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Analysis of Chemical Representations in the Physical Sciences Textbooks for Grade 12 Learners in South Africa

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Abstract

Textbooks play a prominent role in the teaching and learning of chemistry. It is the major organiser and the intended curriculum teachers adapt for their instructional practices. Although chemistry is abstract in nature, the use of visuals or images in textbooks to depict chemical phenomena at different levels remains a meaningful approach to help facilitate students' understanding of chemistry. Therefore, this study analysed chemical representations in the chemistry components of the Physical Sciences textbooks for grade 12 learners in South Africa. Three textbooks were selected and analysed using the five criteria developed by Gkitzia, Salta and Tzougraki (2011). The findings revealed that the chemical representations in the textbooks were largely at the macroscopic and hybrid levels, with surface features that are ambiguous or explicit and representations that are unlinked to text. In addition, there were few sub-microscopic, multiple, and mixed representations in the textbooks. An interesting result is that a majority of the chemical representations had appropriate captions. The implications of these findings for textbook authors or publishers were discussed.

Introduction

Research on textbook analysis in science education is well-documented. For instance, there is an extensive body of research on textbook analysis that focused on the nature of science (e.g. Abd-El-Khalick, et al., 2017; Aydin & Tortumlu, 2015; Irez, 2009; Ramnarain & Chanetsa, 2016), errors and misconceptions or alternative conceptions about chemical concepts (Bergqvist, Drechsler, De Jong & Rundgren, 2013; Pedrosa & Dias, 2000), the types of questions/problems included in textbooks (Davila & Talanquer, 2010; Gillette & Sanger, 2014), the inscriptions in chemical reactions (Aydin et al., 2014; Han & Roth, 2005) across grade levels, topics and in different contexts. Research interest on textbook analysis is connected to the enormous influence textbooks have on students' learning of science, particularly chemistry. As such, research on the quality of textbooks will continue to remain a focus of research to science educators, and researchers in different contexts and levels of education (Khine, 2013).

Chemistry, by its nature, is abstract (Johnstone, 2000; Taber, 2013), and is conceived to be difficult to teach and learn (Özmen, 2011). The study of chemistry deals with natural phenomena that are not open to direct observation or experience. The understanding of these phenomena requires specialised symbol systems invented by chemists to help visualise and communicate chemical concepts. While there is an aspect of chemistry that can be directly experienced in laboratory experiments, Johnstone (2000) acknowledged that for chemistry to be well-understood, there is the need to move from the *tangible* to the *sub-micro* level where "*the behaviour of substances is interpreted in terms of the unseen and molecular, and recorded in some representational language and notation*" (p. 35). This informed Johnstone's thought of chemistry at three different levels of macroscopic, sub-microscopic and symbolic – that complement each other in explaining chemical phenomena.

According to Kozma and Russell (2005), by the means of these specialised symbols/external representations (chemical equations, molecular formulas, molecular models, and Fischer projections), learners visualise chemistry and are able to create mental images (as internal representations) of chemical phenomena that helps them to understand molecular structures and the relationships between atoms, molecules and ions. Kozma and Russell (2005) proposed and described this ability as *representational competence* – "*a set of skills and practices that allow a person to use various representations or visualizations, to think about, communicate, and act on chemical phenomena…*" (p. 131). However, studies have shown that students rarely used visual representations to discuss the molecular level of chemical reactions in reporting laboratory activities, instead, they focus on macroscopic descriptions of the chemical concepts Kozma, 2000; 2003). This has far-reaching implications for learners who may not be able to represent and translate chemical phenomena between the levels in solving chemical problems. Therefore, developing conceptual understanding of chemistry could remain a learning challenge (*e.g.,* Gkitzia, Salta & Tzougraki, 2011, 2020; Ramnarain & Joseph, 2012).

Consequently, Shehab and BouJaoude (2016) suggested that the development of representational competencies should become a major objective in chemistry curriculum documents. Interestingly, this advocacy is already reflected in the South African Curriculum and Assessment Policy Statement (CAPS) document for Physical Sciences. For instance, the CAPS document states that teachers should link macroscopic, sub-microscopic and symbolic representations in their explanations of reduction-oxidation (redox) reactions (Department of Basic Education [DoBE], 2011). While this is commendable, it is important to understand how this curriculum expectation is [re]presented or interpreted in the Physical Sciences texts by textbook authors or publishers. This raises a question of whether authors or publishers take this into consideration in their design and integration of chemical representations in textbooks.

Irez (2009) argue that the presentation of uniformed ideas in textbooks could affect students' understanding in direct or indirect ways. Chemistry subject-specific information that learners encounter in their use of textbooks must be such that can promote or foster their representational competence of chemical phenomena. Since textbooks are readily available resources from which students can understand chemical concepts and develop representational skills, research focus on how textbooks present these chemical phenomena is relevant and appropriate. Hence, this study examined how chemical representations are presented in Grade 12 Physical Sciences textbooks.

Theoretical Foundations

The frameworks developed by Mayer (2002) and Gkitzia, Salta and Tzougraki (2011) have been used in several studies to analyse visual representations in chemistry textbooks. Mayer (2001, 2002) propounded a "cognitive theory of multimedia learning" and used this concept along with research evidence from literature to develop eight principles that could enhance the effective design and implementation of multimedia instruction. According to Mayer (2002), the eight principles use the dual channel of "auditory-verbal and visual-pictorial" inputs to address limited cognitive capacity and support students' active processing required for conceptual understanding of difficult concepts and principles in solving novel problems. Mayer's multimedia learning principles have implications on how visual representations are presented in textbooks, as the contiguity principles urges the simultaneous use of texts and images to help students develop conceptual understanding of the chemical concepts.

Inspired by Johnstone's (1993) levels of chemistry, Gkitzia et al. (2011) developed and validated a rubric that include other typologies of representations or visualisations of chemical phenomena. These typologies describe chemical representations that combines Johnstone's (1993) levels to form multiple, hybrid or mixed representations. An elaborate description of the criteria developed by Gkitzia et al. (2011) is presented in the method section. The *macroscopic* representations depict chemical phenomena that are observable through the human senses. These involve direct experiences in the laboratory and everyday life, such as change in colour of chemical substances during chemical reactions, or in pictures or diagrams (Treagust, Chittleborough, & Mamiala, 2003). The s*ub-microscopic* representations use ball and stick, and the space filling models as molecular models to depict the features and movement of, and relationships between unseen particles (*e.g.,* atoms, ions, and molecules) (Wu & Shah, 2004). The s*ymbolic* representations are the letters, symbols, numbers, and signs used to represent atoms, molecules, ions involved in chemical reactions. The quantitative relationships between them are expressed using graphs and formulas in algebraic form.

Review of Literature on Chemical Representations

As mentioned earlier, there is extensive empirical research on textbook analysis in chemistry education. Other studies have focused on chemical representations in textbooks used by high school or college students (*e.g*., Demirdöğen, 2017; Nyachwaya & Wood, 2014; Gkitzia et al., 2011; Kapici & Açikalin-Savaşci, 2015; Shehab & BouJaoude, 2016; Upahi & Ramnarain, 2019). Gkitzia et al. (2011) developed five criteria and applied this as an instrument to analyse a Grade 10 Greek chemistry textbook. Findings revealed that macroscopic, sub-microscopic, symbolic, and multiple representations were the most common types of representations used. In terms of relatedness of representations to text, more than half of the chemical representations were completely related. Only about one-third of the representations explicitly mentioned the surface features. The remaining two-thirds of the representations either had ambiguous or implicit labelling. The majority of the representations had appropriate captions. Researchers have adapted this instrument to analyse chemical representations in chemistry textbooks used in different countries. For instance, Shehab and BouJaoude (2016) evaluated Grades 10 – 12 Lebanese high school chemistry textbooks and reported findings comparable to the work of Gkitzia et al. (2011). In more than half of the multiple representations, the degree of correlation between the subordinate representations were equivalent.

Nyachwaya and Wood (2014) also adapted and used the rubric to evaluate representations in physical chemistry textbooks used in the United States. In their study, the representations were largely symbolic, followed by sub-microscopic representations. Macroscopic representations were reported as the least, while mixed and hybrid representations were non-exist. Interestingly, a majority of the representations had explicit surface features and were completely related to text. Representations were appropriately captioned for students to comprehend. Similarly, Nyachwaya and Gillaspie (2016) examined general chemistry textbooks for the number of representations, physical integration to the text, labelling, figure indexing, extended captions, representation function, and conceptual integration. The result showed that a high proportion of the representations were representational, which presents the information in a new way. About 80% of representations in the textbooks were directly integrated with appropriate captions. With respect to indexing, a large number of the representations were either indexed on a different page or not indexed at all. Kapici and Açikalin-Savaşci (2015) investigated visual representations of a particulate nature of matter in

Grades 6 – 8 Turkish science textbooks. The authors also reported findings that showed the prevalence of macroscopic representations, followed by sub-microscopic, symbolic, and multiple representations. The least used visuals were the hybrid and mixed representations. The results further showed that two-thirds of visuals were completely related and linked. A surprising result was that more than half (63%) of the visuals were not appropriately captioned.

We have noted that chemists invented and use chemical representations to reflect on their investigations, explain and justify their findings (Kozma, 2003). These representations, in their different forms, have been a useful framework to support teachers' instructional practices and students' understanding of chemical concepts. If students are to think as chemists, textbook authors or publishers must adapt the representations of chemical phenomena that align with Johnstone's (1982) levels of chemistry. While we do not claim that the integration of visual images as chemical representations in textbooks will automatically translate to students' use of these visualisations in their reasoning/explanations, we argue that their appropriate presence could be a step towards familiarising students with the different levels of depicting a chemical phenomenon (Shehab & BouJaoude, 2016). Likewise, teachers who rely on textbooks could also become familiar with these representations and how best to incorporate them in their explanations of chemical concepts during classroom activities and as assessment tools.

In analysing chemical representations in the Physical Sciences textbooks, our goal was to determine how the textbooks present and link visuals at the different levels of representations to explain chemical phenomena. We also intend to enrich studies about chemical representations in the Physical Sciences textbooks. In South Africa, studies on textbooks analyses have only focused on examining the nature of science (*e.g.*, Ramnarain, 2017; Ramnarain & Chanetsa, 2016; Ramnarain & Padayachee, 2015), science practices (Ndumanya, Ramnarain & Wu, 2021), quality of science textbooks (Swanepoel, 2010). To the best of our knowledge, there is no cited work that has analysed chemical representations in the Physical Sciences textbooks used by South African learners. Therefore, this study examined characteristics of chemical representations in Grade 12 Physical Sciences textbooks used by South African learners. Specifically, the study sought to provide answers to the following research questions.

1. What is the degree of interpretation of surface features of chemical representations in the Grade 12 Physical Sciences textbooks?
2. What is the extent of relatedness of text to chemical representations in the Grade 12 Physical Sciences textbooks?
3. How appropriate are the existence and properties of captions in the Grade 12 Physical Sciences textbooks?

Context for the Research

In South Africa, the school system has four phases that include the: foundation (Grades R – 3), intermediate (Grades 4 – 6), senior (Grades 7 – 9) and further education and training (FET) (Grades 10 – 12) phases. Science is taught in all the phases but not as a general course. From Grades 4 – 9, chemistry is taught with other sciences, namely, biology and physics as Natural Sciences. At the FET phase, the combination of chemistry and physics are taught to Grades 10 – 12 learners as Physical Sciences. The CAPS for Physical Sciences is designed/formulated for the FET phase that spans three years. The CAPS document is standardized, and it culminates into the National Senior Certificate, also known as matriculation examination at the exit-class of Grade 12. The CAPS that is an amendment of the National Curriculum Statement aims to produce learners who will be able to "*identify and solve problems and make decisions using critical and creative thinking…collect, analyze, organize and critically evaluate information;*

communicate effectively using visual, symbolic and/or language skills in various modes…and demonstrate an understanding of the world as a set of related systems by recognizing that problem solving contexts do not exist in isolation" (DoBE, 2011, p. 5). In implementing this curriculum document, textbooks are listed as key resource materials to support teachers' instruction and learners' learning of the Physical Sciences. As such, high school learners' typically used textbooks to study, alongside other resources.

Research Method

Data Sources

This research is a qualitative study that employed content analysis to examine chemical representations in the Physical Sciences textbooks used by Grade 12 learners in South Africa. Krippendorff (2004) defined content analysis as a "*research technique for making replicable and valid inferences from texts to the contexts of their use*" (p. 18). In content analysis, inferences are made from different types of data: verbal, pictorial, symbolic, and written communication. Content analysis also includes quantitative aspect. In quantitative content analysis, data collection begins with pre-determined codes and categories. In the present study, we adopted a deductive approach to analyse Physical Sciences textbooks using Gkitzia et al.'s (2011) criteria as the analytical framework.

Three Grade 12 Physical Sciences textbooks were selected for analysis. The textbooks are included in the approved list of textbooks for school purchases by the DoBE. While we may not have information on the market share of the selected textbooks, the books are commonly used among high school learners, and are generally available in bookstores in South Africa. The sample of textbooks may also not be comprehensive; however, it can reasonably be construed as a representative and fit for purpose. Copies of the textbooks were obtained from the library of the second author. The three textbooks analysed in this study are labelled and hereafter referred to as Textbook 1, Textbook 2, and Textbook 3. Given that Physical Science is a combination of chemistry and physics subjects, only the chemistry components in each of the textbooks were identified and analyzed for chemical representations.

Data Analysis

Before the analysis, all the images (pictures or figures), diagrams and drawings that depict chemical phenomena were identified as the units of analysis. A total number of 371 chemical representations were identified from the textbooks. Since our interest was not to compare the visualisations in the three textbooks, we merged the representations together. These units of analysis were the chemical representations we coded and analysed based on the Gkitzia et al.'s (2011) criteria and their typologies (see Table 1).

To ensure the reliability of the analysis, 20% of the chemical representations were randomly selected and coded independently by two raters. The raters compared their results, and where there were discrepancies, the raters discussed extensively and reached a consensus. Following this step, the remaining representations were coded and analysed by the first author. The inter-rater reliability was calculated and established at 92% for types of representations, 78% for the interpretation of surface features, 85% for relatedness to text, 80% for the existence and properties of captions. These reliability values indicate a good measure of agreement between the raters and was considered acceptable.

The rubric built on Johnstone's three levels of chemistry. While there have been different modifications and [re]interpretation of this framework among chemistry educators, the initial three levels of macroscopic, submicroscopic, and symbolic can be used together to explain chemical phenomena. This has led to additional levels: hybrid, multiple and mixed representations. Put together, these six levels/types of representation formed the first criterion in the Gkitzia's rubric. A detailed description of the characteristics of the five criteria labelled as C1–C5 and their typologies is provided in the next paragraphs and summarised in Table 1.

C1: Types of representation: A representation could be coded into any of these six typologies: macroscopic, submicroscopic, symbolic, hybrid, multiple and mixed. The first three types of representations are based on Johnstone's original definitions (1991). A representation is coded as *hybrid* if it combines the features of two levels of representations, while a *multiple* representation depicts a chemical phenomenon at more than one level of representation simultaneously. On the other hand, a representation is coded as *mixed* if one of the three levels of representation and another kind of representation such as analogy are used together (Gkitzia et al., 2011).

C2: Interpretation of surface features: This criterion examines the clarity of the surface features of chemical representation. Clarity of labelled features could help students understand content and develop correct mental images of chemical phenomena. Surface features of a representation could either be coded as explicit, implicit, or ambiguous. Interpretation and meaning of surface features that are clearly mentioned in the text or included in the caption are coded *explicit*. A representation is coded *implicit* if the meaning of a surface feature is included in the text but not clearly mentioned. For a representation with no indication of the meaning of surface features, such was coded *ambiguous*.

C3: Relatedness to text: This criterion measures explicit reference of representations within the texts content. It investigates the extent to which a representation is comprehensible, related and linked to the text. The work of Pozzer and Roth (2003) suggested a clear articulation between images and texts that could help textbook users establish a link and make sense of the chemical phenomenon in pictures or diagrams. The criterion has five typologies that include: (i) completely related and linked, (ii) completely related and unlinked, (iii) partially related and linked, (iv) partially related and unlinked, (v) unrelated. A chemical representation is coded *completely related* if it depicts the exact text content. A chemical representation is coded partially related if the representation depicts a similar subject to the text but not the exact one. In contrast, a representation is labeled *unrelated* if it is not linked to the text content. In addition, a representation is coded as *linked* or *unlinked* if the text refers to it by using a direct link or not respectively, that is, with or without a phrase such as, "as shown in a Figure".

C4: Existence and properties of a caption: The basis of this criterion is to examine the presence and appropriateness of captions. A caption that is brief, explicit, and comprehensive is coded *appropriate* because it provides autonomy for a chemical representation and guides the textbook user on what to look for, and how to read and understand the image or visual (Pozzer & Roth, 2003). A caption is coded *problematic* if it does not provide a correct description of the visual representation. Where a caption is non-existent, it is simply coded as *no caption*.

C5: Degree of correlation between representations comprising a multiple representation: This criterion investigates the extent to which correlation between representations that forms multiple representations are clearly indicated. It examines how sufficient and clearly linked the macroscopic, sub-microscopic, and symbolic levels that forms multiple representations are. This is important for students to be able to understand and translate between the representations. A multiple representation is coded as *sufficiently linked* if the links between different levels are clearly indicated with the use of arrows or signs. A multiple representation is coded as *insufficiently linked* if links between different levels are implicit without the use of arrows or signs to clearly indicate the levels. *Unlinked* multiple representations are placed next to each other with no indication of their equivalence.

Table 1. Criteria and their typologies for the analysis of chemical representations (Gkitzia *et al.*, 2011)

Criterion	Typology of criterion
C1: Types of representations	i. Macroscopic ii. Sub-microscopic 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 and linked ii. Completely related and unlinked iii. Partially related and linked iv. Partially related and unlinked v. Unrelated
C4: Existence and properties of caption	i. Existence of appropriate caption (explicit, brief, comprehensive, providing autonomy) ii. existence of problematic caption iii. No caption
C5: Degree of correlation between representations comprising a multiple one	i. Sufficiently linked ii. Insufficiently linked iii. Unlinked

Results

The results of our analysis of Physical Sciences textbooks are presented to answer the research questions.

1. What is the degree of interpretation of surface features of chemical representations in the Grade 12 Physical Sciences textbooks?

Table 2 shows how the types of representations differ in terms of the interpretation of surface features. The Macro (M) representations have surface features that can be categorised as explicit (53), implicit (35) and ambiguous (131). Most of the Hybrid (H) representations have surface features that are explicit (62), followed by implicit (30) and ambiguous (13). While there are fewer Symbolic (S), Sub-micro (SM), Multiple (M) and Mixed (MI) representations in the textbooks, the interpretations of their surface features are largely ambiguous (see Table 2). The predominance of ambiguous surface features can better be appreciated in Figure 1 (see examples of chemical representations with surface features in the Supplementary Material). Chemical representations that have surface features classified as ambiguous indicate that no meaning or explanation is attached, and as such students are left to decode the meaning of the features by themselves.

Table 2. Frequencies of interpretation of surface features based on types of representations

Types of representations	Interpretation of surface features			Total
	Explicit	Implicit	Ambiguous	
Macro (M)	53	35	131	**219**
Sub-micro (SM)	4	2	18	**24**
Symbolic (S)	1	-	15	**16**
Multiple (M)	1	2	2	**5**
Hybrid (H)	62	30	13	**105**
Mixed (MI)	1	-	1	**2**
Total	**122**	**69**	**180**	**371**

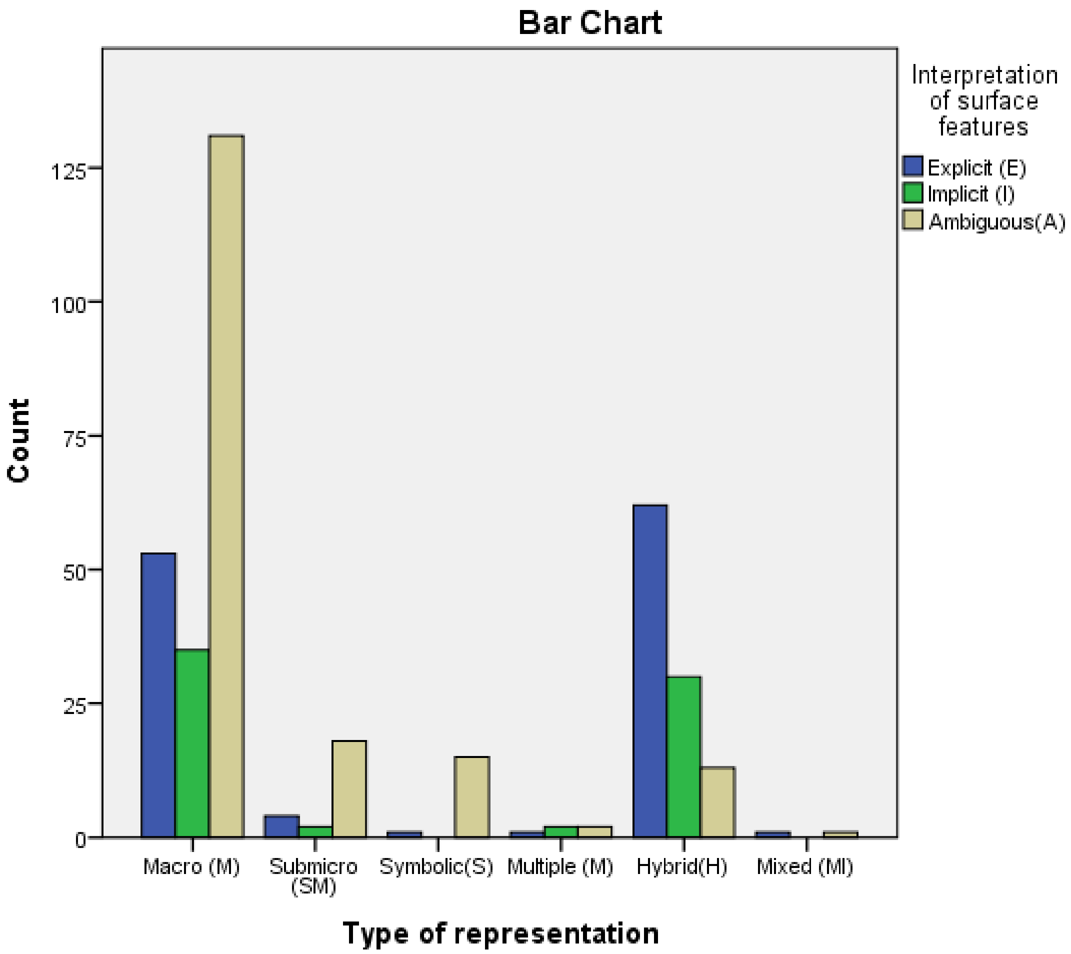

Figure 1. A graphical distribution of the types of representations in chemistry textbooks

2. What is the extent of relatedness of text to chemical representations in the Grade 12 Physical Sciences textbooks?

From Table 3, a sizable number of the chemical representations in the Physical Sciences textbooks were completely related and linked (142). However, a majority of the representations found to be completely related were unlinked (147). The next prevalent categories were the representations that are partially related and unlinked (47), and unrelated (30). The number of representations that are partially related and linked was relatively small (5). The relatedness of representations to text are distributed across the different types of representations. The relatedness of representations to text that are completely linked (77) and unlinked (91) were also significantly high for Macro (M) representations, followed by Hybrid (H) representations. Although there is a decrease in the number of representations that are partially related (linked/unlinked) and unrelated, their presence in the textbooks have the potential to constrain or limit students' understanding of the chemical phenomena depicted by the representations.

Table 3. Frequencies of the relatedness to text based on types of representations

Types of representations	Relatedness to text					Total
	Completely related and linked (CL)	Completely related and unlinked (CU)	Partially related and linked (PL)	Partially related and unlinked (PU)	Unrelated (U)	
Macro (M)	77	91	4	33	14	**219**
Sub-micro (SM)	7	12	-	5	-	**24**
Symbolic (S)	1	5	-	-	10	**16**
Multiple (M)	4	1	-	-	-	**5**
Hybrid (H)	51	38	1	9	6	**105**
Mixed (MI)	2	-	-	-	-	**2**
Total	**142**	**147**	**5**	**47**	**30**	**371**

3. How appropriate are the existence and properties of captions in the Grade 12 Physical Sciences textbook?

In answering research question 3, analysis of chemical representations for the existence and properties of captions indicates that a majority of the representations have appropriate captions that are explicit, brief, and comprehensive as shown in Table 4. While there was evidence of representations with no caption (58), 45 out of 371 representations had problematic captions (see an example in Supplementary Material). In terms of the distribution of properties of captions among the types of representations, the captions of Macro (M) and Hybrid (H) representations were the highest compared to others. Although Sub-micro (SM) representations in the textbooks are relatively small (24), the existence of appropriate captions for SM representations is noteworthy as they depict mental images of intangible chemical concepts or phenomena.

Table 4. Frequencies of existence and properties of caption based on types of representations

Types of Representations	Existence and properties of a caption			Total
	Appropriate caption	problematic caption	No caption	
Macro (M)	174	23	22	**219**
Submicro (SM)	18	3	3	**24**
Symbolic (S)	6	1	9	**16**
Multiple (M)	5	-	-	**5**
Hybrid (H)	64	17	24	**105**
Mixed (MI)	1	1	-	**2**
Total	**268**	**45**	**58**	**371**

Discussion

The main goal of this study was to examine chemical representations in Physical Sciences textbooks using the criteria developed by Gkitzia et al. (2011). Given the importance of chemical representations in the teaching and learning of chemistry, the use or integration of images in textbooks must be such that they are meaningful and appropriate if they are to help students construct correct mental images of chemical phenomena they portray. Findings from our analysis showed that the chemical representations in Physical Sciences textbooks were predominantly macroscopic, followed by hybrid, and then sub-microscopic. The number of symbolic, multiple, and mixed representations were quite low. For textbooks with chemical representations that are largely macroscopic, one wonders how learners will be able to construct mental models and develop in-depth understanding of chemical concepts that is said to be possible at the sub-microscopic level. These findings are consistent with other studies (Demirdöğen, 2017; Gkitzia et al., 2011; Shebab & Boujaoude, 2016). However, it is noteworthy that the presence of hybrid representations was quite high/significant compared to multiple and mixed representations. The hybrid representations depict the co-existence of two or three levels of representations that afford learners opportunity to see and mentally process the translations of chemical phenomenon between the levels of representation (Chittleborough & Treagust, 2008). The low proportion of multiple and mixed representations indicate inadequate integration of representations. The significant presence of these categories of representation would have shown how chemical phenomena at different levels are related. Treagust et al. (2003) has cautioned that the predominance of chemical phenomena at one level may likely lead to what the authors described as "*fragmented knowledge*" of chemical concepts.

With respect to the surface features of chemical representations, nearly half of the total representations were ambiguous. Only about one-third were explicit. Surface features of a representation should be clearly labelled and explicit enough to enhance students' meaning-making from their correct interpretation of the representation. The large number of ambiguous representations in the textbooks raises serious concern as learners are left to decipher or interpret the surface features by themselves. The implication is that learning could be hindered if extraneous cognitive overload occurs in learners because of poorly designed instructional materials, in this case textbooks. This finding is consistent to what is reported about Greek and

Lebanese textbooks (see Gkitzia et al., 2011; Shehab & BouJaoude, 2016), but differs from the results on Turkish textbooks (Demirdöğen, 2017).

From our analysis, the majority of the representations were completely related. While more than half of the representations were unlinked, only about one-third were found to be linked. This suggest that the phenomenon described in the text content were related to the representations, however, explicit reference in the text that would have served to link representations, which are often referred to as Figure, with numbers assigned, were missing. Regarding types of representations and their relatedness to text, a sizable number of macroscopic and hybrid, followed by sub-microscopic were unlinked. Textbook users may struggle to establish a link between the representation that depicts a phenomenon and the text content, and thereby cause a cognitive overload and a possible misconception in learning that arises from incorrect interpretation. This view is supported by Wu and Shah (2004) who proposed that chemical representations and the accompanying texts should be closely presented for students to understand the relationship between them.

Furthermore, our results indicate that most of the representations were accompanied by appropriate captions. Appropriate captions that are brief, explicit, and comprehensive makes chemical representations clear and understandable to textbook users. The existence of problematic captions with text content that are not clear, and representations with no caption, was high for representations at the macroscopic level. We found similar reports in the analysis of Turkish, Greek, and Lebanese textbooks (Demirdöğen, 2017; Gkitzia et al., 2011; Shehab & BouJaoude, 2016). We argue that a near 100% appropriate captions of chemical representations in textbooks is possible as reported in the study of Nyachwaya and Wood (2014) if textbook authors take cognizance of the Mayer’s (2002) principle of multimedia learning and the contiguity principle that encourage the use of words and pictures/images simultaneously in their design of textbooks.

These findings have implications for curriculum planners, textbook authors, and publishers. The results of our analysis have shown the representations in the textbooks were largely at macroscopic level. Therefore, textbook authors should recognise that for students to understand chemical phenomena depicted by representations, it is important to move from the macroscopic to submicroscopic representations where the behaviour of substances is interpreted in terms of the unseen and molecular (Johnstone, 2000). As such, there is the need to increase other types of representations as much as the macroscopic.

Conclusion

In this study, we have analysed chemical representations in the chemistry components of Physical Sciences textbooks used in South Africa. Our findings showed that the chemical representations used to depict chemical phenomena in the textbooks were largely at the macroscopic level, with surface features that are ambiguous and unlinked representations to text content. While chemical phenomena can be depicted at the discrete levels, the predominant use of macroscopic, sub-microscopic or symbolic does not seem to advance the notion that chemical phenomena can be presented using a combination of the different types of representations. Textbook authors must take cognizance of the fact that integration of these levels as hybrid, multiple and mixed representations have the potential to support students’ representational competence and increase their understanding of chemical concepts. In addition, since teachers also rely on the textbooks for their instructional practices, availability of the types of representations and how these representations are linked could provide them with visualizations resources to support students' conceptual understanding of chemical concepts. One limitation of this study is the generalizability of findings. The findings do not reflect the nature of chemical representations in all the Physical Sciences textbooks used by South African learners. Therefore, this highlights a possible line of future research that may examine all the Physical Sciences textbook to draw a general conclusion in light of the five criteria developed by Gkitzia et al. (2011).

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