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A Content Analysis of Chemical Representations in Voltaic Cells Concept on General Chemistry Textbooks

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ABSTRACT

Chemistry learning requires the integration of macroscopic, submicroscopic, and symbolic representations. In topics like voltaic cells, textbooks often fail to connect these levels coherently. This study aims to evaluate the quality and integration of chemical representations related to voltaic cells in general chemistry textbooks used in Indonesian undergraduate programs. A qualitative descriptive approach was employed through content analysis using a rubric that includes five criteria: representation type, interpretation of surface features, relatedness to text, caption quality, and correlation among multiple representations. Five widely used textbooks were selected through purposive sampling. The findings revealed that while all textbooks presented macroscopic and symbolic representations, submicroscopic depictions were often incomplete or absent. In addition, several representations lacked clear labeling, informative captions, and strong text–image connections, which may hinder students' conceptual understanding. Only a few textbooks, such as Whitten and Silberberg, effectively combined multiple levels within a single visual. The study concludes that textbook representations must be pedagogically purposeful, well-integrated, and visually clear to support meaningful learning of electrochemical concepts.

1. Introduction

Chemistry is the science that studies matter, its properties, the changes it undergoes, and the energy changes that occur during these processes (Whitten et al., 2013). Understanding chemistry requires a way of thinking that involves interconnected levels of representation (Langitasari, 2016). These levels are categorized as macroscopic, submicroscopic, and symbolic (Chandrasegaran et al., 2007; Johnstone, 2000). The macroscopic level relates to observable chemical phenomena experienced in everyday life, such as color changes and the formation of gases or precipitates. The submicroscopic level describes phenomena that are not visible, involving atoms, molecules, ions, and their structures. Meanwhile, the symbolic level represents these phenomena through symbols, chemical equations, molarity, graphs, and pictorial representations (Chandrasegaran et al., 2007; Johnstone, 2000; Treagust et al., 2003)

Many students struggle to fully understand chemistry because they are unable to integrate these three levels of representation (Johnstone, 2000; Treagust et al., 2003b). They tend to rely heavily on the macroscopic level, as it is directly observable and relatable (Upahi & Ramnarain, 2019). In contrast, the submicroscopic level is often difficult to comprehend due to its abstract and intangible nature (Chittleborough & Treagust, 2008). According to Üce & Ceyhan (2019), this incomplete understanding, along with students' inability to connect between representational levels, leads to misconceptions and difficulties in constructing new concepts. One chemistry topic that frequently lead to misconceptions is voltaic cells (Asnawi et al., 2017; Dewata & Melyanti, 2011; Dindar et al., 2010; Dorsah & Yaayin, 2019; Huddle et al., 2000; Nisa & Fitriza, 2021). Misconceptions often occur in several aspects of voltaic cells, such as the electron transfer processes, the position and direction of electron flow, oxidation and reduction reactions, the role of the salt bridge, and the functions of the anode and cathode.

These misconceptions can be reduced through several approaches, one of which involves the use of accurate chemical representations in instructional materials, such as textbooks (Hasanah et al., 2024). Upahi & Ramnarain (2019) emphasized that visual representations in textbooks support meaningful learning by helping students visualize abstract phenomena. Therefore, textbooks play a crucial role in the learning process (Blongkod et al., 2022). However, previous studies have shown that many textbooks still contain misconceptions, particularly in topics such as electrochemistry (Sanger & Greenbowe, 1999). Moreover, most chemistry textbooks disproportionately focus on the symbolic level, often at the expense of adequately integrating macroscopic and submicroscopic representations (Addiin & Masykuri, 2016; Mar & Sanchez, 2017). In response, a chemical representational analysis is needed to inform the development of textbooks that more effectively support students' conceptual understanding.

Several previous studies have analyzed various chemistry topics in textbooks. For instance, Chen et al. (2019) analyzed redox reactions in secondary school textbooks used in Chinese communities. Demirdöğen (2017) examined various topics including chemical reactions, properties of substances, amount of substance, and gas laws. Fadila & Qurrata Aini (2025) studied chemical representations of chemical bonding in Kurikulum Merdeka textbooks. Similarly, Hasanah et al. (2024) focused on general chemistry textbooks, while Septiani & Qurrata Aini (2025) explored the topic of acids and bases. In the context of voltaic cells, Sanger & Greenbowe (1999) examined misconceptions in general chemistry textbooks, while Shin et al. (2002) evaluated the conceptual accuracy of high school science textbooks.

Unlike previous studies that focused either on general misconceptions or on specific representation levels in other topics, this study explores the quality and integration of all three representational levels in the context of voltaic cells. Therefore, the objective of this study is to evaluate the quality and integration of chemical representations related to voltaic cells in general chemistry textbooks used in Indonesian undergraduate programs, particularly in terms of how macroscopic, submicroscopic, and symbolic levels are presented and connected. This evaluation is important, as well-designed representations can help students build coherent mental models of abstract electrochemical processes. Clarifying how such representations are constructed and connected can provide insights for improving future textbook visuals in chemistry education.

2. Methodology

Research Design

This study used a descriptive generic qualitative research approach to explore and understand phenomena, processes, or perspectives related to a particular issue (Merriam, 1998). This type of research is characterized by its emphasis on meaning-making, with the researcher actively engaged in both data collection and analysis, aiming to produce comprehensive and in-depth descriptions. In this study, the descriptive approach was used to explore chemical representations in General Chemistry textbooks through content analysis. According to Fraenkel et al. (2012), content analysis seeks to understand human behavior by analyzing communication expressed through textbooks, essays, newspapers, political speeches, and images. In this study, the representations were categorized to examine what conceptual information they aim to communicate in the analyzed textbooks. Although primarily qualitative, the content analysis also incorporated quantitative elements, as the identified chemical representations were classified and examined based on their percentage of occurrence.

Sample

Fraenkel et al. (2012) emphasized that developing a sampling plan is essential in content analysis. In this study, purposive sampling was used. The textbooks analyzed in this research include Brown et al. (2009) (A); Silberberg S (2007) (B); Chang R & Overby J (2019) (C), Zumdahl S & Zumdahl L (2010) (D); Whitten et al. (2013) (E). These textbooks were chosen because they serve as primary references for School Chemistry and General Chemistry courses at the Universitas Pendidikan Indonesia as documented in the Semester Learning Plans (RPS) used to guide instruction in the chemistry education program.

Instrument

In this study, an assessment rubric developed by Gkitzia et al. (2011) was used. This rubric is designed to evaluate chemical representations found in textbooks. Several previous studies have also employed this rubric to analyze chemical representations in textbooks, including those by Chen et al. (2019); Demirdöğen (2017); Fadila & Qurrata Aini (2025); Septiani & Qurrata Aini (2025); al. (2007); Chandrasegaran et al. (2007). In this study, the rubric was applied to analyze representations found in selected General Chemistry textbooks to enable systematic classification and interpretation of their characteristics. The rubric includes five key criteria: type of representation, interpretation of surface features, relatedness to text, existence and properties of a caption, and degree of correlation between the components comprising a multiple representation. Table 1 shows the criteria and typology of representations according to Gkitzia et al. (2011)

Table 1. Criteria and Typology of Chemical Multirepresentation

	Criteria		Typology for each criterion
C1	Type of representation	i	Macroscopic
		ii	Submicroscopic
		iii	Symbolic
		iv	Multiple
		v	Hybrid
		vi	Mixed
C2	Interpretation of surface features	i	Explicit
		ii	Implicit
		iii	Ambiguous
C3	Relatedness to text	i	Completely related & linked
		ii	Completely related & unlinked
		iii	Partially related & linked
		iv	Partially related & unlinked
		v	Unrelated
C4	Existence and properties of a caption	i	Appropriate
		ii	Problematic
		iii	No caption
C5	Degree of correlation between the components comprising a multiple representation	i	Sufficiently linked
		ii	Insufficiently linked
		iii	Unlinked

(Gkitzia et al., 2011)

The first criterion (C1) in the rubric developed by Gkitzia et al. (2011) focuses on the types of representations, which include macroscopic, submicroscopic, symbolic, multiple, hybrid, and mixed form. The macroscopic (i), submicroscopic (ii), and symbolic (iii) types align with the classifications proposed by Johnstone (2000); Treagust et al. (2003b); Chandrasegaran et al. (2007). A representation is considered multiple (iv) when it simultaneously presents two or three levels of chemical understanding, with each level depicted separately. In contrast, a hybrid (v) representation integrates features from two or three levels into a single, cohesive image. A mixed representation (vi) refers to a combination of one level of chemical representation with another form of depiction, such as an analogy.

The second criterion (C2), interpretation of surface features, assesses the clarity of meaning in a representation, particularly whether the surface features are clearly labeled. Representations are categorized as explicit (all surface features clearly labeled) (i), implicit (only some labeled) (ii), or ambiguous (none labeled) (iii). The third criterion (C3), relatedness to the text, evaluates how clearly and logically a representation corresponds to the accompanying text. This criterion has five categories. A representation is completely related (i, ii) if it accurately illustrates the exact content discussed in the text. If it is relevant to the general topic but not to specific content, it is considered partially related (iii, iv). Representations with no connection to the text are considered unrelated (v). This criterion also considers the presence of textual references to the representation: when the text explicitly directs the reader to it (e.g., "as shown in the figure"), it is categorized as linked (I, iii); otherwise, it is unlinked (ii, iv).

The fourth criterion (C4), existence and properties of a caption, examines whether a representation is accompanied by a caption and whether the caption is appropriate. There are three categories: existence of an appropriate caption (clear, concise, and enables students to understand the representation without necessarily referring to the main text) (i), problematic caption (ii), and no caption (iii). The fifth criterion (C5), degree of correlation between the components (subordinate representations) comprising a multiple representation, applies only to representations identified as multiple under the first criterion. It assesses how clearly the relationship between the components is shown, specifically, whether individual parts are visually connected and indicate equivalence in their surface features. The categories are: sufficiently linked (clear relationships among components) (i), insufficiently linked (only some relationships shown) (ii), and unlinked (no clear connections) (iii).

Data Collection

Data were collected through content analysis of selected General Chemistry textbooks. The study focused on specific subtopics of voltaic cells that were aligned with the intended learning outcomes: the working principles of voltaic cells, as well as the spontaneity of electrochemical reactions. Only representations related to these subtopics were selected for further analysis.

Data Analysis

The extracted representations were analyzed using the rubric previously described (Gkitzia et al., 2011). Initial coding was carried out by the researcher and then refined through a Focus Group Discussion (FGD) with three chemistry education experts, each specializing in analytical chemistry, physical chemistry, and chemical education. This discussion served as a form of expert triangulation to enhance the credibility and accuracy of the interpretation. Although the study adopted a qualitative approach, frequencies and percentages were calculated to describe patterns in the types and functions of representations, strengthening the study's confirmability and dependability.

3. Results and Discussion

Research Results

A total of 21 visual representations related to voltaic cells were identified across five general chemistry textbooks. Table 2 presents the results of the qualitative analysis, detailing the concepts presented, figure descriptions, and the classification of representation criteria based on Gkitzia et al. (2011).

Table 2. Results of Analysis of Representations in Five Chemistry Textbooks Based on Chemical Representation Criteria

Book	Concept	Figure	C1	C2	C3	C4	C5
A	Spontaneous reaction	20.3	i, ii, iii, iv	ii	i	i	i
	Voltaic cells (using porous disc)	20.4	i, iii	ii	iii	ii	-
	Voltaic cells (using salt bridge)	20.5	i, ii, iii, iv, v	ii	iii	ii	i
	Voltaic cells (using porous disc)	20.6	i, ii, v	ii	iii	ii	-
B	Spontaneous reaction	21.4	i, ii, iii, iv	ii	iii	i	i
	Voltaic cells (using salt bridge)	21.5A	i, ii, iii, iv	i	i	i	i
	Voltaic cells (higlighting changes in metals)	21.5B	i	iii	iii	i	-
	Voltaic cells (using inert metals)	21.6	i, ii, iii, v	ii	i	ii	-
C	Spontaneous reaction (using Zn-$CuSO_4$)	4.10A	i, ii, iii, iv	ii	iii	i	i
	Spontaneous reaction (using Cu-$AgNO_3$)	4.10B	i, ii, iii, iv	ii	v	i	i
	Voltaic cells	18.1	i, ii, iv, v	ii	i	ii	i
D	Voltaic cells	18.1	i, iii, iv	ii	i	i	ii
		18.2	i, ii, iii, iv, v	iii	i	i	ii
		18.3	i, ii, iii, iv, v	iii	iii	i	ii
		18.4	i, ii	ii	iii	i	-
		18.5	i, ii, iii, v	ii	i	ii	-
E	Voltaic cells (using $CuSO_4$/$ZnSO_4$)	21-6	i, ii, iii, iv, v	iii	i	ii	i
	Spontaneous reaction (using Zn-$CuSO_4$)	Un-named-A	i	ii	iv	i	
	Spontaneous reaction (using Cu-$ZnSO_4$)	Un-named-B	i	ii	v	i	-
	Voltaic cells (using $CuSO_4$/$AgNO_3$)	21-7	i, ii, iii, iv, v	i	i	ii	i
	Spontaneous reaction (using Cu-$AgNO_3$; Ag-$CuSO_4$)	Un-named	i, ii, iii, iv	ii	iv	iii	i

To support these qualitative findings, Table 3 provides a quantitative summary of the percentage distribution for each representation criterion across the textbooks. This overview highlights patterns and tendencies in how the multiple levels of chemical representation are integrated and presented.

Table 3. Percentage Distribution of Representation Categories Based on Gkitzia's Criteria

Criteria	Tipology	Percentage of Chemistry Textbook Typology (%)				
		A	B	C	D	E
Type of representation	i	100	100	100	100	100
	ii	75	75	100	80	60
	iii	75	75	67	80	60
	iv	50	50	100	60	60
	v	50	25	33	60	40

	vi	0	0	0	0	0
Interpretation of surface features	i	0	25	0	0	20
	ii	100	50	100	60	60
	iii	0	25	0	40	20
Relatedness to text	i	25	50	33	60	40
	ii	0	0	0	0	0
	iii	75	50	33	40	0
	iv	0	0	0	0	40
	v	0	0	33	0	20
Existence and properties of a caption	i	25	75	67	80	40
	ii	75	25	33	20	40
	iii	0	0	0	0	20
Degree of correlation between the components comprising a multiple representation	i	100	100	100	0	100
	ii	0	0	0	100	0
	iii	0	0	0	0	0

Discussion

This analysis is guided by the aim of evaluating both the representational quality (such as clarity of labeling, captions, and text-image linkage) and the integration of the three levels of chemical representation levels proposed by Johnstone (macroscopic, submicroscopic and symbolic). These aspects are essential for promoting students' conceptual understanding, as fragmented or unclear representations may hinder their ability to mentally connect macroscopic phenomena with submicroscopic processes and symbolic notations. Such difficulties can contribute to persistent misconceptions, especially when visual materials fail to effectively support meaning-making across representational levels.

1st Criterion (C1): Types of Representation

The analysis showed that most textbooks examined in this study incorporate macroscopic-level representations to illustrate spontaneous redox reactions, with the notable exception of Zumdahl's textbook, which omits this foundational concept. A consistent pattern emerged across the sources: each book features a visual depiction of a zinc strip being placed into a copper(II) sulfate solution. These illustrations commonly include both initial and final conditions, allowing learners to observe changes such as the formation of a metallic deposit and the fading of solution color, hallmarks of redox processes observable at the macroscopic level.

In several textbooks, such as Chang (Figure 4.10B) and Whitten (Unnamed Figure), the macroscopic representation extends beyond the Zn–$CuSO_4$ system by including additional examples, such as copper immersed in silver nitrate. This broader range of cases may help students generalize the concept of redox spontaneity beyond a single reaction. Moreover, Whitten explicitly contrasts spontaneous and non-spontaneous reactions by including an example where copper is placed in zinc sulfate, showing no observable change. This comparative strategy supports learners in distinguishing conditions under which redox reactions do or do not occur spontaneously. Providing both positive and negative cases, spontaneous and non-spontaneous, strengthens the representational value at the macroscopic level. It helps prevent overgeneralization and encourages deeper conceptual understanding, particularly for students who often rely on directly observable cues.

Beyond spontaneous reactions, macroscopic representations of voltaic cells are also featured in all analyzed textbooks, with varying levels of visual clarity and contextual support. Brown consistently displayed macroscopic diagrams in both photographic and animated forms, incorporating $CuSO_4/ZnSO_4$ cells with porous discs (Figures 20.4 & 20.6) and salt bridges (Figure 20.5). Silberberg (Figures 21.4–21.6) also featured Daniell cells, but uniquely included configurations with inert electrodes (e.g., carbon) and different electrolytes (I^- and MnO_4^- in acid), offering a broader example that may help prevent the misconception that the electrode must match the ion in solution. However, similar to Chang and Whitten, Silberberg did not present porous disc configurations, potentially reinforcing the idea that ion transfer in voltaic cells occurs exclusively via salt bridges. Additionally, Silberberg, Zumdahl, and Whitten relied exclusively on animated illustrations at the macroscopic level, which may reduce the representational authenticity and disconnect students from real-life experimental observations.

Zumdahl provided both salt bridge and porous disc setups, but his macroscopic representations were less explicit. Rather than depicting specific observable phenomena, the images were embedded within a conceptual narrative progression, which, while structurally coherent, may limit clarity at the macroscopic level. According to Johnstone's triangle (Johnstone, 2000), anchoring understanding in tangible macroscopic phenomena is essential before progressing to submicroscopic and symbolic levels. Therefore, Zumdahl's narrative-heavy approach may hinder students' ability to concretely visualize the phenomena involved.

The analysis shows that not all textbooks incorporate submicroscopic representations in their presentation of spontaneous redox reactions. This finding aligns with Upahi & Ramnarain (2019) who emphasized that students tend to rely heavily on macroscopic features, partly due to the absence of submicroscopic content. As noted by Chittleborough & Treagust (2008), the abstract and intangible nature of submicroscopic concepts often hinders student comprehension. To reduce misconceptions, it is essential that textbooks integrate submicroscopic representations consistently and explicitly.

Among the textbooks analyzed, Brown (Figure 20.3), Silberberg (Figure 21.4), and Chang (Figure 4.10A) successfully presented submicroscopic processes in both text and visuals. These include the oxidation of Zn to Zn^{2+}, the reduction of Cu^{2+} to Cu, and electron transfer between species, with visualizations that support conceptual understanding. Chang's Figure 4.10B, although lacking textual explanation, provided labelled submicroscopic visuals that depict the transformation of Ag^+ to Ag and Cu to Cu^{2+}. Similarly, Whitten's unnamed figures offered submicroscopic explanations for both Zn–$CuSO_4$ and Cu–$AgNO_3$ reactions, describing electron flow and redox changes either in the text or imagery. In contrast, Zumdahl's textbook did not include submicroscopic representations of spontaneous redox reactions, consistent with its broader narrative-driven style discussed earlier. The absence of submicroscopic content in some representations may contribute to students' incomplete understanding of redox processes at the particulate level, reinforcing the need for instructional materials that visualize chemical phenomena beyond observable effects.

The analysis of submicroscopic representations of voltaic cells revealed varying degrees of completeness and clarity across the textbooks, particularly in terms of visual representation as emphasized in Gkitzia et al. (2011). Since submicroscopic phenomena involve abstract entities such as ions, atoms, and electron movement, reliance solely on textual descriptions (as seen in some cases) is insufficient for meaningful learning. Visual representation is critical to help students conceptualize invisible processes.

Among the textbooks, Whitten provides the most comprehensive submicroscopic representations. Figures 21-6 and 21-7 clearly illustrate oxidation–reduction at electrodes, electron flow, and ion migration within the salt bridge, supported by text explanations clarifying the role of Cl^- and K^+ in maintaining electrical neutrality. Silberberg (Figures 21.5–21.6) also presents strong particle-level visuals, including varied electrolytes and inert electrodes, enhancing contextual understanding. Chang (Figure 18.1) similarly integrates submicroscopic level with consistent textual support. In contrast, Brown delivers fragmented coverage: Figure 20.6 shows ion and electron movement effectively, Figure 20.4 lacks visual representation and relies solely on text, while Figure 20.5 offers only partial integration. Zumdahl adopts a narrative-driven approach; although Figures 18.2, 18.3, and 18.5 include visual cues of ion and electron flow, inconsistent visual–textual alignment and the absence of clear submicroscopic detail in Figure 18.4 may hinder student understanding.

Overall, only a few textbooks, particularly Whitten, Silberberg, and Chang, offer well-developed submicroscopic visualizations of voltaic cells. Their accurate representations at the submicroscopic level are essential for understanding electrochemical processes. This highlights the importance of consistent visual support in facilitating students' understanding of abstract electrochemical phenomena. In contrast, textbooks that rely on narrative descriptions or omit visual representations altogether may hinder students' ability to comprehend redox reactions at the particulate level.

At the symbolic level, all the textbooks analyzed incorporate symbolic representations, though primarily in the form of chemical equations. Gkitzia et al. (2011) pointed out that relying solely on chemical equations can hinder students' ability to fully grasp and interpret the underlying chemical phenomena. As emphasized by Gilbert & Treagust (2009), effective submicroscopic representations are essential to complement symbolic forms, providing the necessary context for students to develop a coherent understanding of chemical processes.

The macroscopic, submicroscopic, and symbolic levels are mostly presented in multiple forms, with only a few instances of hybrid forms. Multiple representations typically connect the macroscopic level (phenomena) with the submicroscopic level (the redox reaction process) using arrows or layout structure. In contrast, hybrid representations are usually found in the integration of the macroscopic phenomena with the submicroscopic level, such as the depiction of ion flow within the salt bridge. Mixed representations, however, are not found in any of the textbooks. The representations used in these textbooks are entirely literal and formal, without employing narrative or analogical visual approaches. This absence suggests that authors prioritize direct scientific exposition over pedagogical strategies that might help students bridge representational levels through analogical reasoning. Figure 1 illustrates an example from Whitten's textbook that combines multiple and hybrid representations. It simultaneously presents the macroscopic apparatus of a voltaic cell, submicroscopic views of redox changes at each electrode, and symbolic chemical equations, thereby exemplifying both representational forms.

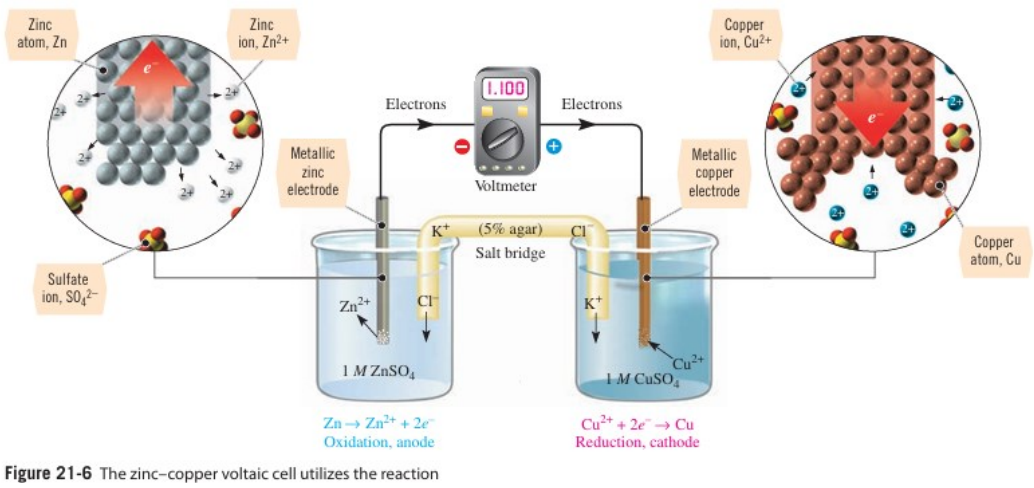
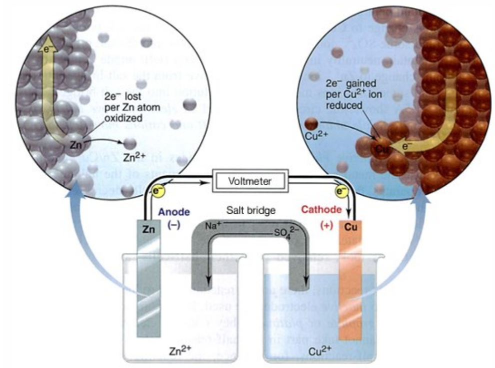


Figure 1. Example of Macroscopic, Submicroscopic, Symbolic Representations Combined to form Multiple and Hybrid Representations

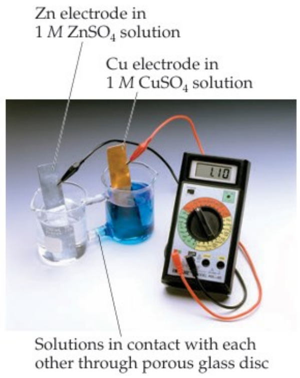
2nd Criterion (C2): Interpretation of Surface Features

This analysis corresponds to Criterion 2 of the Gkitzia et al. (2011) rubric, which evaluates the clarity of surface features such as labeling. Based on the analysis, textbooks contain more implicit labels than explicit ones. In contrast, only a few books include representations that fall into the ambiguous category. According to J. Gilbert & Treagust (2009), students often struggle to understand the intended message of a representation. Therefore, when visual information is minimal or entirely absent, the potential for misconceptions increases significantly.

Figure 2 presents examples of both explicit (a) and implicit (b) representations. In Figure 2 (a), the author provides clear labels for every component shown in the diagram. This allows students to understand all parts of the voltaic cell and the processes occurring within it, even though the system is complex. In contrast, Figure 2 (b) includes labels for the solutions, metals, and the porous disc, but does not label the voltaic cell as a whole. This omission may lead to the misconception that the voltmeter is not part of the voltaic cell system.



(a)



(b)

Figure 2. (a) Example of Explicit Representations, (b) Example of Implicit Representatinions

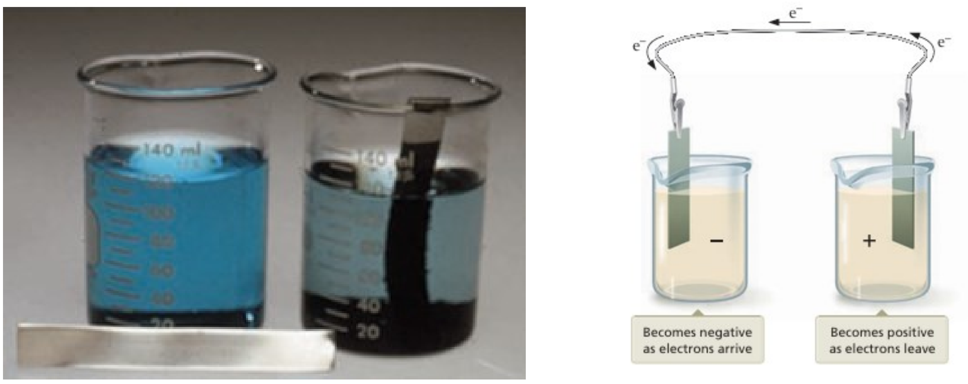
3rd Criterion (C3): Relatedness to text

The analysis of the third criterion based on Gkitzia's rubric shows that half of the textbooks fall into the categories of completely related and linked and partially related and linked, while a small portion are categorized as partially related and unlinked or unrelated. Ideally, textual explanations and accompanying images should be fully related in order to support students' comprehensive understanding of chemistry. This is supported by Wu & Shah (2004), who emphasized that text and images should be placed in close proximity to facilitate comprehension. Moreover, representations should be explicitly linked, as unlinked visuals may confuse students about which image the text is referring to.

Figure 3 (a) illustrates an example of a partially related and unlinked text-image relationship. The accompanying text describes the process that occurs during a spontaneous redox reaction between zinc and copper(II) sulfate, mentioning that the solution fades in color and the zinc strip becomes coated with a dark brownish layer. However, since the image does not depict the process described, students may struggle to interpret it correctly. Moreover, the text does not include a linking phrase such as *"see Figure A"*, which can further confuse students about which phenomenon is being discussed.

While Figure 3 (a) is an example of a partially related and unlinked representation, there are also cases where the text and image are completely related and linked, yet may still lead to potential misconceptions due to the way the explanation is phrased. For example, in Figure 3 (b), the text states that electrons move from the Fe^{2+} compartment to the MnO_4^- compartment, which causes an excess of negative charge in the latter and positive charge in the former. This explanation is considered completely related and linked, as it clearly references the figure and describes the chemical process.

However, the sentence *"the problem is that if the electrons flowed from the right to the left compartment, the left compartment would become negatively charged and the right compartment would experience a build-up of positive charge"* could lead students to misinterpret the movement of charge, imagining that electrons swim through the solution, directly causing the imbalance of charge. The misconception arises because the specific electrode reactions are not explained, which may cause students to think that the negative charge in the MnO_4^- compartment results directly from incoming electrons, rather than from the redox reaction occurring at the electrode once the electrons arrive. This example shows that even when text and image are technically linked and related, students may still struggle to understand the concept clearly if essential mechanistic details are not explicitly presented. This highlights the importance of not only text–image integration (C3), but also the type of representation (C1) and the clarity of labels (C2). Without clear labeling and appropriate representation types, students may misinterpret the source or cause of charge imbalances in electrochemical cells.



(a) (b)

Figure 3. (a) Example of Partially Related and Unlinked Representations (B) Example of Completely Related and Linked Representations

4^th^ Criterion (C4): Existence and properties of a caption

Captions serve as essential components of visual representations, as they can convey core conceptual information without requiring direct reference to the main text. Unclear or ambiguous captions may lead to student misconceptions regarding the intended concept (Gkitzia et al., 2011). Based on the analysis, nearly all of the examined textbooks include captions, some of which are clear and informative, while others exhibit issues related to clarity and conceptual alignment. Figure 4 (a) shows an image accompanied by an appropriate caption. Because the caption is complete, students can understand the context of the image without needing to refer to the text explanation. In contrast, Figure 4 (b), although it illustrates all levels (macroscopic, submicroscopic, and symbolic), lacks a clear caption, which may cause confusion and hinder students' understanding of the image.

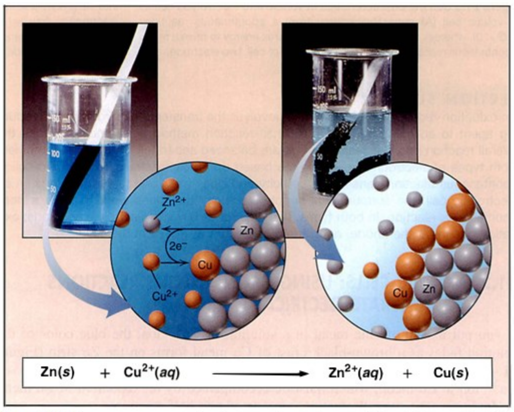


Figure 21.4 The spontaneous reaction between zinc and copper(II) ion. When a strip of zinc metal is placed in a solution of Cu^{2+} ion, a redox reaction begins (*left*), in which the zinc is oxidized to Zn^{2+} and the Cu^{2+} is reduced to copper metal. As the reaction proceeds (*right*), the deep blue color of the solution of hydrated Cu^{2+} ion lightens, and the Cu "plates out" on the Zn and falls off in chunks. (The Cu appears black because it is very finely divided.) At the atomic scale, each Zn atom loses two electrons, which are gained by a Cu^{2+} ion. The process is summarized with symbols in the balanced equation.

(a)

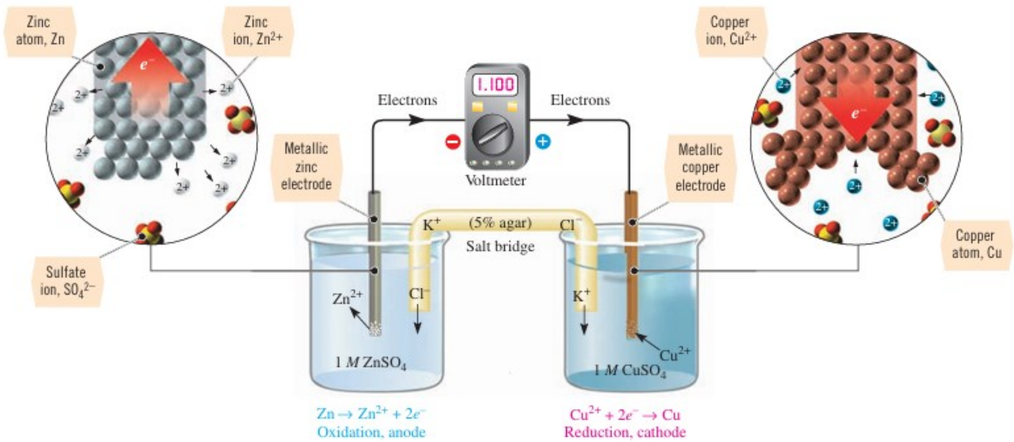


Figure 21-6 The zinc–copper voltaic cell utilizes the reaction

(b)

Figure 4 (a) Example of appropriate caption (b) Example of problematic caption

5th Criterion (C5): Degree of correlation between the components comprising a multiple representation

Almost all of the analyzed textbooks fall under the "sufficiently linked" category for this criterion. Figure 5 illustrates an example of a sufficiently linked representation. In the figure, the macroscopic level (the voltaic cell phenomenon) is connected to the submicroscopic level through an arrow. This emphasizes that the submicroscopic level being shown represents the processes occurring at the electrode and in the solution, as indicated by the arrow. Without this arrow or if the macroscopic and submicroscopic levels were presented separately, students might become confused when viewing the submicroscopic explanation, wondering which part of the system is being described.

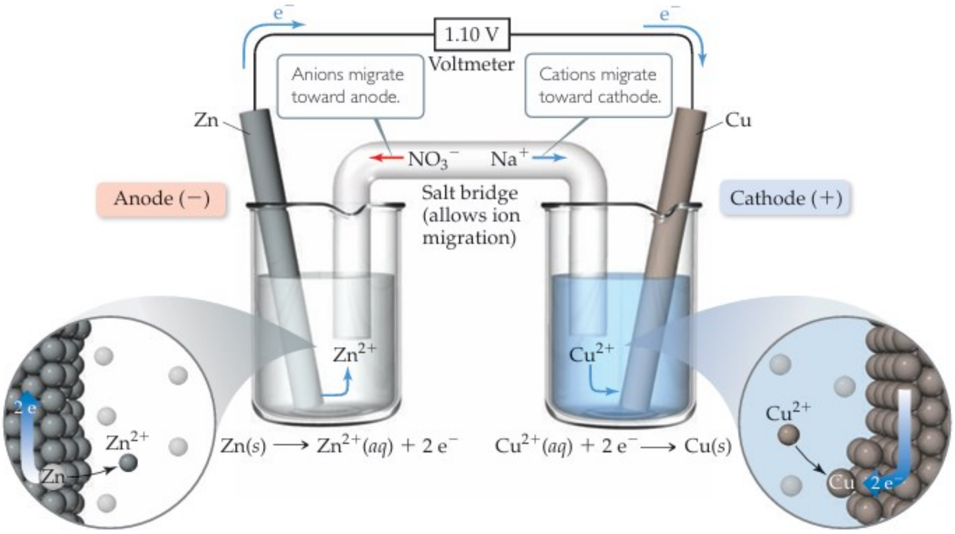


Figure 5. Example of sufficiently linked representations

The findings of this analysis carry important implications for both chemistry educators and textbook authors. For educators, it is crucial to recognize that the quality of visual representations in textbooks significantly influences students' conceptual understanding, particularly in topics involving abstract phenomena such as electron transfer and ion migration. When representations are incomplete, unclear, or disconnected from accompanying text, students may develop misconceptions or fail to grasp the underlying processes. Therefore, teachers should not rely solely on textbook visuals but instead critically evaluate the representations presented and, when necessary, provide complementary explanations, supplementary visuals, or analogies to bridge representational gaps and support student understanding.

For textbook developers, the findings of this study highlight the need to incorporate representations that are not only scientifically accurate but also pedagogically meaningful. Visuals should do more than merely depict laboratory equipment or reaction setups, they should intentionally connect macroscopic observations, submicroscopic processes, and symbolic representations in a coherent and integrated manner. To support students in interpreting visual materials effectively, representations must be accompanied by clear labeling, well-crafted captions, and explicit references within the text. In addition, the use of multiple representations (such as separate visuals for each level that are thematically linked) can reinforce understanding by allowing students to examine chemical phenomena from various angles. Meanwhile, hybrid representations, which simultaneously present different representational levels within a unified image, can facilitate students' transitions between these levels and promote a deeper, more cohesive understanding of chemical concepts. Textbook authors are also encouraged to adopt narrative or analogical visual approaches where appropriate, as these can help bridge abstract ideas with students' everyday experiences, making complex content more accessible and memorable.

4. Conclusion

This study evaluated the quality and integration of visual representations of spontaneous redox reactions and voltaic cells in general chemistry textbooks using Gkitzia's rubric. The analysis revealed that while macroscopic and symbolic aspects are generally well presented, submicroscopic representations are often incomplete or missing. This limits students' opportunities to understand the invisible processes underlying observable chemical changes. Furthermore, weaknesses such as unclear labeling, insufficient captions, and weak connections between text and images reduce the clarity and instructional value of the materials. Although some textbooks demonstrated good practice by integrating representational levels within a single figure, these examples were limited, and many still rely on fragmented visuals.

The research has successfully addressed its objective by identifying key patterns, strengths, and shortcomings in the visual representation of electrochemical concepts. The findings emphasize the need for coherent, well-integrated visuals to help students build accurate mental models of redox processes and voltaic cells. Future studies may explore how students interpret these representations during learning activities or examine how textbooks can be revised to better align with representational best practices. Additionally, researchers could investigate how representational quality influences conceptual understanding in actual classroom settings. These insights can guide the development of more effective chemistry textbooks and learning materials.

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References

Addiin, I., & Masykuri, M. (2016). Analisis Representasi Kimia pada Materi Pokok Hidrolisis Garam dalam Buku Kimia Kelas XI SMA/MA. *JKPK: Jurnal Kimia Dan Pendidikan Kimia*, *1*(2).

Asnawi, R., Effendy, & Yahmin. (2017). Kemampuan Berpikir Ilmiah Siswa dan Miskonsepsi pada Materi Elektrokimia. *Jurnal Ilmu Pendidikan*, *23*(1).

Blongkod, R., Hafid, R., & Mahmud, M. (2022). Pengaruh Penggunaan Buku Teks Terhadap Hasil Belajar Siswa Pada Mata Pelajaran IPS Terpadu Kelas VIII di SMP Cokroaminoto Solog Kabupaten Bolaang Mongondow. *Aksara: Jurnal Ilmu Pendidikan Nonformal*, *8*(3), 2131. doi.org/10.37905/aksara.8.3.2131-2140.2022

Brown, T., Lemay, H. E., Bursten, B. E., Murphy, C., Woodward, P., & Stoltzfus, M. E. (2009). *Chemistry: The Central Science* (15th edition). New Jersey: Pearson Prentice Hall.

Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2007). The Development of a Two-tier Multiple-choice Diagnostic Instrument for Evaluating Secondary School Students' Ability to Describe and Explain Chemical Reactions Using Multiple Levels of Representation. *Educ. Res. Pract*, *8*(3), 293–307.

Chang R, & Overby J. (2019). *Chemistry*. New York: McGraw-Hill.

Chen, X., de Goes, L. F., Treagust, D. F., & Eilks, I. (2019). An Analysis of the Visual Representation of Redox Reactions in Secondary Chemistry Textbooks from Different Chinese Communities. *Education Sciences*, *9*(1). doi.org/10.3390/educsci9010042

Chittleborough, G., & Treagust, D. (2008). Correct Interpretation of Chemical Diagrams Requires Transforming from One Level of Representation to Another. *Research in Science Education*, *38*(4), 463–482. doi.org/10.1007/s11165-007-9059-4

Demirdöğen, B. (2017). Examination of Chemical Representations in Turkish High School Chemistry Textbooks. *Journal of Baltic Science Education*, *16*(4).

Dewata, I., & Melyanti, N. O. (2011). Analisis Proses Pembelajaran Pokok Bahasan Elektrokimia di Kelas XII SMAN 1 Panti. *Ta'dib*, *14*(1).

Dindar, A. Ç., Bektaş, O., & Çelk, A. Y. (2010). What are the Pre-service Chemistry Teachers' Explanations on Chemistry Topics? *The International Journal of Research in Teacher Education*, *1*, 32–41.

Dorsah, P., & Yaayin, B. (2019). Altering Students Misconceptions in Electrochemistry Using Conceptual Change Texts. *International Journal of Innovative Research and Development*, *8*(11). doi.org/10.24940/ijird/2019/v8/i11/nov19021

Fadila, I., & Qurrata Aini, F. (2025). Study of Chemical Multirepresentation on Chemical Bonding Material in Independent Curriculum Chemistry Textbooks. *Journal of Educational Sciences*, *9*(3), 1137–1152. doi.org/10.31258/jes.9.3.p.1137-1152

Fraenkel, J., Wallen, N., & Hyun, H. (2012). *How to Design and Evaluate Research in Education* (8th edition). New York: McGraw-Hill.

Gilbert, J., & Treagust, D. (2009). *Multiple Representations in Chemical Education*. Dordrecht: Springer Netherlands.

Gkitzia, V., Salta, K., & Tzougraki, C. (2011). Development and Application of Suitable Criteria for the Evaluation of Chemical Representations in School Textbooks. *Chemistry Education Research and Practice*, *12*(1), 5–14. doi.org/10.1039/c1rp90003j

Hasanah, D., . W., Mulyani, S., & Widhiyanti, T. (2024). Multiple Representations Analysis of Chemical Bonding Concepts in General Chemistry Books. *KnE Social Sciences*. doi.org/10.18502/kss.v9i8.15554

Huddle, P. A., White, M. D., & Rogers, F. (2000). Using a Teaching Model to Correct Known Misconceptions in Electrochemistry. *Journal of Chemical Education*, *77*(1). doi.org/10.12691/wjce-4-5-3

Johnstone, A. H. (2000). Teaching of Chemistry - Logical or Psychological? *Chemistry Education: Research and Practice in Europe*, *1*(1), 9–15.

Langitasari, I. (2016). Analisis Kemampuan Awal Multi Level Representasi Mahasiswa Tingkat I pada Konsep Reaksi Redoks. *EduChemia: Jurnal Kimia Dan Kependidikan*, *1*(1). dx.doi.org/10.30870/educhemia.v1i1.436

Mar, J., & Sanchez, P. (2017). Integrated Macro-Micro-Symbolic Approach in Teaching Secondary Chemistry. *Kimika*, *28*(2), 22–29. doi.org/10.26534/kimika.v28i2.238

Merriam, S. (1998). *Qualitative Research and Case Study Applications in Education*. San FransiscoJossey-Bass.

Nisa, N. A., & Fitriza, Z. (2021). Identifikasi Mikonsepsi Siswa Menengah Atas (SMA) Pada Pembelajaran Kimia Materi Redoks dan Elektrokimia : Studi Literatur. *Edukatif: Jurnal Ilmu Pendidikan*, *3*(4), 1191–1198. doi.org/10.31004/edukatif.v3i4.516

Sanger, M. J., & Greenbowe, T. J. (1999). An Analysis of College Chemistry Textbooks as Sources of Misconceptions and Errors in Electrochemistry. *Journal of Chemical Education*, *76*(6). doi.org/10.1021/ed076p853

Septiani, A., & Qurrata Aini, F. (2025). Description of Chemical Multirepresentation on Acid-Base Material in Merdeka Curriculum Chemistry Textbooks. *Journal of Educational Sciences*, *9*(1), 352–365. doi.org/10.31258/jes.9.1.p.352-365

Shin, T.-H., Lee, S.-K., & Choi, B.-S. (2002). Analysis of Voltaic Cell Described in the Science Textbooks of Secondary Schools. *Journal of the Korean Chemical Society*, *46*(4). doi.org/10.5012/jkcs.2002.46.4.363

Silberberg S. (2007). *Principles of General Chemistry*. New York: McGraw-Hill.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2003). The Role of Submicroscopic and Symbolic Representations in Chemical Explanations. *International Journal of Science Education*, *25*(11), 1353–1368. doi.org/10.1080/0950069032000070306

Üce, M., & Ceyhan, İ. (2019). Misconception in Chemistry Education and Practices to Eliminate Them: Literature Analysis. *Journal of Education and Training Studies*, *7*(3), 202. doi.org/10.11114/jets.v7i3.3990

Upahi, J. E., & Ramnarain, U. (2019). Representations of Chemical Phenomena in Secondary School Chemistry Textbooks. *Chemistry Education Research and Practice*, *20*(1), 146–159. doi.org/10.1039/c8rp00191j

Whitten, K., Davis, R., Peck, L., & Stanley, G. (2013). *Chemistry* (10th edition). Boston: Cengange Learning.

Wu, H. K., & Shah, P. (2004). Exploring Visuospatial Thinking in Chemistry Learning. *Science Education*, *88*(3), 465–492. doi.org/10.1002/sce.10126

Zumdahl S, & Zumdahl L. (2010). *Chemistry* (8th edition). Boston: Cengange Learning.

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