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ANALYSIS OF GENERAL CHEMISTRY TEXTBOOKS BASED ON MULTIPLE REPRESENTATIONS OF THE CELL POTENTIAL CONCEPT

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ABSTRACT

Textbooks function as core learning resources in chemistry, particularly for explaining abstract ideas through visual representations. This study examines how the concept of electrochemical potential cells is represented in five college level general chemistry textbooks using five analytic criteria covering representation type, explicitness, connectedness, information sufficiency, and conceptual relatedness. The sample comprises widely adopted texts that span foundational topics to ensure relevance across common curricula. The analysis identified a distinct pattern within each category. Category C1 was dominated by symbolic representations at 74.7 percent. Category C2 showed predominantly explicit presentations at 79.3 percent. Category C3 reflected fully related and connected representations. Category C4 demonstrated complete presence of appropriate information at 100 percent. Category C5 included three levels of conceptual relatedness with quite related at 74.2 percent, not quite related at 19.4 percent, and not related at 6.5 percent. The findings outline the current quality of visual representations of potential cells in higher education materials and indicate areas where integration across macroscopic, submicroscopic, and symbolic levels could be strengthened. Educators, textbook authors, and curriculum developers can apply these insights to design materials that support deeper conceptual understanding and more coherent transitions between representations.

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INTRODUCTION

Textbooks play a crucial role for students and educators in chemistry education worldwide. High-quality visual representations are increasingly necessary to support learning. Analyses of chemistry textbooks report that visualizations dominate the content, with 87–95% of pages containing visual representations [1]. Such representations are vital because many chemical concepts and entities are abstract and cannot be directly observed, so connections among macroscopic, submicroscopic, and symbolic phenomena are needed to foster comprehensive understanding [2].

Conceptual understanding in chemistry depends on the ability to coordinate these three levels of representation. The three-level representation framework explains that difficulties often arise when learners must process all three levels simultaneously [3].

The linkage among levels—commonly described as intertextuality—helps students bridge what they observe, what they conceive in terms of particles or ions, and what they express as symbols or equations, which supports deeper understanding [4]. Effective representations facilitate translation across levels, reduce misconceptions, and strengthen conceptual knowledge [5].

Electrochemistry presents distinct challenges because many processes occur at the particle level and remain unobservable. Electron transfer, redox change, the direction of spontaneity, and calculation of cell potentials from E° tables require advanced abstract reasoning [6]. Visual representations serve as a bridge between observable phenomena and the underlying theoretical constructs in this domain.

Research has examined the quality and types of representations in chemistry textbooks [5], [7], including work on electrochemistry. Limited attention has been given to the subtopic of cell potential, especially with respect to textual integration and clarity of surface features. Evidence indicates that surveying representational forms in general chemistry textbooks is a broadly applicable approach; the quality and interconnectedness of representations can foster conceptual change, and studies from multiple regions report abundant representations that are not fully integrated with text [8].

Many investigations emphasize counts or types of representations rather than connectivity and integration across components [9]–[11]. Systematic evaluation of the effectiveness and integration of representational forms in general chemistry textbooks remains scarce [12], [13]. The present study analyzes the presentation of cell-potential material in general chemistry textbooks using five criteria for evaluating visual representations [12]. The analysis categorizes representation types and evaluates how interconnections among macroscopic, submicroscopic, and symbolic levels are presented in an integrated manner, providing a comprehensive view of how textbooks support understanding of cell-potential concepts.

The findings are expected to benefit educators, curriculum designers, and textbook authors. Evidence on the quality and coherence of visual representations can guide development or revision of materials that more effectively connect macroscopic, submicroscopic, and symbolic phenomena. Instructional resources can then be selected or adapted to better support students' conceptual understanding. The study extends prior work by examining not only the frequency of representations but also their interconnection and integration, using the five established criteria [12], to provide a more complete picture of how cell-potential concepts are presented

METHODS

1. Research Design

The study employs a qualitative descriptive approach using content analysis [14], [15]. Content analysis was selected because it enables systematic, structured, and replicable examination of visual and textual elements—two core components of textbook materials. The method is widely used in science-textbook evaluations for extracting representational patterns and objectively testing relationships among components [15]. The approach addresses the research question concerning the extent to which visual representations (macroscopic, submicroscopic, symbolic) are interconnected in the presentation of cell potential, within the framework described in [12].

2. Research Target

Five general-chemistry textbooks widely used at the university level in Indonesia served as the sample. To maintain relevance to current curricula, editions published between 2010 and 2023 were selected. Selection criteria were: (1) coverage of electrochemistry, with emphasis on the cell-potential subtopic; (2) documented adoption in undergraduate and graduate courses across multiple Indonesian universities; and (3) inclusion of widely used international general-chemistry textbooks employed in many programs. Purposive sampling was employed to ensure that the analyzed books reflect the diversity of publishers, authoring teams, and presentation styles commonly found in introductory chemistry education in Indonesia. The five textbooks selected for analysis are listed in Table 1.

Table 1. The identities of the five books.

Book Code	Book identity (Author, Year and Title)
B1	Brady, J. E., Jespersen, N. D., & Hyslop, A. (2012). *Chemistry the molecular nature of matter 6th Edition*. New Jersey: John Wiley & Sons, Inc.
B2	Silberberg, M. S. (2013). *Principles of General Chemistry Third Edition*. New York: McGraw-Hill
B3	Brown, T. E., Lemay, & Brunce,E.(2012). *Chemistry: The Central Science.* New York: Pearson Pretince Hall
B4	Whitten, Kennerth W, dkk. (2014). *Chemistry: Teenth Edition*. Brooks Cole : USA
B5	Chang, R. (2007). *Chemistry 10th edition*. New York: McGraw-Hill

3. Instrument and Collecting Data

The research instrument consists of an analysis sheet based on five criteria for evaluating visual representations [12], comprising (C1) type of representation, (C2) conceptual consistency, (C3) clarity of surface features, (C4) relevance to accompanying text, and (C5) integration across levels of representation. Each criterion was explicitly operationalized for the context of cell-potential material. In C1, representations were coded as macroscopic when they depicted directly observable phenomena such as a voltaic-cell setup, submicroscopic when they depicted particles or ions, and symbolic when they contained reaction equations or calculations of cell potential. In C3, representations were coded explicit when all visual components were fully described in labels or text, and implicit when only a subset of components was described. Categories, typologies, and definitions for the five criteria follow [12] and are summarized in Table 2.

Table 2 .Criteria for evaluating textbooks analysis from Gkitzia et al. [12].

Category	Typology	Description
C1 : Type of representation	i. Macroscopic	Macroscopic from voltaic cell circuit, solution colour, electrode metal, salt bridge, and voltmeter.
	ii. Submicroscopic	Movement of electrons on the anode, on the cathode and on the salt bridge.
	iii. Symbolic	A notation describes the components of voltaic cell.
	iv. *Multiple*	Two or three levels of chemistry depicted simultaneously.
	v. *Hybrid*	Representation of two or three complementary levels that form a single representation.
	vi. Mix	Representation of two or three levels is likened to an analogy.
C2: Interpretation of surface features	i. Eksplisit	When surface feature is explained with a clear meaning.
	ii. Implisit	When some surface feature is explained with a clear meaning.
	iii. Ambigous	When none of the surface feature are identified.
C3: Relatedness to text	i. Completely related and linked	The experimental picture of voltaic cell or the SHE picture is related to the text content, where the presented context is appropriate.
	ii. Completely related and unlinked	The experimental picture of the voltaic cell or the SHE picture is appropriate, but the text content is unliked.
	iii. Partially related and linked	The experimental picture of the voltaic cell or the SHE picture is only a few that are related, and the text refers to a direct link.
	iv. Partially related and unlinked	The experimental picture of the voltaic cell or the SHE picture is only a few that are related, and the text does not refer to a direct link.
	v. Unrelated	When the picture not related to the text content.
C4: Existence and properties of a caption	i. The existence of appropriate information	The presented description is accurate, concise, and comprehensive.
	ii. There is information accompanied by problems	There are issues or discrepancies in the information presented.
	iii. Without explanation	There is no additional explanation or clarification.
C5: Degree of correlation between the components (subordinate representations) comprising a multiple representation.	i. Quite related	The correlation between multiple representations is quite related.
	ii. Not quite related	The correlation between multiple representations is not quite related.
	iii. Not related	The correlation between multiple representations is not related.

The unit of analysis in this study was each image, diagram, or illustration that appeared in the cell-potential subtopic, together with the text that directly explained it. All representations from the five books were scanned or photographed into digital format, then stored and managed using Microsoft Excel for labeling, coding, and analytic notes. The coding process was conducted manually by two researchers working independently, using a codebook developed from operational definitions. Prior to the primary analysis, pilot coding was conducted on 10% of the data to align interpretations and refine the codebook. The analysis proceeded sequentially: Stage 1, coding C1 and C2 for all units; Stage 2, coding C3 with cross-checks against the C1 and C2 results; Stage 3, coding C4; and Stage 4, integration analysis (C5) to determine the extent to which interconnections among representation levels were displayed. The results of each stage formed the basis for the next stage, ensuring a progressive and interconnected analytic flow. Coding reliability was tested using percentage agreement, calculated as:

$$Percentage\ Agreement = \frac{Number\ of\ Agreements}{Total\ Number\ of\ Item\ Coded} x\ 100\%$$

In the initial coding, the level of agreement among coders was 90%. After discussion to resolve interpretive differences, the final level of agreement reached 95%. Discrepancies were resolved through discussion until consensus, and the consensus codes were used for further analysis. The sample comprised textbooks commonly used in Indonesia, with two internationally adopted titles widely used across countries, enabling application of this analytical framework to evaluate visual representations of electrochemistry topics in general chemistry textbooks.

RESULT AND DISCUSSION

Several studies have documented persistent difficulties in learning electrochemistry, particularly cell potential [6], [11]–[13]. Many processes are not directly observable and are difficult to visualize, which complicates explanation and learning [14], [15]. The topic is highly abstract and challenging to master [12]. Students often struggle to use standard reduction potentials; when applying the standard hydrogen electrode (SHE), they may produce values inconsistent with theory [12]. Recognizing this complexity, the present analysis examined chemical representations in educational materials.

Chemical representations related to cell potential were examined across five general-chemistry textbooks used at various universities. Four concept labels organized the analysis: (1) standard reduction potential, (2) standard cell potential, (3) non-standard cell potential, and (4) the relationship between cell potential (E°_cell) and Gibbs free energy (ΔG°). These labels are addressed within electrochemistry chapters. Table 3 summarizes the analysis of these four labels across the five books.

For clarity, the books are coded as:

- B1 = Book 1
- B2 = Book 2
- B3 = Book 3
- B4 = Book 4
- B5 = Book 5.

Table 3. Concept Labels Analysis Across Textbooks.

No.	Concept labels	B1	B2	B3	B4	B5
1.	Standard reduction potential	✓	✓	✓	✓	✓
2.	Standard cell potential	✓	✓	✓	✓	✓
3.	Non-standard cell potential	✓	✓	✓	✓	✓
4.	The relationship of cell potential (E^o_{cell}) and Gibb free energy (ΔG^o)	✓	✓	✓	✓	✓

Table 4. Number of Representations in C1.

Concept labels	Typology	Book					Total	% of Total
		B1	B2	B3	B4	B5		
Standard reduction potential	Macroscopic	3	1	2	3	3	12	12,1
	Submicroscopic	0	1	1	2	0	4	4,0
	Symbolic	17	15	6	17	16	71	71,7
	Multiple	0	1	1	1	0	3	3,0
	Hybrid	3	0	1	2	3	9	9,1
	Mix	0	0	0	0	0	0	0,0
	Total						**99**	
Standard cell potential	Macroscopic	4	4	5	5	2	20	19,2
	Submicroscopic	1	1	2	4	1	9	8,7
	Symbolic	15	20	7	9	7	58	55,8
	Multiple	0	1	2	4	1	8	7,7
	Hybrid	3	3	2	0	0	8	7,7
	Mix	0	0	1	0	0	1	1,0
	Total						**104**	
Non-standard cell potential	Macroscopic	0	0	0	0	0	0	0,0
	Submicroscopic	0	0	0	0	0	0	0,0
	Symbolic	5	10	8	8	10	41	100,0
	Multiple	0	0	0	0	0	0	0,0
	Hybrid	0	0	0	0	0	0	0,0
	Mix	0	0	0	0	0	0	0,0
	Total						**41**	
The relationship of cell potential (E^o_{cell}) and Gibb free energy (ΔG^o)	Macroscopic	0	0	0	0	0	0	0,0
	Submicroscopic	0	0	0	0	0	0	0,0
	Symbolic	9	13	5	6	16	49	100,0
	Multiple	0	0	0	0	0	0	0,0
	Hybrid	0	0	0	0	0	0	0,0
	Mix	0	0	0	0	0	0	0,0
	Total						**49**	

Table 5. Total Number of Criteria 1 (C1).

Category	Typology	Book					Total	% of Total
		B1	B2	B3	B4	B5		
C1	Macro-scopic	7	5	7	8	5	32	10,9
	Submicro-scopic	1	2	3	6	1	13	4,4
	Symbolic	46	58	26	40	49	219	74,7
	Multiple	0	2	3	5	1	11	3,8
	Hybrid	6	3	3	2	3	17	5,8
	Mix	0	0	1	0	0	1	0,3

Total	**293**

The analysis conducted regarding the scope, accuracy, and depth of the concepts aims to determine the explanations regarding cell potential based on the level representation (C1), as seen in Table 4. The total number of representations in Criterion 1 (C1) is summarized above in Table 5.

Table 4 reports a total of 293 visual representations on electrochemistry, divided into six types: macroscopic (32 instances, 10.9%), submicroscopic (13, 4.4%), symbolic (219, 74.7%), multiple (11, 3.8%), hybrid (17, 5.8%), and mixed (1, 0.3%). Symbolic representations account for roughly three-quarters of all cases and remain dominant across nearly all concept labels, with the subtopics "Non-standard cell potential" and "Relationship between E°cell and ΔG°" presented exclusively in symbolic form. Submicroscopic representations are minimal (<5%), and macroscopic representations constitute about one-tenth of the total.

The pattern suggests that textbooks prioritize symbols and equations, whereas particle-level (submicroscopic) and real-world (macroscopic) depictions appear less frequently. Limited submicroscopic representation may hinder conceptual understanding because coordination across macro–submicroscopic–symbolic levels is a key competence in chemistry [4], [16].

Prior studies also indicate that symbolic dominance without submicroscopic support can elevate cognitive load and weaken representational fluency [12], [17]. The next section reviews and compares in detail how the five textbooks implement C1 to highlight differences in representational practice

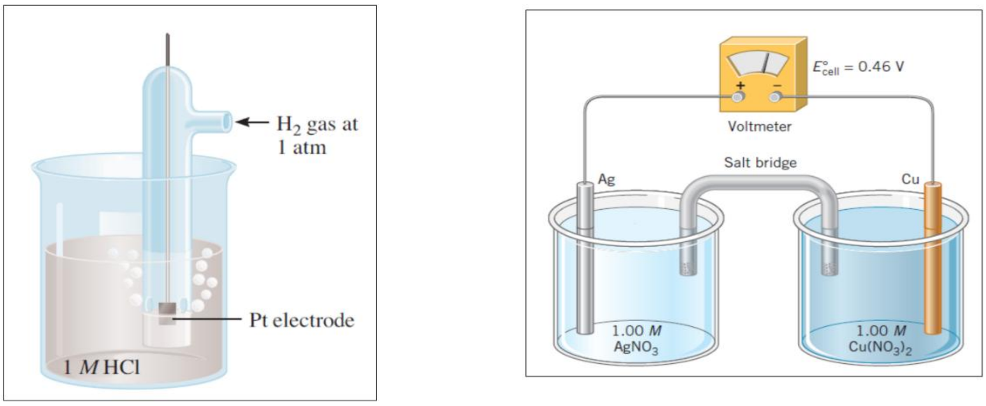
1. C1 (Type of Representation)

a. Macroscopic Representation

Macroscopic representations such as those in Table 4 and Table 5 appeared 32 times (10.9% of total C1 representations), with Macroscopic representations, as summarized in Table 4 and Table 5, appeared 32 times (10.9% of total C1 representations), with the highest count in B4 (8) and the lowest in B2 (5). All books include macroscopic depictions for standard reduction potential and standard cell potential. For standard reduction potential, each book visualizes the Standard Hydrogen Electrode (SHE), as in Figure 1(a), providing an experimental context through observable phenomena. Standard cell potential is illustrated with images of a voltaic cell, a directly observable electrochemical system (see Figure 1(b)). Macroscopic examples for these two concept labels are shown in Figure 1.

Evidence underscores the importance of macroscopic features in chemistry learning because this level is directly observable to students [18]. SHE images and voltaic-cell circuits anchor electrochemistry in observable experience and support meaning-making. No book provides macroscopic representations for non-standard cell potential or for the relationship between E°_cell and ΔG°. The abstract nature of these concepts limits direct visualization and can impede learning, a difficulty reported in prior work on insufficient macroscopic integration [19]. Limited macroscopic support for these topics may hinder comprehensive conceptual understanding [5].

The distribution indicates a stronger emphasis on concepts with tangible visual form than on more theoretical constructs, addressing the first research question regarding how variation in representation types is used to support understanding of cell-potential concepts.



a. b.

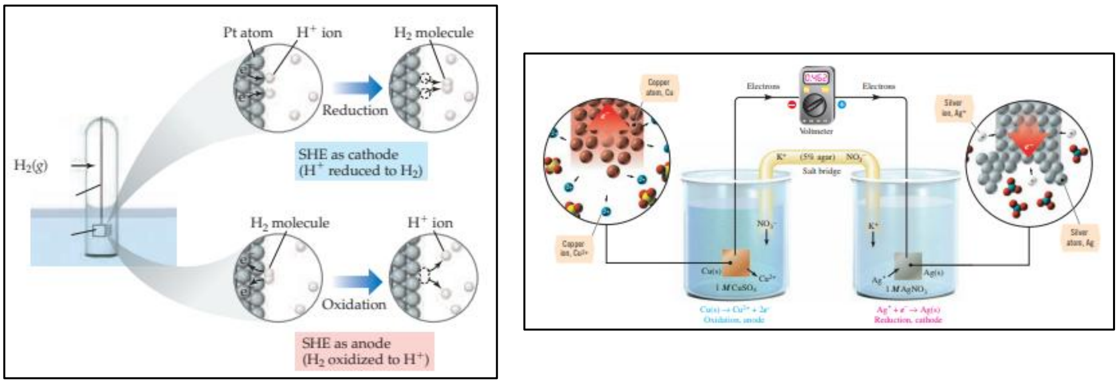
Figure 1. Macroscopic representation of (a) standard reduction potential in B5, and (b) standard cell potential in B1.

b. Submicroscopic Representation

Submicroscopic representations ranked as the second-lowest category across the five textbooks, accounting for 13 of 293 instances (4.4%; Table 5). Most textbooks rarely provide particle-level visualizations of electrochemical phenomena, even though such depictions help students connect macroscopic observations with interactions among ions and molecules [3]. The low proportion aligns with findings that submicroscopic content is least represented in textbooks despite its critical role in developing deep conceptual understanding [12], [19].

Within the standard reduction potential label, only four submicroscopic representations were identified: one in B2, one in B3, and two in B4. One example (Figure 2a, B4) pairs a standard hydrogen electrode (SHE) with atomic- and ionic-level depictions of oxidation and reduction of H_2. Such visualization supports understanding of electron transfer and hydrogen-ion formation while mitigating common redox misconceptions reported in [19], [20].

For the standard cell potential label, nine submicroscopic representations were found: B1 (1), B2 (1), B3 (2), B4 (4), and B5 (1). One example (Figure 2b, B3) shows a voltaic cell at the particle level, including ion movement at Ag and Cu electrodes. Visual access to these processes clarifies the origin of potential difference and the direction of electron flow—details that are difficult to convey through text or macroscopic images alone.



a. b.

Figure 2. Submicroscopic level of (a) standard reduction potential in B3, and (b) standard cell potential in B4.

No submicroscopic representations were identified for non-standard cell potential or for the relationship between E°cell and ΔG°. The absence limits opportunities for students to bridge macroscopic and submicroscopic reasoning.

Findings indicate that, although submicroscopic representations are essential in chemistry education, their use remains topic-specific and not yet widespread across electrochemistry. Increasing the proportion and quality of particle-level depictions may strengthen representational fluency and support deeper conceptual understanding [21].

c. Symbolic Representation

Symbolic representation was the most dominant across all five textbooks, totaling 219 instances or 74.7% of all representations (Table 5). The dominance indicates an emphasis on symbols, reaction equations, cell notation, and mathematical expressions rather than macroscopic or submicroscopic visualizations. The finding aligns with reports that chemistry texts frequently privilege symbolic forms without sufficient visual cues or narrative scaffolds [12].

Symbolic forms appear in every concept label—from standard reduction potential to the relationship between cell potential and Gibbs free energy—demonstrating their central role in conveying information concisely and efficiently [22]. Example half-reaction for the standard hydrogen electrode in B1:

$$2H^{+}(aq, 1.00\ M) + 2e^{-} \rightleftharpoons H_2(g, 1.00\ atm)$$

When $E^{o}_{H^{+}} = 0\ V\ (exacly)$

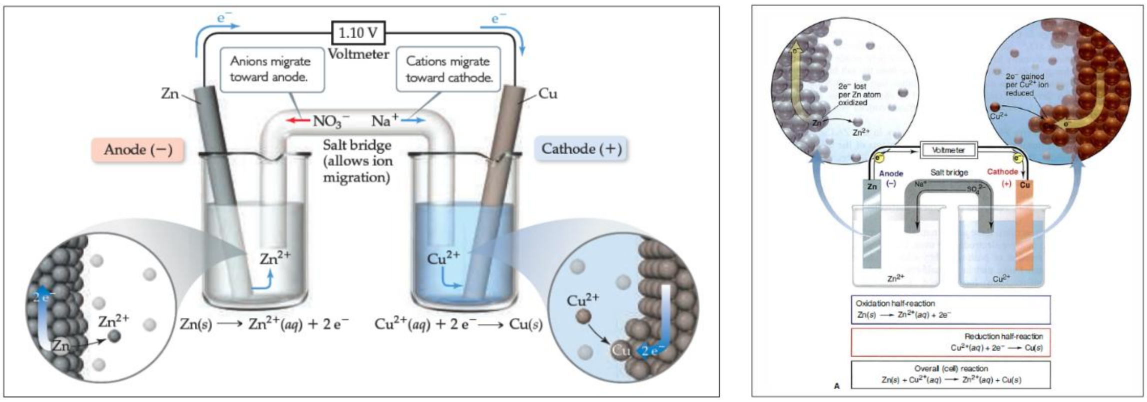
This equation uses chemical symbols (H^+, e^-, H_2), phase notation (aq, g), and standard reduction potential values (E°) to describe the reduction reaction at the SHE concisely without having to visualize it at the particle level.

$Zn_{(s)}\ |\ Zn^{2+}_{(aq)}\ ||\ Cu^{2+}_{(aq)}\ |\ Cu_{(s)}$

Symbolic language offers compact communication, yet it can function as an abstract code that is difficult to interpret without coordinated macroscopic and submicroscopic support [23]. Evidence indicates that conceptual understanding improves when learners connect symbolic representations with other levels; otherwise, cognitive load increases and misconceptions become more likely [24], [5]. A balanced presentation that integrates symbols with particle-level and observable-level visuals is recommended to strengthen representational fluency and deepen understanding.

d. Multiple Representation

Multiple representation is defined as a depiction that simultaneously presents two or three levels of chemical representation—macroscopic, submicroscopic, and symbolic—within a single figure or sequence [12]. Analysis of five textbooks identified multiple representation in two focal concept labels: standard reduction potential and standard cell potential. A total of 11 instances were recorded (3.8% of all representations; Table 5).



a. b.

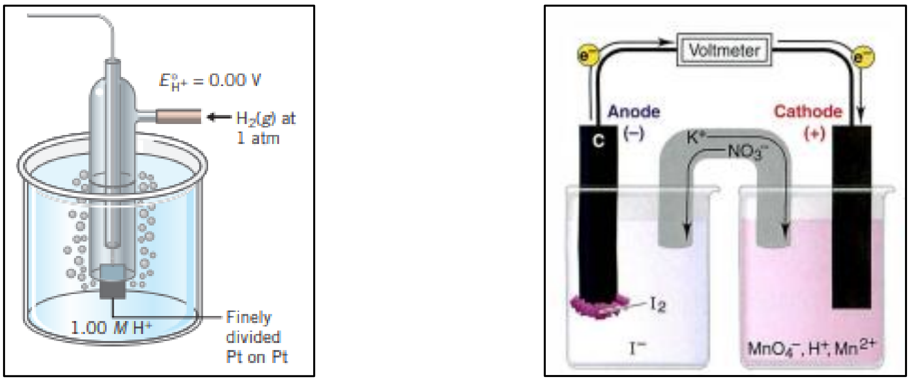
Figure 3. Multiple levels of (a) standard reduction potential in B2, and (b) standard cell potential in B2.

Table 4 details the distribution. For standard reduction potential, instances occurred in B2 (2) and B3 (1). For standard cell potential, instances occurred in B2 (3), B3 (4), B4 (1), and B5 (1). Figure 3a (B2) depicts a voltaic cell with a Standard Hydrogen Electrode (SHE) and a Zn electrode at the macroscopic level, visualizes the redox process at the molecular level (submicroscopic), and presents the corresponding reaction equation (symbolic). Figure 3b (B4) combines an experimental photograph (macroscopic), an illustration of ion motion (submicroscopic), and cell notation (symbolic). The use of multiple representations aligns with the view that macroscopic, real-life experimental contexts are essential in chemistry learning, while submicroscopic explanations are necessary to account for invisible processes [18]. Evidence also indicates that the simultaneous use of macroscopic, submicroscopic, and symbolic levels can address misconceptions and foster a more integrated understanding [23]. By presenting electrochemistry concepts from multiple perspectives, multiple representations enable students to connect observable phenomena with particle-level processes and to interpret how chemical symbols encode those processes.

The analysis also shows that not all multiple representations explicitly connect the levels. In several figures, macroscopic, submicroscopic, and symbolic components are positioned side-by-side without visual markers or explanatory links. Without explicit connections, students tend to treat each level as separate information units, which hinders the development of translation skills across levels [25]. Including arrows, cross-references, and precise labels that signal correspondences among levels should therefore be prioritized in textbook design.

e. Hybrid Representation

Hybrid representation is defined in [1] as a single depiction that combines two or three chemical-representation levels. Analysis of five general-chemistry textbooks shows explicit use of hybrids that merge macroscopic and symbolic information within cell-potential material. Applications concentrate on standard reduction potential and standard cell potential, with no instances in other concept labels. For the standard reduction potential label (Table 4), hybrids occur in B1 (3), B3 (1), B4 (2), and B5 (3). Most figures integrate macroscopic elements (e.g., experimental diagrams or cell circuits) with symbolic information (e.g., notation, reduction-potential values, or standard-condition descriptors) in a single frame. Figure 4a (B1) illustrates the SHE at the macroscopic level accompanied by solution concentration, the standard reduction potential for hydrogen, and pressure data within one illustration.



a. b.

Figure 4. Hybrid level of (a) Standard reduction potential in B1, and (b) Standard cell potential in B2.

Within the standard cell potential label, hybrids appear in B1 (3), B2 (3), and B3 (2). Figure 4b (B2) depicts a voltaic-cell assembly with inert electrodes at the macroscopic level while simultaneously presenting symbolic information such as solution identities, electrode labels, cathode–anode designation, and the direction of electron flow. The integrated layout links observable features directly to abstract chemical information.

In chemistry education—particularly for the challenging topic of cell potential [19], [20]—hybrid representations play a critical role. Evidence in [15] indicates that visual representations enhance conceptual mastery, and the complementary pairing of two levels outlined in [12] can bridge gaps between abstract ideas and observable phenomena. Usage across textbooks remains uneven, leaving opportunities to optimize learning by adopting hybrids more consistently.

f. Mix Representation

According to Gkitzia [1], a mixed representation is defined as the presentation of a chemical level enriched with an analogy, aimed at facilitating the understanding of complex concepts. From the five general chemistry textbooks analyzed, only textbook B3 explicitly uses mixed representation, and even then, it only occurred once (0.3% of the total 293 representations) and was limited to the label of standard cell potential.

This example is illustrated in Figure 5, where a visual analogy accompanies the depiction of a voltaic cell, helping students understand the principle of how the cell works. The use of such analogies aligns with Duit's [26] view that analogies can serve as cognitive bridges to connect abstract new concepts with students' existing knowledge. However, this finding also suggests that the application of mixed representation in standard cell potential materials remains very limited.

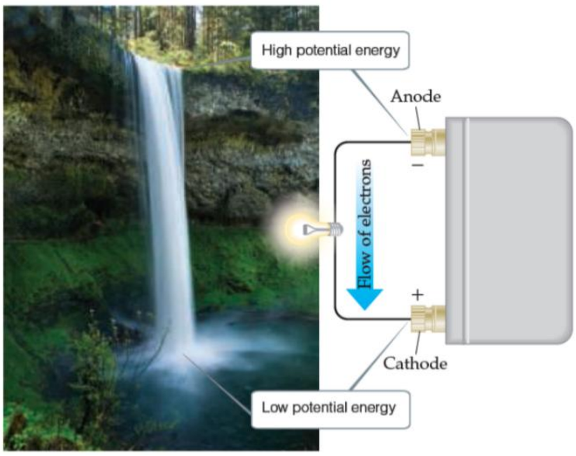


Figure 5. Mix level of standard cell potential in B3.

2. C2 (Interpretation of Surface Features)

The interpretation of surface features refers to representations that are clearly and specifically labeled, classified into three typologies: explicit, implicit, and ambiguous [1]. In the context of learning electrochemistry material, especially cell potential, which is often considered abstract and complex for students to understand [12], clear and specific feature interpretation is significant. To build a strong understanding and reduce student confusion in chemistry learning, explicit visual representations are crucial, where the meaning of each element is clearly stated [21], [22]. implicit or ambiguous representations can hinder the learning process and cause misconceptions, and the fact that students are often unaware of the existence of various conceptions that limit their further science learning [23], [24]. Therefore, the use of carefully designed visual representations, with clear labels and explanations, is essential to facilitate the understanding of cell potential concepts and electrochemistry material as a whole.

The interpretation of surface features will be analyzed and described based on four concept labels of cell potential: standard reduction potential, standard cell potential, non-standard cell potential, and the relationship between cell potential (E^o_{cell}) and Gibb free energy (ΔG^o). The analysis is shown in Table 6.

Table 6. Typology of C2 (Interpretation of surface features).

Concept labels	Typology	Book					Total	% of Total
		B1	B2	B3	B4	B5		
Standard reduction potential	Eksplisit	3	1	1	3	3	11	91,7
	Implisit	0	0	1	0	0	1	8,3
	Ambigous	0	0	0	0	0	0	0,0
	Total						12	
Standard cell potential	Eksplisit	2	2	4	3	1	12	70,6
	Implisit	0	1	0	1	1	3	17,6
	Ambigous	1	0	0	1	0	2	11,8
	Total						17,0	
Non-standard cell potential	Eksplisit	0	0	0	0	0	0	0,0
	Implisit	0	0	0	0	0	0	0,0
	Ambigous	0	0	0	0	0	0	0,0
	Total						0,0	
The relationship of cell potential (Eocell) and Gibb free energy (ΔGo)	Eksplisit	0	0	0	0	0	0	0,0
	Implisit	0	0	0	0	0	0	0,0
	Ambigous	0	0	0	0	0	0	0,0
	Total						0,0	
	Total Number						**29**	

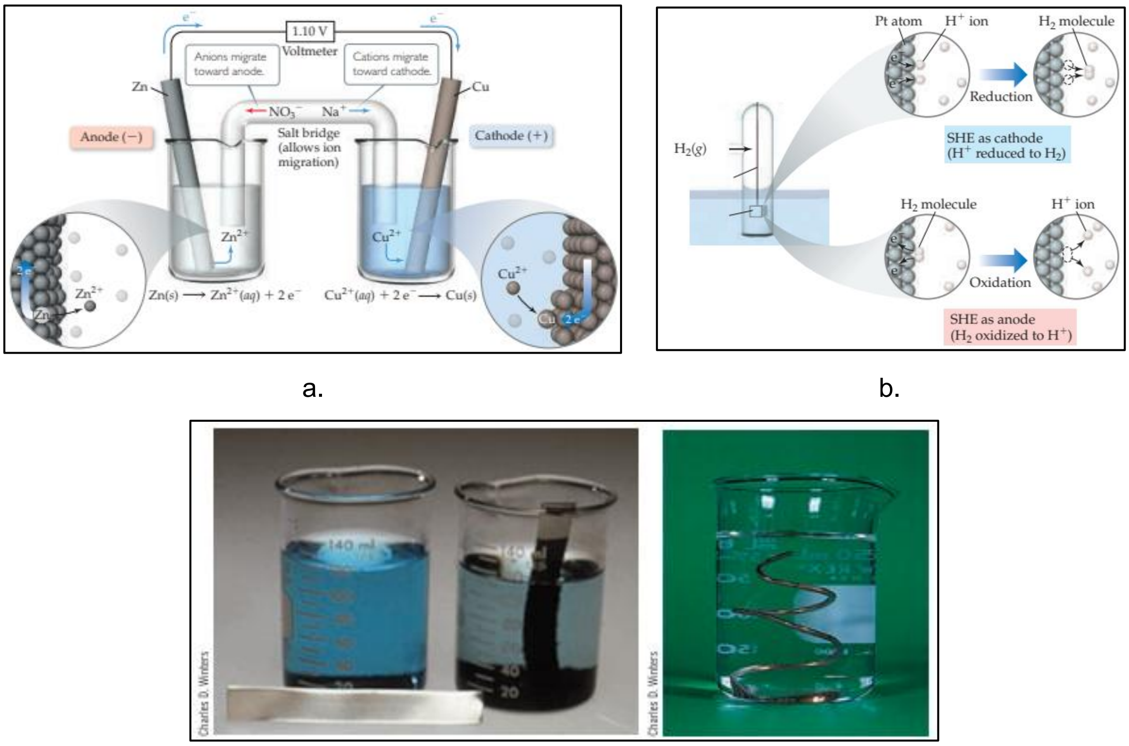
However, the interpretation of surface features on the concept labels of non-standard cell potential and the relationship of cell potential (E^o_{cell}) and Gibbs free energy (ΔG^o) is not found in the five general chemistry books. Figure 3 below is an examples of an explicit, implicit and ambigous surface feature.

Figure 6 (a) shows an explicit representation of standard cell potential in a voltaic-cell circuit from B3. Based on Table 6, explicit representations under the standard cell-potential label account for 91.7%. As defined in [1], a representation is explicit when all surface features are presented clearly and unambiguously. The figure displays essential components—anode, cathode, electrodes, voltmeter reading, and direction of electron movement—so students can readily follow the underlying process. Well-designed visuals with explicit surface features support meaning that is accessible at a glance [7].

Figure 6 (b) presents an implicit representation for the standard reduction-potential label found in B3 (8.3%). Unlike books that present this concept explicitly, the figure includes only one labeled arrow, H_2O (g), while other arrows lack explanation, which may cause confusion. In [1], implicit representations are those in which the meanings of surface features are not fully specified; similar issues are reported in [25].

Figure 6 (c) exemplifies an ambiguous representation within the standard cell-potential label (11.8%) in B4. No arrows or explanatory labels accompany the figure, preventing immediate interpretation by students. Ambiguity of this kind is associated with difficulty in comprehension and a higher need for instructor clarification [27].

The number of C2 representations in each typology is summarized in Table 7.



a. b.

c.

Figure 6. (a) Explicit picture of standard cell potential, (b) Implicit picture of the reduction cell potential, (c) ambiguous picture of standard cell potential concept label.

Table 7. Total Number of Criteria 2 (C2)

Category	Typology	Book					Total	% of Total
		B1	**B2**	**B3**	**B4**	**B5**		
C2	Eksplisit	5	3	5	6	4	23	79,3
	Implisit	0	1	1	1	1	4	13,8
	Ambigous	1	0	0	1	0	2	6,9
	Total						**29,0**	

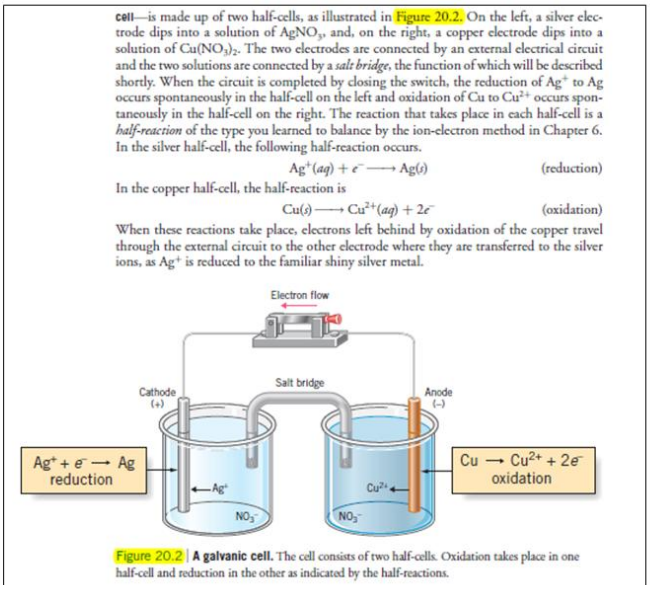
3. C3 (Relatedness to Text)

Relatedness to text evaluates the clarity and strength of the connection between a visual representation and the accompanying prose. In the context of cell potential, figures should support the text by visualizing processes such as electron flow and ion movement. This criterion comprises five categories—completely related and linked; completely related and unlinked; partially related and linked; partially related and unlinked; unrelated. After analysis, C3 was identified only under the labels standard reduction potential and standard cell potential, with 32 representations. A detailed breakdown appears in Table 8.

Table 8. Typologi of C3 (Relatednees to the text).

Concept labels	Typology	Book					Total	% of Total
		B1	**B2**	**B3**	**B4**	**B5**		
Standard reduction potential	Completely related and linked	3	1	2	3	3	12	100,0
	Completely related and unlinked	0	0	0	0	0	0	0,0
	Partially related and linked	0	0	0	0	0	0	0,0
	Partially related and unlinked	0	0	0	0	0	0	0,0
	Unrelated	0	0	0	0	0	0	0,0
	Total						**12**	
Standard cell potential	Completely related and linked	4	4	5	5	2	20	100,0
	Completely related and unlinked	0	0	0	0	0	0	0,0
	Partially related and linked	0	0	0	0	0	0	0,0
	Partially related and unlinked	0	0	0	0	0	0	0,0
	Unrelated	0	0	0	0	0	0	0,0
	Total						20	
Non-standard cell potential	Completely related and linked	0	0	0	0	0	0	0,0
	Completely related and unlinked	0	0	0	0	0	0	0,0
	Partially related and linked	0	0	0	0	0	0	0,0
	Partially related and unlinked	0	0	0	0	0	0	0,0
	Unrelated	0	0	0	0	0	0	0,0
	Total						0	
The relationship of cell potential (Eocell) and Gibb free energy (ΔGo)	Completely related and linked	0	0	0	0	0	0	0,0
	Completely related and unlinked	0	0	0	0	0	0	0,0
	Partially related and linked	0	0	0	0	0	0	0,0
	Partially related and unlinked	0	0	0	0	0	0	0,0
	Unrelated	0	0	0	0	0	0	0,0
	Total						0	
	Total Number						**32**	

Both concept labels—and the corresponding counts—show that all analyzed representations fall into category (i) completely related and linked. Every figure contains explicit references and clear connections to the text, enabling students to coordinate what they read with what they see. For example, the Cu–Ag voltaic-cell figure from B1 (Figure 7) and its accompanying text are fully complementary: the image and prose explain the same process, reinforcing understanding through a multiple-representation display. The total for C3 is summarized in Table 9.



cell—is made up of two half-cells, as illustrated in Figure 20.2. On the left, a silver electrode dips into a solution of $AgNO_3$, and, on the right, a copper electrode dips into a solution of $Cu(NO_3)_2$. The two electrodes are connected by an external electrical circuit and the two solutions are connected by a *salt bridge*, the function of which will be described shortly. When the circuit is completed by closing the switch, the reduction of Ag^+ to Ag occurs spontaneously in the half-cell on the left and oxidation of Cu to Cu^{2+} occurs spontaneously in the half-cell on the right. The reaction that takes place in each half-cell is a *half-reaction* of the type you learned to balance by the ion-electron method in Chapter 6. In the silver half-cell, the following half-reaction occurs.

$$Ag^+(aq) + e^- \longrightarrow Ag(s) \qquad \text{(reduction)}$$

In the copper half-cell, the half-reaction is

$$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^- \qquad \text{(oxidation)}$$

When these reactions take place, electrons left behind by oxidation of the copper travel through the external circuit to the other electrode where they are transferred to the silver ions, as Ag^+ is reduced to the familiar shiny silver metal.

Figure 20.2 | **A galvanic cell.** The cell consists of two half-cells. Oxidation takes place in one half-cell and reduction in the other as indicated by the half-reactions.

Figure 7. An example of the application of representation analysis regarding a category that is completely related and linked.

Table 9. Total Number of Criteria 3 (C3).

Category	Typology	Book					Total	% of Total
		B1	**B2**	**B3**	**B4**	**B5**		
C3	Completely related and linked	7	5	7	8	5	32	100,0
	Completely related and unlinked	0	0	0	0	0	0	0,0
	Partially related and linked	0	0	0	0	0	0	0,0
	Partially related and unlinked	0	0	0	0	0	0	0,0
	Unrelated	0	0	0	0	0	0	0,0
	Total						**32,0**	

Based on Table 9, all representations are type (i), which supports comprehension. Other factors also influence how well students interpret a figure, notably the presence of captions. Well-crafted captions allow students to grasp a representation without reading the entire passage. The next section therefore examines C4, the existence and properties of captions.

4. C4 (Existence and Properties of a Caption)

Existence and properties of a caption are criterion that assesses whether an appropriate caption accompanies a representation or if there are problems with the captioning [1]. Captions are essential because they help readers understand the content and message of the representation presented, making it easier for students to interpret the representation without relying entirely on the explanatory text [7]. Criterion C4 has been met in all five general chemistry books analyzed, as shown in Table 10**.**

Based on Table 10, visual representations under the labels standard cell potential and standard reduction potential met the typology *appropriate information present*. All images were accompanied by informative and precise captions. Appropriate and accurate captions support understanding and minimize extraneous cognitive load [5].

Figure 8 (B2) exemplifies compliance with C4. The caption explains the experimental context, reaction direction, electrode potential values, and the calculation of cell potential. Captions play a crucial role in enhancing comprehension; prior work notes that well-written captions help convey content without requiring readers to consult the full explanatory text [7]. The total number for Criterion 4 is presented in the Table 11.

Table 10. Typology of C4: Existence and properties of a caption.

Concept labels	Typology	Book					Total	% of Total
		B1	B2	B3	B4	B5		
Standard reduction potential	The existence of appropriate information	3	1	2	3	3	12	100,0
	There is information accompanied by problems	0	0	0	0	0	0	0,0
	Without explanation	0	0	0	0	0	0	0,0
	Total						12	
Standard cell potential	The existence of appropriate information	4	4	5	5	2	20	100,0
	There is information accompanied by problems	0	0	0	0	0	0	0,0
	Without explanation	0	0	0	0	0	0	0,0
	Total						20	
Non-standard cell potential	The existence of appropriate information	0	0	0	0	0	0	0,0
	There is information accompanied by problems	0	0	0	0	0	0	0,0
	Without explanation	0	0	0	0	0	0	0,0
	Total						0	0,0
The relationship of cell potential (Eocell) and Gibb free energy (∆Go)	The existence of appropriate information	0	0	0	0	0	0	0,0
	There is information accompanied by problems	0	0	0	0	0	0	0,0
	Without explanation	0	0	0	0	0	0	0,0
	Total						0	0,0
	Total Number						**32**	

Table 81. Total Number of Criteria 4 (C4)

Category	Typology	Book					Total	% of Total
		B1	B2	B3	B4	B5		
C4	The existence of appropriate information	7	5	7	8	5	32	100,0
	There is information accompanied by problems	0	0	0	0	0	0	0,0
	Without explanation	0	0	0	0	0	0	0,0
	Total						**32**	

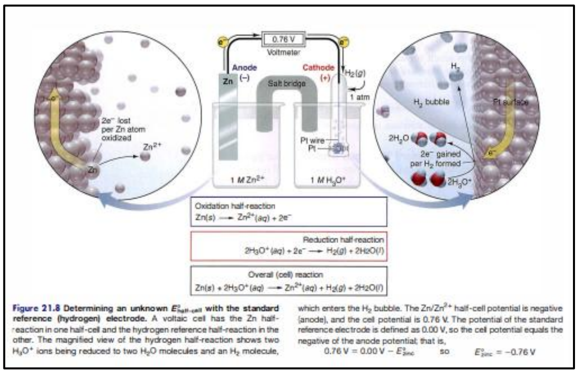


Figure 8. A well-captioned representation fulfilling Criterion C4 (existence and properties of a caption), showing the measurement of Zn^{2+}/Zn standard electrode potential using the SHE.

The presence of clear and accurate captions across all representations constitutes a positive finding for student learning. Ensuring that students integrate information across representation levels requires more than captions alone. Criterion 5 (C5) evaluates these connections—macroscopic to submicroscopic, macroscopic to symbolic, or all three—and is addressed in the next section.

5. C5: Degree of Correlation Between The Components (Subordinate Representations) Comprising a Multiple Representation

Criterion 5 (C5) focuses on evaluating the extent to which the components of multiple representations (macroscopic, submicroscopic, and symbolic) are connected based on the previously identified C1 criteria. This criterion is divided into three typologies, namely quite related, not quite related, and not related. The combination of representations will undoubtedly be beneficial [4], and the use of multiple representations simultaneously in learning chemistry can reduce student misconceptions [20], especially for abstract topics such as cell potential. Some studies reveal that students have difficulty connecting the three levels of chemical representations, as well as how they change from one representation to another [1], [19], [20], [26].

Based on an analysis of five general chemistry textbooks, all books were identified as containing C5 criteria, but only in the labels for standard reduction potential and standard cell potential. Based on 31 identified representations, the quite related typology accounted for 74.2%. A small portion belonged to the not-quite-related typology, accounting for 19.4%, and 6.5% belonged to the not-related category. Therefore, the discussion of the C5 criteria in this study will focus on these two concept labels, as shown in **Table 12.**

Table 92. Total Number of Criteria 5 (C5).

Category	Typology	Book					Total	% of Total
		B1	B2	B3	B4	B5		
C5	Quite related	4	4	7	7	1	23	74,2
	Not quite related	3	1	0	0	2	6	19,4
	Not related	1	0	0	1	0	2	6,5
Total							**31,0**	

A more in-depth analysis of the two concept labels identified as meeting criterion 5 (C5), namely, standard reduction potential and standard cell potential. 70.0% of the visual representations on the standard reduction potential concept label were categorized as quite related, and 30.0% were categorized as not quite related. Meanwhile, in the standard cell potential concept label, all typologies were identified, namely 76.2% quite related typologies, 14.3% not quite related typologies, and 9.5% unrelated typologies. The details can be seen in Table 13 below.

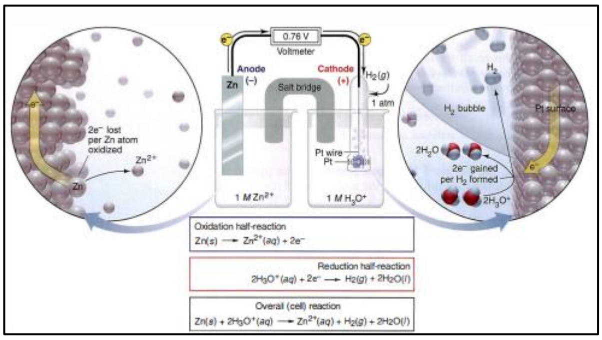
Table 13. Classification of C5 Typologies Based on the Degree of Correlation Between Representational Components Across Two Concept Labels in Five Chemistry Textbooks.

Concept labels	Typology	B1	B2	B3	B4	B5	Total	% of Total
Standard reduction potential	Quite related	1	1	2	3	0	7	70,0
	Not quite related	2	0	0	0	1	3	30,0
	Not related	0	0	0	0	0	0	0,0
	Total						10	
Standard cell potential	Quite related	3	3	5	4	1	16	76,2
	Not quite related	1	1	0	0	1	3	14,3
	Not related	1	0	0	1	0	2	9,5
	Total						21	
Non-standard cell potential	Quite related	0	0	0	0	0	0	0,0
	Not quite related	0	0	0	0	0	0	0,0
	Not related	0	0	0	0	0	0	0,0
	Total						0,0	
The relationship of cell potential (Eocell) and Gibb free energy (ΔGo)	Quite related	0	0	0	0	0	0	0,0
	Not quite related	0	0	0	0	0	0	0,0
	Not related	0	0	0	0	0	0	0,0
	Total						0,0	
	Total Number						**31**	

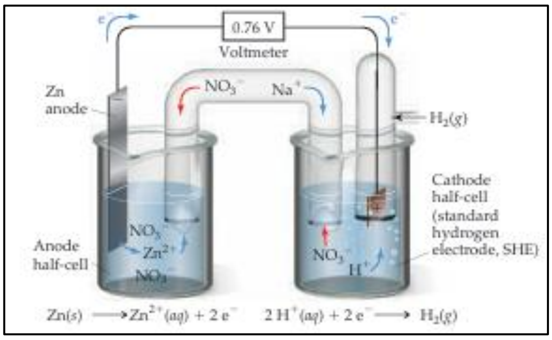
a. Standard reduction potential

Only B2, B3, and B4 present multiple representations with the *quite related* typology. B2 and B4 (Figure 9(a)) demonstrate strong cross-level connections—macroscopic (voltaic-cell circuit), submicroscopic (visualization of ions and electrons in each compartment), and symbolic (redox equation). Arrows indicate electron flow, and color coding differentiates ions, electrons, and other elements, guiding readers through the redox process and the mechanism that produces cell voltage. B3 (Figure 9(b)) includes two levels (macroscopic and symbolic) and still makes interrelations explicit via arrows and symbols that track electron flow; classification remains *quite related*.

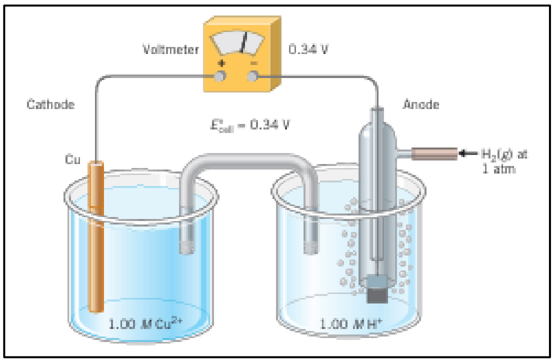
B1 and B5 fall under *not quite related*. Both provide two levels—macroscopic (voltaic-cell diagram) and symbolic (descriptions of solution, electrodes, and voltmeter reading)—in parallel, which allows partial understanding. Lack of explicit mapping between diagram features (e.g., circles) and the chemical species they represent motivates the *not quite related* classification [12].



a.



b.



c.

Figure 9. Comparison of multiple representations related to standard cell potential in selected chemistry textbooks. a) B2: three-level representation classified as a quite related typology. (b) B3: Two-level representation classified as quite related typology (c).

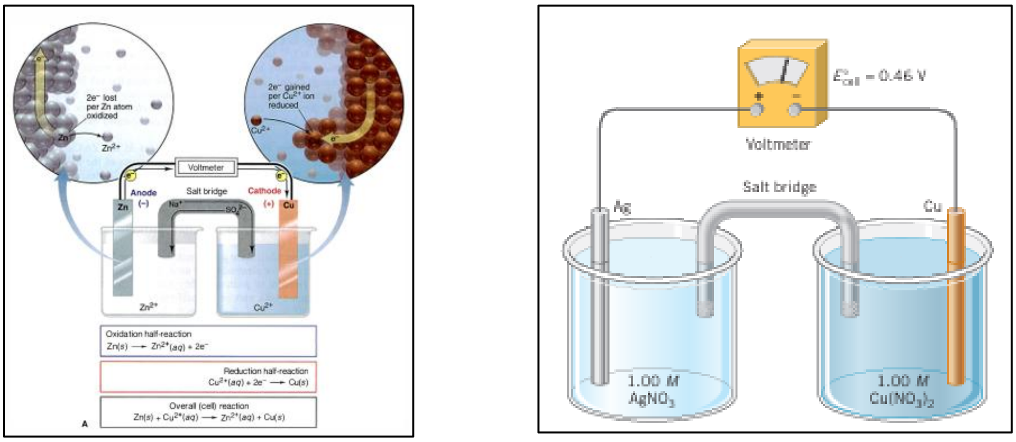
b. Standard cell potential

Representations for the standard cell potential across the five textbooks fall into two typologies—*quite related* and *not quite related*. Most instances in B1–B5 meet the *quite related* typology (Table 13). Figure 7(a) from B2 offers a complete, explicit example, displaying three levels within one illustration: macroscopic (Cu–Zn voltaic-cell circuit), submicroscopic (visualizations of Zn^{2+} and Cu^{2+} ions, electron flow, and redox processes highlighted by magnification near the electrodes), and symbolic (half-cell and overall reactions). Arrows, color coding for particles, and consistent labels reinforce cross-level correspondence and clarify how electron transfer from anode to cathode yields a potential difference.

Figure 7(b) from B1 exemplifies the *not quite related* typology. The figure contains two levels—macroscopic (Ag–Cu voltaic-cell diagram) and symbolic (reported cell potential of 0.46 V)—without an explicit explanation of how the two levels correspond. Direction of electron flow, oxidation–

reduction processes, and electrode roles are not indicated visually. Classification under C5 as *not quite related* follows the scheme in [12].

Among the analyzed texts, B3 provides the most consistent C5 integration, with seven representations categorized as *quite related* and none as *not quite related* or *unrelated*. Consistency arises from stable visual conventions and integrated informational cues. B5 provides limited integration; only one representation is categorized as *quite related* for the standard cell-potential label, none for the standard reduction-potential label, and several instances fall under *not quite related*. The analysis is descriptive of representational practice rather than a global evaluation of the textbooks.



a. b.

Figure 7. Standard cell-potential representations. (a) B2: three-level (macro–submicro–symbolic), *quite related*; arrows, color coding, and labels link components. (b) B1: two-level (macro + symbolic), *not quite related*; lacks explicit cross-level mapping.

Disconnected multiple representations hinder transfer across levels (e.g., from symbolic to macroscopic or from macroscopic to submicroscopic), increasing the likelihood of misconceptions in electrochemistry [5], [27]. Integrated designs function as bridges across levels and support the process visualization required for conceptual understanding [5], [27].

CONCLUSION

Analysis across five general-chemistry textbooks shows variation in the depth and relevance of visual representations. Four concept labels related to cell potential were examined; symbolic forms were most frequent (74.7%), followed by macroscopic (10.9%). Hybrid (5.8%), submicroscopic (4.4%), and mixed (0.3%) representations appeared infrequently. Findings indicate that student understanding improves when connections among representation levels are made explicit. Many learners struggle to link one level to another; textbooks that omit clear cross-level mapping can invite misconceptions, particularly in electrochemistry [19]. Difficulties arise when students must connect observable phenomena to invisible ionic/electronic processes and then express these using symbols or equations. Textbook authors are advised to integrate representations consistently for cell-potential content, using device cues such as arrows for electron flow, clear electrode labels, and balanced inclusion of redox equations alongside particle-level depictions. Educators should scrutinize adopted texts—especially for conceptually dense topics—and favor materials that present multiple, explicitly interconnected representations to support more meaningful learning.The research carries practical implications for educators, textbook authors, and students. Results can guide the selection and development of representation-based teaching materials and inform the design of visual content that is more structured and interactive. For learners, well-designed representations ease concept acquisition, facilitate cross-level reasoning, and reduce the likelihood of misconceptions.The study contributes evidence on the importance of integrating visual representations in chemistry textbooks, with particular relevance to cell potential, and can inform the development of resources that better support conceptual and meaningful learning in chemistry

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