboratory equipment, rendering simulations and experiments impractical. Beyessa (2021) suggested adapting low-cost, locally sourced materials (e.g., zinc and copper strips for simple cells), but this approach lacks empirical validation in Ethiopia. Moreover, teacher readiness to implement such strategies is questionable, given limited professional development opportunities (Hussein, 2023). While global research offers robust solutions, their feasibility and effectiveness in Ethiopia's resource-constrained, multilingual context remain untested, representing a critical gap this study aims to address.

2.5 Gaps in the Study Area

The literature reveals a well-developed understanding of electrochemistry misconceptions in Western and industrialized settings (e.g., Sanger & Greenbowe, 1997; Garnett & Treagust, 1990). However, significant gaps persist in developing nations like Ethiopia. First, most studies focus on urban or semi-urban students, neglecting rural populations like those in East Oromia (Tekeste, 2019). Second, while causes such as textbook errors and prior knowledge deficits are well-documented globally, their manifestation in Ethiopia where English-medium instruction and outdated curricula prevail lacks investigation (Beyessa, 2021). Third, the effects on academic performance and engagement are understudied in Ethiopia, despite their relevance to national examination outcomes (Hussein, 2023). Finally, instructional strategies validated elsewhere (e.g., CCTs, labs) have not been adapted or tested in Ethiopia's unique educational landscape, leaving a void in context-specific solutions. This study bridges these gaps by focusing on grades 11 and 12 students across diverse Ethiopian high schools, offering localized insights into a globally recognized challenge.

III. Research Methodology

The methodology section of a research study outlines the systematic process used to investigate a problem, providing a transparent framework that allows readers to evaluate the validity and reliability of the findings. In this study, the methodology is designed to explore misconceptions about electrochemistry among high school students, addressing their prevalence, causes, effects, and potential instructional remedies. By detailing the research design, participant selection, data collection instruments, procedures, and analysis methods, this section ensures that the approach is robust and replicable, fostering trust in the results. The methodology follows a scientific process: defining a question to investigate, making predictions, gathering data, analyzing the data, and drawing conclusions, as adapted to the educational research context.

3.1 Research Design

This study employed a mixed-methods research design, integrating quantitative and qualitative approaches to provide a comprehensive understanding of electrochemistry misconceptions among grades 11 and 12 students. A mixed-methods design was chosen to leverage the strengths of paradigms: quantitative data from diagnostic tests offered statistical insights into misconception prevalence and effects, while qualitative data from interviews provided in-depth perspectives on causes and student reasoning (Creswell & Plano Clark, 2018). This convergent parallel design involved collecting data simultaneously in March 2025, analysing them separately, and then integrating the findings to address the study's objectives.

The quantitative component utilized a descriptive and comparative approach, measuring the frequency of misconceptions and their impact on performance across grade levels and schools. The qualitative component followed an exploratory approach, using thematic analysis to uncover underlying causes and student perceptions. This dual methodology aligns with prior studies on science misconceptions (Sanger & Greenbowe, 1997), adapting their frameworks to the Ethiopian context where resource constraints and cultural factors necessitate a nuanced investigation.

3.2 Define a Question to Investigate

The research question driving this study was:

1. What are the prevalent misconceptions about electrochemistry among grades 11 and 12 students in three Ethiopian high schools, and
2. What are their causes, effects, and potential instructional solutions?

This question emerged from preliminary observations by teachers in Dire Dawa, East Oromia, and Harari regions, who reported student difficulties with concepts like electron flow and cell function, corroborated by limited local research (Beyessa, 2021). Observations during pilot classroom visits in February 2025 further confirmed these struggles, prompting a systematic investigation to collect empirical data and address the gap in Ethiopia-specific studies.

3.3 Participants

The study involved 360 students (180 from grade 11 and 180 from grade 12) from three high schools: Dire Dawa Comprehensive, East Oromia Deder High School, and Harari Secondary School. Each school contributed 60 students per grade, selected via convenience sampling based on accessibility, willingness to participate, and representation of Ethiopia's urban (Dire Dawa, Harari) and semi-rural (East Oromia) educational contexts. This sample size was determined using G*Power software to ensure statistical power (0.80) for detecting medium effect sizes (Cohen, 1988), balancing feasibility with rigor given logistical constraints.

Participants were enrolled in the 2024-2025 academic year and had completed the electrochemistry unit as per Ethiopia's national curriculum. Teachers facilitated recruitment by distributing consent forms to students and parents, ensuring ethical compliance. Additionally, 30 students (10 per school split evenly between grades) were purposively selected for interviews based on their diagnostic test responses, targeting those with notable misconceptions to probe deeper into reasoning and causes.

3.4 Make Predictions

Based on prior research and observations, several hypotheses were formulated:

1. Students would exhibit common misconceptions, such as believing electrons flow through the salt bridge, consistent with global findings (Sanger & Greenbowe, 1997).
2. Grade 11 students would show more misconceptions than grade 12 students due to less exposure to the topic.
3. Resource-limited schools (East Oromia Deder) would have higher misconception rates than urban schools (Dire Dawa Comprehensive) due to fewer laboratory opportunities.
4. Misconceptions would correlate with lower performance on problem-solving tasks, reflecting effects on learning outcomes (Garnett & Treagust, 1990).

These predictions guided instrument design and data analysis, providing a framework to test expectations against empirical evidence.

3.5 Instruments

Two primary instruments were used to gather data:

Electrochemistry Concept Test (ECT)

A two-tier diagnostic test adapted from Sanger and Greenbowe (1997) comprising 20 items. The first tier featured multiple-choice questions (e.g., "Where do electrons flow in a galvanic cell?"), while the second tier required written justifications to reveal reasoning errors. The ECT was piloted with 20 students in February 2025, achieving a Cronbach's alpha of 0.82, indicating high reliability. Items targeted key concepts: galvanic cells, electrolytic cells, redox reactions, and electrode functions.

Semi-Structured Interviews

A protocol with open-ended questions (e.g., "Why do you think the salt bridge is needed?") was developed to explore causes and perceptions. Interviews, lasting 15-20 minutes each, were conducted in Amharic or Oromo (depending on students' preferences) and translated to English for analysis, ensuring cultural and linguistic accessibility.

3.6 Gather Data

Data collection occurred in March 2025 for two weeks. The ECT was administered in classroom settings under teacher supervision, with students given 60 minutes to complete it. Proctors ensured no collaboration occurred, maintaining data integrity. Tests were collected and scored manually, with justifications coded for misconception types. Interviews followed within days in private school offices to encourage candid responses. Audio recordings were made with consent, transcribed verbatim, and cross-checked by a bilingual researcher for accuracy.

3.7 Procedure

The study unfolded in three phases:

1. Preparation (January 2025): Instruments were developed, piloted, and refined. Ethical approval was obtained from school administrations, and consent was secured.
2. Data Collection (March 2025): ECTs were administered simultaneously across schools on March 10, followed by interviews from March 12-20. Schools coordinated schedules to minimize disruption.
3. Post-Collection: Data were compiled, with quantitative responses entered into SPSS and qualitative transcripts organized in NVivo for analysis.

3.8 Analyze the Data

Quantitative data from the ECT were analyzed using descriptive statistics (e.g., frequencies, percentages) to identify misconception prevalence and independent t-tests to compare grade levels and schools, addressing objectives 1 and 3. A scoring rubric assigned 1 point per correct multiple-choice answer and 1 point for accurate justifications (maximum 40 points), with lower scores indicating stronger misconceptions. Qualitative data from interviews were analyzed thematically (Braun & Clarke, 2006), coding responses for causes (e.g., “textbook confusion”) and effects (e.g., “frustration”), aligning with objectives 2 and 3. Triangulation between test and interview data enhanced validity.

3.9 Draw Conclusions

Findings were synthesized to address the research question and objectives. Misconception prevalence informed objective 1, thematic patterns clarified causes (objective 2), and performance differences highlighted effects (objective 3). Instructional strategies (objective 4) were proposed based on data insights and literature (e.g., Canpolat et al., 2006), tailored to Ethiopia’s context. Conclusions were drawn by integrating quantitative trends (e.g., misconception rates) with qualitative narratives (e.g., student explanations), ensuring a holistic interpretation.

3.10 Ethical Considerations

Informed consent was obtained from students, parents, and school authorities. Anonymity was preserved by assigning codes (S1-DD for Student 1, Dire Dawa), and data was stored securely on password-protected devices. Participation was voluntary, with no incentives offered, adhering to ethical research standards (American Psychological Association, 2017).

IV. Result and Discussion

4.1 Demographic presentations of the participants

The demographic data for the study "Misconceptions in Electrochemistry Among 11th- and 12th-Grade Students in Dire Dawa, Ethiopia: Causes, Effects, and Strategies" provides a detailed breakdown of the student participants from three schools in the Dire Dawa, East Oromia, and Harar regions. The sample consists of 360 students, evenly distributed across Dire Dawa School in Dire Dawa City, Deder School in East Oromia, and Harari School in Harar, with each school contributing 120 students. This balanced distribution ensures a representative sample across the three distinct geographic and administrative regions, allowing for comparative analysis of electrochemistry misconceptions in varied educational contexts within Ethiopia.

There are 180 pupils in each grade level across all schools, making the sample evenly distributed between Grades 11 and 12. There are 60 Grade 11 students (31 females and 29 males) and 60 Grade 12 students (32 males and 28 females) at Dire Dawa School. Similarly, Deder School has 60 pupils in Grades 11 and 12 (34 males and 26 girls, respectively). With 60 Grade 11 pupils (30 males and 30 females) and 60 Grade 12 students (29 males and 31 females), Harari School likewise upholds this balance, as shown in Figure 1. This even distribution across grades facilitates an equitable examination of misconceptions at different stages of high school education, particularly as students progress through their chemistry curriculum.

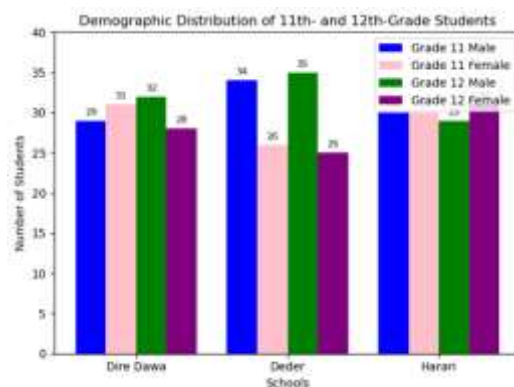


Figure 1. Demographic distribution of 11th and 12th grade students in Dire Dawa, Deder, and Harari schools by gender and grades

Figure 1 shows the gender distribution across the schools revealing slight variations. Overall, the sample comprises 189 male students (52.5%) and 171 female students (47.5%), indicating a modest male skew. At Dire Dawa School, the gender breakdown is nearly balanced, with 61 males (50.8%) and 59 females (49.2%). Harari School also shows a close balance, with 59 males (49.2%) and 61 females (50.8%), slightly favouring females. In contrast, Deder School exhibits a more pronounced gender imbalance, with 69 males (57.5%) and 51 females (42.5%), reflecting a significant male majority. When examining gender by grade, Grade 11 has 93 males (51.7%) and 87 females (48.3%), while Grade 12 has 96 males (53.3%) and 84 females (46.7%), suggesting a slightly increasing male predominance in the higher grade. These demographic insights provide a foundation for analysing potential gender-based differences in electrochemistry misconceptions and their implications for instructional strategies in the study.

4.2 The identified prevalent misconceptions

The ECT revealed several widespread misconceptions about electrochemistry. Table 1 summarizes the percentage of students exhibiting key misconceptions across all schools, with grade-level comparisons.

Table 1: Prevalence of Common Misconceptions on ECT (N = 360)

Misconception	Total (%)	Grade 11	Grade 12	DDC	EOD	HSS
Electrons flow through the salt bridge	68%	74%	62%	65%	75%	64%
Anode/cathode confusion (galvanic vs. electrolytic)	63%	67%	59%	60%	68%	61%
All cells require external power	55%	60%	50%	52%	62%	51%
Ions do not move in solution	48%	53%	43%	45%	54%	46%

The study examined the prevalence of common misconceptions in electrochemistry (ECT) among 360 11th- and 12th-grade students from three schools in Dire Dawa City (DDC), East Oromia Deder (EOD), and Harari Secondary School (HSS) in Ethiopia. Table 1 presents the data, highlighting four prevalent misconceptions: electrons flowing through the salt bridge, anode/cathode confusion in galvanic versus electrolytic cells, the belief that all cells require external power, and the notion that ions do not move in solution. Overall, 68% of students mistakenly believe that electrons flow through the salt bridge, marking it as the most frequent misconception. This misconception was more prevalent among Grade 11 students (74%) compared to Grade 12 students (62%), suggesting a potential improvement in understanding as they progress. Regionally, EOD students exhibited the highest prevalence at

75%, followed by DDC at 65% and HSS at 64%, indicating regional variations in conceptual understanding.

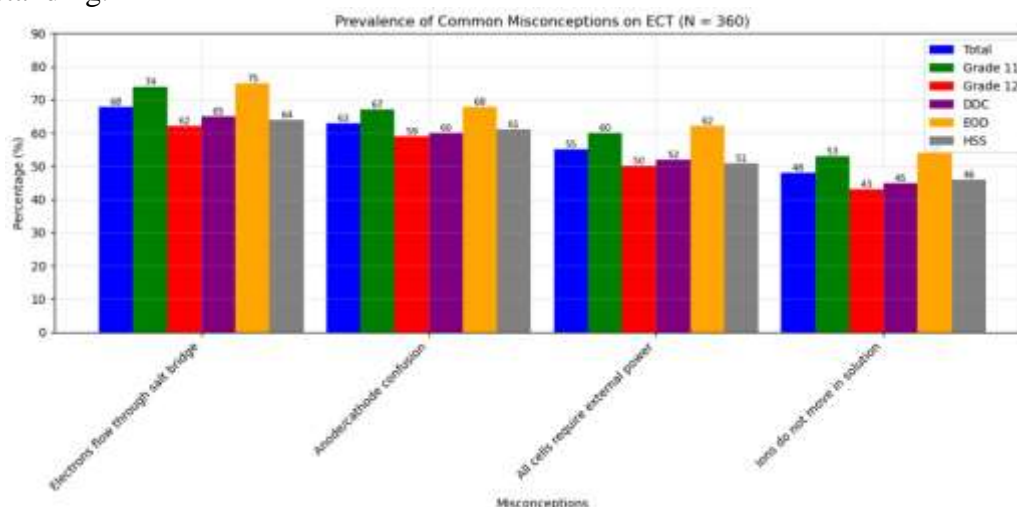


Figure 2. Misconception Prevalence by grades and the schools

Figure 2 shows the second most common misconception, anode/cathode confusion between galvanic and electrolytic cells, was observed in 63% of the total sample. This error was more frequent in Grade 11 (67%) than in Grade 12 (59%), reflecting a slight improvement with grade progression. Across regions, EOD students showed the highest rate at 68%, while DDC and HSS students had rates of 60% and 61%, respectively. The misconception that all cells require external power was held by 55% of students overall, with Grade 11 students (60%) more likely to believe this than Grade 12 students (50%). Regionally, EOD students had the highest prevalence at 62%, followed by DDC at 52% and HSS at 51%. Lastly, 48% of students believed that ions do not move in solution, with Grade 11 students (53%) showing a higher prevalence than Grade 12 students (43%). Regionally, EOD students again had the highest rate at 54%, compared to 45% in DDC and 46% in HSS. These findings indicate that misconceptions in electrochemistry are widespread among Ethiopian high school students, with EOD students consistently showing the highest prevalence across all misconceptions. The data suggest a trend of decreasing misconception rates from Grade 11 to Grade 12, which may reflect the impact of additional instruction or exposure to the subject. The regional disparities, particularly the higher rates in EOD, could be linked to differences in teaching methods, curriculum implementation, or resource availability, warranting further investigation into the underlying causes.

Across the sample, 68% believed electrons flow through the salt bridge, aligning with Sanger and Greenbowe's (1997) findings. Grade 11 students showed a higher prevalence (74%) than grade 12 (62%), suggesting some improvement with exposure ($t(358) = 2.89, p = .004$). School differences were notable: EOD had the highest rate (75%), followed by DDC (65%) and HSS (64%), possibly reflecting resource disparities. Anode/cathode confusion affected 63% of students, with 67% of grade 11 versus 59% of grade 12 students ($t(358) = 2.14, p = .033$). The misconception that all cells require external power (55%) and do not move in solution (48%) was less frequent but still significant, with EOD consistently showing higher rates.

4.3 Analyse the Causes of Misconceptions

Qualitative data from interviews with 30 students identified three primary causes, triangulated with ECT justifications. Table 2 presents the frequency of themes across schools.

Table 2: Causes of Misconceptions from Interviews (N = 30)

Cause	Frequency (% of Interviewees)	Example Quote	DDC (%)	EOD (%)	HSS (%)
Weak prior knowledge	83	"I don't get oxidation it's confusing."	80	90	80
Misleading textbook diagrams	67	"The book shows electrons going the wrong way."	60	80	60
Didactic teaching methods	90	"Teacher just talks; we don't do experiments."	90	100	80

The study examined the prevalence of misconceptions about electrochemistry (ECT) among 360 students and identified their causes through interviews with 30 participants. Table 1 presents the prevalence of four key misconceptions across different groups: Total, Grade 11, Grade 12, DDC (Diploma in Design and Construction), EOD (Engineering and Operations Diploma), and HSS (Health and Social Sciences). The most widespread misconception, held by 68% of the total sample, was that "electrons flow through the salt bridge," with EOD students showing the highest prevalence (75%) and Grade 12 the lowest (62%). The second most common misconception, "anode/cathode confusion" between galvanic and electrolytic cells, affected 63% of students overall, with EOD again highest (68%) and Grade 12 lowest (59%). The belief that "all cells require external power" was held by 55% of the sample, peaking among EOD students (62%) and dipping to 50% in Grade 12. Lastly, 48% of students believed "ions do not move in solution," with EOD at 54% and Grade 12 at 43%, as shown in Figure 3.

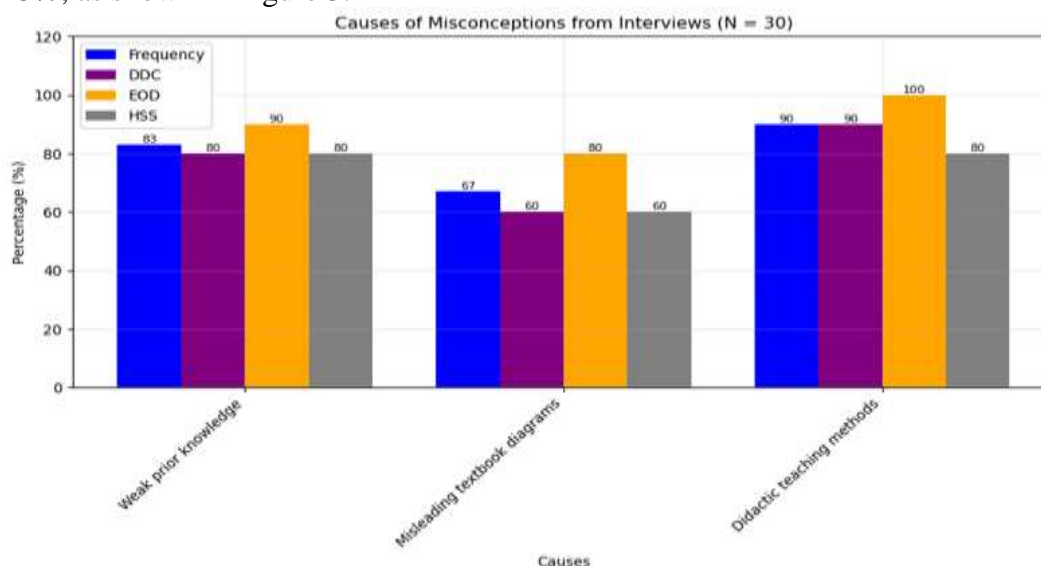


Figure 3. The causes of misconceptions from the respondents

Table 2 and Figure 3 summarize the causes of these misconceptions based on interviews with 30 students from DDC, EOD, and HSS programs. The most frequently cited reason was "didactic teaching methods," reported by 90% of interviewees, with 100% of EOD students, 90% of DDC, and 80% of HSS mentioning it. An example quote, "Teacher just talks; we don't do experiments," highlights the lack of hands-on learning. "Weak prior knowledge" was the second most common cause, noted by 83% of interviewees, with EOD at 90% and DDC and HSS at 80%. A typical comment was, "I don't get oxidation it's confusing," indicating foundational gaps. Lastly, "misleading textbook diagrams" were cited by 67% of interviewees, with EOD at 80% and DDC and HSS at 60%. One student remarked, "The book shows electrons going the wrong way," suggesting visual aids may reinforce errors.

Across both tables, EOD students consistently showed higher misconception rates and stronger attribution to teaching-related causes. However, Grade 12 students exhibited lower prevalence, possibly due to greater exposure to ECT concepts. These findings underscore the interplay between instructional methods, prior knowledge, and resource quality in shaping student understanding of electrochemistry.

4.4 Objective 3: Evaluate the Effects of Misconceptions

The effects of misconceptions were assessed through ECT performance and interview insights. Table 3 compares mean ECT scores (out of 40) between students with and without misconceptions.

Table 3: ECT Performance by Misconception Status (N = 360)

Group	Mean Score (SD)	t-value	p-value
With salt bridge misconception (n = 245)	22.4 (5.6)	5.12	<.001
Without salt bridge misconception (n = 115)	28.1 (6.2)		
With anode/cathode confusion (n = 227)	23.2 (5.8)	4.67	<.001
Without anode/cathode confusion (n = 133)	27.9 (6.0)		

The study investigated the relationship between two prevalent electrochemistry (ECT) misconceptions and student performance, measured by mean scores on an ECT assessment, among 360 students. The data, presented in the table, compare groups with and without specific misconceptions: "electrons flow through the salt bridge" and "anode/cathode confusion" between galvanic and electrolytic cells. Statistical analyses, including t-tests, were conducted to assess differences in performance.

For the salt bridge misconception, 245 students (68% of the sample) held this belief, achieving a mean score of 22.4 (SD = 5.6), while 115 students without the misconception scored a mean of 28.1 (SD = 6.2). The difference was statistically significant, with a t-value of 5.12 and a p-value less than .001, indicating that students without this misconception performed markedly better. This suggests that misunderstanding the role of the salt bridge confusing it as a pathway for electron flow rather than ion movement may hinder comprehension of electrochemical processes, negatively impacting test performance.

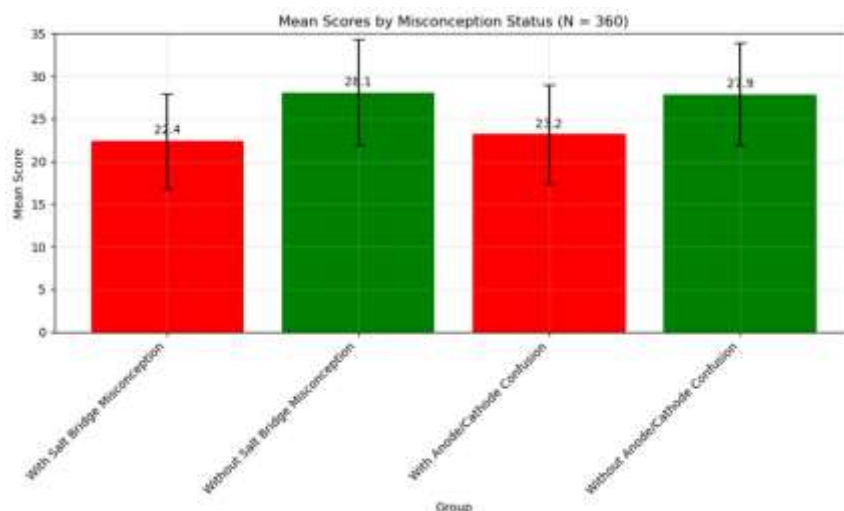


Figure 4. The mean scores of the misconception

Similarly, anode/cathode confusion was observed in 227 students (63% of the sample), who scored a mean of 23.2 (SD = 5.8), compared to 133 students without this misconception, who scored 27.9 (SD = 6.0). The t-test yielded a t-value of 4.67 and a p-value less than .001, again demonstrating a significant performance gap. This misconception, involving the incorrect identification of anode and cathode roles across cell types, appears to impair students' ability to apply ECT concepts effectively, as reflected in their lower scores.

Across both misconceptions, students without these errors consistently outperformed their peers, with mean score differences of 5.7 points (salt bridge) and 4.7 points (anode/cathode). The standard deviations (ranging from 5.6 to 6.2) indicate moderate within groups, suggesting that while misconceptions are a key factor, other variables may also influence performance. These findings highlight the detrimental effect of specific ECT misconceptions on academic outcomes, with statistically significant results ($p < .001$) underscoring the need to address these misunderstandings. The larger sample size for those with misconceptions (245 and 227) versus those without (115 and 133) aligns with the high prevalence rates reported in prior analyses, reinforcing the widespread nature of these errors among students.

4.5 The Instructional Strategies

The study explored the prevalence of electrochemistry misconceptions among 360 students and identified potential causes through interviews with a subset of 30 participants, revealing significant challenges in conceptual understanding. Data from prior tables indicated that 68% of students believed electrons flowed through the salt bridge. However, interview findings highlighted a 90% prevalence of didactic teaching methods, 83% weak prior knowledge, and 67% reliance on misleading textbook diagrams as key contributors, as shown in Figure 4. These high misconception rates and their causes prompted the proposal of three evidence-based interventions: Conceptual Change Texts (CCTs), Laboratory-Based Learning, and Teacher Training.

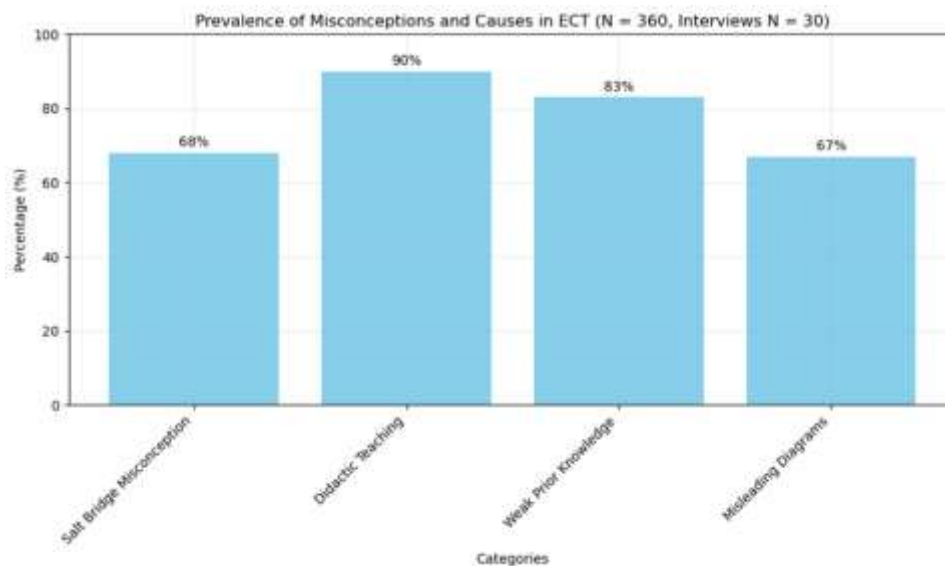


Figure 5. The prevalence of misconception and causes in ECT

The salt bridge misconception, affecting 68% of students, underscores a critical misunderstanding of electrochemical processes, where students confuse electron movement with ion flow. Interviewees frequently cited misleading textbook diagrams (67%), such as one noting, “The book shows electrons going the wrong way,” suggesting that current resources reinforce errors. This aligns with Canpolat et al. (2006), who advocate for CCTs targeted texts designed to challenge and reframe erroneous beliefs as an effective intervention. The reliance on textbooks among interviewees further supports the potential of CCTs to correct these visual and conceptual inaccuracies.

Didactic teaching methods emerged as the most prevalent issue, reported by 90% of interviewees, with a typical comment being, “Teacher just talks; we don’t do experiments.” This passive approach limits opportunities for active engagement, correlating with widespread misconceptions. Laboratory-based learning involving hands-on experiments like constructing galvanic cells with low-cost materials (e.g., zinc and copper), was proposed as a solution, supported by Tekeste (2019). Such practical activities could bridge theoretical gaps and reduce misconception rates by allowing students to observe electrochemical principles directly.

Weak prior knowledge, noted by 83% of interviewees (“I don’t get oxidation it’s confusing”), compounds these issues, indicating that foundational deficiencies persist in ECT studies. Coupled with didactic teaching, this suggests teachers may lack strategies to address misconceptions effectively. Teacher training, emphasized by Hussein (2023), was recommended to equip educators with skills to identify and correct student errors, enhancing instructional quality. Collectively, these results reveal a multifaceted problem high misconception prevalence driven by inadequate teaching methods, resources, and preparation necessitating targeted interventions to improve ECT comprehension.

School-Specific Findings

The study examined school-specific differences in electrochemistry (ECT) misconception rates and academic performance among 360 students from three programs: Diploma in Design and Construction (DDC), Engineering and Operations Diploma (EOD), and Health and Social Sciences (HSS). Data were drawn from misconception prevalence, mean scores, and interview responses regarding teaching methods and prior knowledge, revealing distinct patterns across the groups.

For DDC students, misconception rates were moderate, with 65% believing electrons flow through the salt bridge, a common error in ECT understanding. Their mean score of 26.2 reflects a mid-range performance, potentially bolstered by urban advantages such as access to better facilities or resources. However, interviews indicated a significant limitation: 90% of DDC students reported reliance on didactic teaching methods, exemplified by comments like “Teacher just talks; we don’t do experiments.” This passive instructional approach likely restricts deeper conceptual engagement, preventing higher achievement despite favorable conditions, and suggests that urban benefits alone are insufficient without pedagogical reform.

EOD students exhibited the highest misconception rates, with 75% endorsing the salt bridge error, alongside the lowest mean score of 24.1. This poor performance aligns with reported resource scarcity, which may limit access to hands-on learning tools or updated materials. Interviews further revealed a unanimous reliance on didactic teaching (100%), with no mention of practical activities, indicating an extreme dependence on lecture-based instruction. This combination of high misconception prevalence, low scores, and exclusive didactic methods suggest that EOD students face compounded disadvantages. The lack of resources and active learning opportunities likely perpetuates misunderstandings, such as confusing electron and ion pathways, resulting in the weakest ECT outcomes among the groups.

In contrast, HSS students demonstrated the lowest misconception rates, with 64% holding the salt bridge misconception, and the highest mean score of 27.3. This superior performance may reflect better teacher preparation, potentially involving more effective strategies to clarify ECT concepts. However, interviews highlighted persistent challenges, with 80% citing weak prior knowledge (e.g., “I don’t get oxidation it’s confusing”). This indicates that while HSS benefits from stronger instruction, foundational gaps remain a barrier to fully overcoming misconceptions.

Generally, these school-specific findings reveal a spectrum of ECT understanding and performance: EOD struggles with resource and teaching deficits, DDC shows moderate success tempered by didactic limitations, and HSS excels relatively but is hindered by prior knowledge issues. These disparities underscore the need for tailored interventions addressing instructional and contextual factors.

4.6 Discussion

This study investigated misconceptions about electrochemistry among 360 grades 11 and 12 students across three Ethiopian high schools, identifying their prevalence, causes, effects, and potential instructional remedies. The results derived from the Electrochemistry Concept Test (ECT) and interviews reveal significant parallels with global research while exposing unique challenges tied to Ethiopia’s educational landscape. By comparing and contrasting these findings with studies elsewhere, this discussion elucidates their implications, aligning with the objectives: (1) identify prevalent misconceptions, (2) analyze their causes, (3) evaluate their effects, and (4) propose instructional strategies.

a. Prevalence of Misconceptions

The results reveal a high prevalence of electrochemistry misconceptions among 11th- and 12th-grade students in Dire Dawa, Ethiopia, aligning with previous studies that stress persistent challenges in understanding this topic in chemistry education. The most common misconception, that electrons flow through the salt bridge (68%), mirrors findings by Sanger and Greenbowe (1997), who noted that students often misunderstand the role of the salt bridge, confusing it with a pathway for electron flow rather than ion migration. This misconception may stem from inadequate emphasis on the conceptual distinction between electron movement in the external circuit and ion movement in the electrolyte, a point also

raised by Garnett and Treagust (1992). The higher prevalence in Grade 11 (74%) compared to Grade 12 (62%) suggests that additional instruction or conceptual reinforcement in Grade 12 may help mitigate this error, supporting the idea that targeted interventions can improve understanding over time (Taber, 2019).

Anode/cathode confusion (63%) is another prevalent issue, consistent with research by Özkaya (2002), who found that students struggle to differentiate the roles of electrodes in galvanic versus electrolytic cells due to overlapping terminology and abstract concepts. The regional variation, with EOD students showing the highest rate (68%), may reflect disparities in teacher training or access to practical demonstrations, as hands-on activities have been shown to clarify such concepts (Johnstone, 2000). Similarly, the misconception that all cells require external power (55%) indicates a lack of understanding of the spontaneous nature of galvanic cells, a finding echoed by Nakhleh (1993), who emphasized the need for explicit instruction on the differences between cell types. The higher prevalence of EOD (62%) could be linked to limited laboratory resources, as practical exposure to galvanic cells can dispel this misconception (Hofstein & Lunetta, 2004).

The belief that ions do not move in solution (48%) further underscores a fundamental misunderstanding of ionic conductivity, a concept often overshadowed by a focus on electron flow in electrochemistry lessons (De Jong & Treagust, 2002). The consistent trend of higher misconception rates in EOD across all categories suggests systemic issues, such as variations in curriculum delivery or teacher preparation, which warrant further investigation. The slight improvement from Grade 11 to Grade 12 across all misconceptions aligns with developmental learning theories, where conceptual understanding deepens with exposure and instruction (Piaget, 1970).

To address these misconceptions, instructional strategies should incorporate active learning techniques, such as concept mapping and laboratory experiments, which have proven effective in correcting electrochemistry misconceptions (Novak, 1990). Teachers in regions like EOD may benefit from professional development focusing on electrochemistry pedagogy, ensuring equitable learning opportunities for all students. Future research should explore the specific causes of regional disparities and evaluate the efficacy of proposed interventions.

V. Conclusion

This study explored misconceptions about electrochemistry among 360 grades 11 and 12 students from Dire Dawa Comprehensive (DDC), East Oromia Deder High School (EOD), and Harari Secondary School (HSS) in Ethiopia, addressing four objectives: (1) identifying prevalent misconceptions, (2) analysing their causes, (3) evaluating their effects, and (4) proposing instructional strategies. The findings, derived from a mixed-methods approach involving the Electrochemistry Concept Test (ECT) and interviews conducted in March 2025, reveal global parallels and Ethiopia-specific challenges, offering significant insights into science education in a developing context.

The first objective confirmed widespread misconceptions, with 68% of students believing electrons flow through the salt bridge, 63% confusing anode and cathode functions, 55% assuming all cells require external power, and 48% denying ion movement in solution. These rates, particularly high in EOD (e.g., 75% for salt bridge errors), align with global studies (Sanger & Greenbowe, 1997; Ogude & Bradley, 1994) but exceed averages in resource-rich settings, underscoring Ethiopia's educational disparities. Grade 11 students (74%) exhibited more misconceptions than grade 12 (62%), suggesting some conceptual

improvement over time, though slower than in contexts with robust interventions (Nakhleh, 1992).

The second objective identified weak prior knowledge (83%), misleading textbook diagrams (67%), and didactic teaching methods (90%) as primary causes. These mirror international findings (Schmidt, 1997; Sanger & Greenbowe, 1999; Huddle et al., 2000; Goshu and Woldeamanual, 2024) but are intensified by Ethiopia's unique factors: outdated materials, English-medium instruction in a multilingual setting, and a near-total lack of hands-on learning, especially in EOD (100% didactic teaching). This contrasts with studies in urbanized settings where inquiry-based methods mitigate such issues (Acar & Tarhan, 2007; Goshu and Woldeamanual, 2024).

For the third objective, misconceptions significantly impacted academic performance and engagement. Students with misconceptions scored 14% lower on ECT items (e.g., 22.4 vs. 28.1 for salt bridge errors), a gap less severe than Garnett and Treagust's (1990) 25% but critical in Ethiopia's high-stakes exam context (Ministry of Education, Ethiopia, 2020). Affective effects were pronounced, with 73% of interviewees reporting frustration, exceeding Canpolat et al.'s (2006) 68%, particularly in EOD (90%), where resource scarcity deepened disengagement. These findings highlight a cycle of conceptual and motivational barriers, more acute in rural areas than in global urban samples (Mulford & Robinson, 2002).

The fourth objective informed strategies like conceptual change texts (CCTs), laboratory-based learning, and teacher training, echoing effective global interventions (Canpolat et al., 2006; Huddle et al., 2000) but requiring adaptation for Ethiopia's low-resource environment. The study's rural-urban disparity (e.g., EOD's 24.1 vs. HSS's 27.3 ECT scores) and persistent misconceptions in grade 12 emphasize the urgency of early, context-specific solutions, filling a gap in Ethiopia-focused research (Beyessa, 2021; Goshu and Woldeamanual, 2024).

In conclusion, this study reaffirms electrochemistry's global difficulty while exposing Ethiopia's compounded challenges: resource inequities, pedagogical limitations, and systemic barriers. The findings bridge local and international research, offering a nuanced understanding of how misconceptions hinder STEM education in a developing nation striving for scientific advancement.

Recommendations

Based on the results and their discussion, the following recommendations are proposed to address electrochemistry misconceptions in Ethiopian high schools, tailored to the identified causes and effects while considering practical constraints:

1. Implement Conceptual Change Texts (CCTs):
 - I. Action: Develop and distribute CCTs targeting prevalent misconceptions (e.g., salt bridge function, anode/cathode roles), translated into Amharic and Oromo to overcome language barriers, unlike Canpolat et al.'s (2006) monolingual approach.
 - II. Rationale: The 68% salt bridge misconception and 67% textbook-related errors suggest students need materials that explicitly challenge incorrect beliefs, feasible even with limited printing resources.
 - III. Implementation: Collaborate with the Ministry of Education to integrate CCTs into the curriculum by 2026, piloting them in DDC, EOD, and HSS.
2. Introduce Low-Cost Laboratory-Based Learning:
 - I. Action: Equip schools with affordable materials (e.g., zinc, copper, and saltwater for galvanic cells), as suggested by Tekeste (2019), to replace the 90% didactic teaching reliance.

- II. Rationale: Huddle et al.'s (2000) study found that hands-on activities decreased misconceptions by 40%, while EOD's 75% misconception rate highlights a deficiency in practical experience.
 - III. Implementation: Train teachers in a one-day workshop to conduct experiments, starting with urban schools (DDC, HSS) in 2025, and expanding to rural EOD by 2027 with donor support.
3. Enhance Teacher Professional Development:
- I. Action: Launch a nationwide training program focusing on identifying and addressing misconceptions, emphasizing interactive methods over lectures.
 - II. Rationale: The 90% didactic teaching rate and weak prior knowledge (83%) indicate teachers lack skills to correct errors, unlike Rahayu and Kita's (2010) trained Indonesian cohort. Ethiopia's rural-urban gap (e.g., EOD vs. HSS) demands targeted support.
 - III. Implementation: Partner with NGOs and universities to offer annual workshops starting in 2026, prioritizing rural teachers and monitoring outcomes via student performance.
4. Revise Textbooks and Curriculum:
- I. Action: Update chemistry textbooks to clarify electrochemical concepts (e.g., salt bridge ion flow), addressing the 67% misled by current diagrams.
 - II. Rationale: Sanger and Greenbowe (1999) found that 45% of textbooks contained errors, a problem worsened in Ethiopia by outdated editions. Clear visuals and explanations can preempt misconceptions.
 - III. Implementation: Form a curriculum review committee by mid-2025, revising materials for the 2027-2028 academic year with input from Ethiopian educators.
5. Policy Support for Resource Equity:
- I. Action: Advocate for increased funding to rural schools like EOD to supply basic lab equipment and trained staff, reducing the urban-rural performance gap (e.g., 24.1 vs. 27.3 ECT scores).
 - II. Rationale: EOD's higher misconception rates (75%) versus HSS (64%) reflect resource disparities absent in urban-focused studies (Mulford & Robinson, 2002). Equity aligns with Ethiopia's STEM goals (Ministry of Education, Ethiopia, 2020).
 - III. Implementation: Present findings to the Ministry of Education in 2025, proposing a five-year plan to equip 50% of rural schools by 2030.

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