AMERICAN UNIVERSITY OF BEIRUT

ANALYSIS OF THE CHEMICAL REPRESENTATIONS IN SECONDARY LEBANESE CHEMISTRY TEXTBOOKS

by

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AN ABSTRACT OF THE THESIS OF

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This study focused on the requirements that chemical representations should meet in textbooks in order to enhance conceptual understanding. Specifically, the purpose of this study was to evaluate the chemical representations that are present in seven secondary Lebanese chemistry textbooks. To determine whether the chemical representations present in the chemistry textbooks enhance conceptual understanding and support the three levels approach to teaching chemistry, an instrument adapted from Gkitzia et al (2011) was used. This instrument depends of five basic criteria: (a) type or level, (b) surface features, (c) relatedness to text, (d) existence and properties of a caption, and (e) degree of correspondence between representations comprising a multiple one. The results of the study revealed that the chemical representations used in the selected textbooks are focused on the macro level with either implicit or ambiguous labels. Moreover, the selected textbooks use very few multiple, hybrid or mixed representations. In addition, most chemical representations are accompanied by problematic or no captions. Recommendations for textbook writers and future research are discussed in light of these findings.

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CHAPTER I

Introduction

We live in a complex, rapidly changing, material world. Many aspects of this world require an understanding of the concepts of chemistry. This involves mentally engaging with representations of these concepts and the phenomena to which they relate (Gilbert & Treagust, 2008). The representation of chemical concepts is inherently multimodal. Consequently, successful learning of chemistry involves the construction of mental models at the macroscopic, microscopic and symbolic levels of representation. Recent research shows that the proper use of chemical representations by chemistry teachers enhances the development of mental models at the three levels (Cheng & Gilbert, 2008; Davidowitz & Chittleborough, 2008). This study aims to shift the focus of attention in chemistry education from the content matter to the nature of chemical representations as tools that increase visual literacy and mental model development at the three levels mentioned above. According to Gkitzia et al. (2011), the simple presence of such representations does not ensure that they sufficiently support students' understanding. Moreover, when they do not fulfill certain requirements, they may cause misconceptions. Thus, this study focuses on the requirements that chemical representations should fulfill in textbooks in order to enhance conceptual understanding.

In 1998, the Center for Educational Research and Development (CERD) implemented a new curriculum for all grade levels with a new set of instructional objectives. The implementation of the new curriculum was accompanied by the release of new textbooks on different subjects at different grade levels. In the absence of any cited study that evaluates the structure and content of the new chemistry textbooks, the purpose of this study is to evaluate the chemical representations that are present in the chemistry textbooks used in Lebanon.

Background

Science classrooms expose students to information through a variety of methodologies, including lectures, discussions, readings, lab experiences, cooperative learning, etc. The goal of these activities is to help students construct knowledge of scientific concepts. Students with a deep conceptual understanding of scientific concepts can apply this knowledge to generate inferences, solve problems, and take decisions. To assess the ways in which students learn and apply knowledge, psychologists have focused on cognitive processes including how information gets into memory (encoding), how information is accessed from memory (retrieval) and so on (Rapp, 2005). The large body of existing research on human memory seeks to outline the underlying mechanisms of thought by describing the types of mental representations that are encoded and retrieved during every day experiences. One construct that has received considerable attention with respect to memory is the mental model (Rapp, 2005).

Mental models are internal representations of information and experiences from the outside world. They are abstract concepts that are not directly observed. They are “dynamic representations that can change over time” (Rapp, 2005, p. 44). Individuals often develop and rely on inaccurate mental models (Vosniadou, 2003). Such models can lead to faulty reasoning. For example, one documented model includes children’s belief that the earth is a hallow sphere with a “flat” interior. This model, when applied by children, leads to inaccurate predictions about the earth (Vosniadou& Brewer, 1992).

Similar faulty models can be constructed across ages, experience levels, and topic domains (Carey, 1999).

Recent research has shown that mental models represent the perceptual and conceptual features of the external world, but are not the exact replica of that world (Barsalou, 1999; Rapp & Kurby, 2008). They are "imagistic representations that maintain the visual characteristics and physical feature-based relationships of objects and concepts, but are not inherently visual" (Rapp, 2005, p. 45). This imagistic nature of mental models makes them useful and necessary for considering the visuo-spatial characteristics of a concept or a system.

Science education is a domain in which teaching methodologies have often relied on matches between learning activities (i.e. external representations) and mental model construction. From a constructivist perspective, students come to the science classroom with many faulty mental models that are related to different science concepts. Such models or their misapplications in problem solving may lead to misconceptions. Therefore, helping students construct correct mental models or mediate existing models of scientific concepts become a major goal of science education that may lead to conceptual understanding (Gilbert &Treagust, 2008).

Visualization and Mental Models

Given this background, it is clear why science educators would be interested in the notion of mental models. Nevertheless, defining the circumstances that may or may not lead to the construction of an accurate mental model is not simple (Rapp, 2005). Recent research has shown that carefully designed visualization-based tasks can effectively engender the construction of mental models (Paivio, 1986; Rapp, 2005;

Tversky, 2002). Visualization is concerned with external representations, the systematic and focused public display of information in the form of diagrams, tables, graphs, etc. It is also concerned with internal representation, the mental model production, storage and use of an image that often is the result of external representation (Gilbert, 2008). According to Rapp (2005), visualization has become popular in science education as teachers seek new methods for presenting complex concepts and data to students.

External and internal representations associated with visualization are employed across the physical, social, and intellectual environment (Gilbert, 2008). A fluent performance in visualization has been described as requiring metavisualization and involving the ability to acquire, monitor, integrate, and extend learning from representations (Gilbert, 2005).

Visualization and Chemistry

Chemistry is particularly conceived by many as a difficult subject to teach and learn. Its abstract nature makes it seem unrelated to everyday experience. Moreover, understanding chemistry depends on the constant interplay between the macroscopic, the microscopic, and the symbolic levels. Examples of chemistry concepts that seem difficult to students include the mole concept, atomic structure, kinetic theory, thermodynamics, electrochemistry, chemical reactions, and chemical bonding (Georgiadou & Tsaparlis, 2000). According to Johnstone (1982) an expert in chemistry thinks at three levels: a) the macro level (observable and sensory phenomena), b) the micro level (atoms, molecules, ions), and c) the symbolic level (symbols, equations, mathematical relations). Conceptual understanding of chemistry requires building mental models at each level. This allows a student to shift between the levels and thus be able to solve different chemistry problems in a variety of situations. According to Gilbert (2008), visualization can help students construct mental models at each level especially at the micro level where concepts are unobservable in traditional classroom situations. This takes place when suitable teaching strategies help students develop metavisualization skills at the macro, micro and symbolic levels. Such strategies include conducting laboratory work, using models and virtual representations, defining terms and symbols that are needed to represent chemical information.

Chemical Representations

To explain natural phenomena in terms of molecules, atoms, and sub-atomic particles, and the relationships among them, chemists have developed a variety of chemical representations such as molecular models, chemical structures, formulas, equations, and symbols (Hoffmann & Laszlo, 1991). Chemical representations spatially present the imagery of particles and their geometrical shape in two dimensions and constitute spatial language (Habraken, 1996). They present information that may not be easily understood otherwise and allow chemists to think visually and convey information efficiently through a form of visual display.

Chemical representations can be categorized into three levels: the macroscopic, microscopic and symbolic levels (Gabel, 1998). Chemical representations at the macroscopic level refer to pictures or diagrams that represent observable phenomena. Microscopic representations of chemistry refer to models or other visual displays that depict the arrangement and movement of particles. Representation of the symbolic level include symbols, numbers, and signs used to represent atoms, molecules, compounds, and chemical processes such as chemical symbols, formulas, and structures (Shah & Wu, 2004).

According to Shah and Wu (2004), using chemical representations to perform tasks requires a series of cognitive operations in the spatial domain, such as recognizing the graphic conventions, manipulating spatial information provided by a molecular structure, and mentally tracking the constraints based on concepts. Thus, it is likely that learning chemistry involves students' visuo-spatial abilities that support students to perform certain cognitive operations spatially.

Students' Difficulties when Reading Chemical Representations

Requiring students to use their visuo-spatial abilities to read a certain representation is not an easy task. According to Shah and Wu (2004), when reading a chemical representation, students encounter difficulties in comprehending and interpreting representations and translating and transforming representations. For example, comprehending chemical representations at the macroscopic level and by their surface features is demonstrated by secondary school students as well as college students when they are asked to interpret microscopic and symbolic representations. Ben-Zvi et al (1988) explored the levels of descriptions generated by high school students when they were asked to interpret the meanings of two symbolic representations: H_2O (*l*) and Cl_2 (g). Although most students in the study were able to generate some macroscopic descriptions of water such as its properties, the microscopic representation they used to explain the phenomena were not appropriate. Some students viewed Cl_2 (g) as a representation of one particle instead of a collection of multiple molecules, because they did not recognize that (g) represents chlorine molecules in a gas state and means a large amount of Cl_2 molecules. Furthermore, Krajcik (1991) showed that many students interpreted a chemical equation such as $C(s) + O_2 (g) \rightarrow CO_2 (g)$ as a composition of letters, numbers, and lines instead of a process of bond breaking and bond formation.

In addition to the difficulties in comprehending representations, many students are not capable of providing equivalent representation for a given representation because of the lack of content knowledge (Keig & Rubba, 1993) or a lack of visuo-spatial thinking skill (Tuckey, Selvaratnam, & Bradley, 1991). For example, high school students are frequently unable to make translations among formula, electron configuration, and ball and stick models. Moreover, students encounter difficulties in translating 3D representations into 2D representations.

Students' difficulties in reading chemical representations suggest that these representations are conceptual constructs that convey conceptual knowledge as well as visual diagrams that require domain general visuo-spatial skills to comprehend (Hoffmann & Laszlo, 1991). Visualizing chemical representations requires the cognitive linkages between conceptual components that involve substantial content knowledge of underlying concepts, and visual components that involve encoding and interpreting the symbols and conventions (Wu, Krajcik, & Soloway, 2001).

The Dual Nature of Chemical Representations

Because of the conceptual and visual nature of chemical representations and in order for students to overcome their difficulties in reading chemical representations, Shah and Wu (2004) present three suggestions: (a) there is a need for teachers and students to realize how to think visually and reason with visual displays, especially with those visual and symbolic representations in chemistry, (b) chemistry instruction should indicate the close connections between visual features and conceptual entities and include multiple representations of a specific concept, and (c) students should develop representational skills including abilities to use representations to generate explanations, fluently translate one representation to another, and make connections between representation and concepts.

In light of the above three suggestions, current research focuses on developing learning tools that may specifically (a) provide multiple representations and descriptions, (b) make linked referential connections visible, (c) present the dynamic and interactive nature of chemistry, (d) promote the translation between 2D and 3D representations, and (e) reduce the cognitive load by making information explicit for students. These principles could guide educators and designers to develop chemistry learning tools that help students understand chemistry concepts and practice their representational skills through supporting their visuo-spatial thinking (Shah and Wu, 2004). Such learning tools include textbooks, computer animations, and classroom activities.

Textbooks

According to Irez (2009), textbooks are one of the primary learning tools from which students obtain knowledge. They facilitate topic selection by teachers and provide an orientation in the way these topics are taught. Many teachers also rely on the textbook in deciding what and how to teach, especially when they are teaching outside their area of expertise (Stern & Roseman, 2004).   Since the inadequate and inconsistent scientific knowledge presented in science textbooks will negatively affect students' ideas which may lead to misconceptions, current research on textbooks focuses on developing criteria that may be used by textbook authors to write more reliable textbooks that facilitate learning.

The Literature Framing the Research Problem

According to Mayer's (1997) cognitive theory of multimedia learning, reading a textbook engages the learner in three cognitive processes. The first cognitive process, *selecting*, is applied to incoming verbal information to yield a text base and is applied to incoming visual information to yield an image base. The second cognitive process, *organizing*, is applied to the word base to create a verbally based model of the to-be explained system, and is applied to the image base to create a visually based model of the to be explained system. Finally the third cognitive process, *integrating*, occurs when the learner builds connections between corresponding events in the verbally based model and the visually based model. This theory suggests that it is better to present an explanation in words and pictures together than only in words. This is also confirmed by different studies (Dimopoulos, Koulaidis, & Sklaviniti, 2003; Vasu& Howe, 1989) that emphasize a combination of both visual and verbal methods as being ideal.

In light of the above theory, considerable attention has been devoted to the effect of visual learning on the acquisition of knowledge and the understanding of relationships and processes in science education. According to Dimopoulos et al. (2003), modern science textbooks use many more visual images compared to the past in order to communicate their content to the students. Nevertheless, Styliandou et al. (2002) suggested that visual images could present additional problems for students' making it hard for them to understand the message of the specific topic explained in the textbook, so they emphasize that several factors should be considered when constructing visual images for textbooks such as encoding different meanings of similar symbols in different ways.

Chemical representations are visual images used to represent chemical concepts at different levels. Just like any visual image, the simple presence of a chemical representation does not ensure conceptual understanding of a certain chemistry concept. Moreover, when they do not fulfill certain requirements, they may cause misconceptions. Therefore, chemical representations should be developed based on specific principles that are suggested by current research and stated under “the dual nature of chemical representations” above so that students can comprehend these representations and understand chemistry concepts.

The Research Problem

This study examines chemical representations in existing school textbooks for three main reasons: (a) in light of the suggestions and principles that are proposed by current research to develop and use chemical representations, the analysis and evaluation of current chemical representations becomes necessary; (b) textbooks are the main teaching tools available to all students; they are the educational material that teachers use and students use when they study at home, and (c) studies that have shown that the three levels teaching approach (macro, submicro, symbolic) has a positive effect on students’ conceptual understanding of chemistry concepts (e.g. Jaber, 2009; Talanquer, 2010; Treagust et al., 2003) recommend that textbooks be designed to distinguish the three representational levels in presenting concepts, theories and models using the adequate terminology and tools for each level. In Lebanon, no attempt has been made to systematically analyze chemical representations in secondary chemistry textbooks where the objectives of the curricula require students’ conceptual understanding of different chemical phenomena at the three levels.

This study focuses on the requirements that chemical representations should fulfill in textbooks in order to enhance conceptual understanding. Specifically, the purpose of this study is to evaluate the chemical representations that are present in the secondary chemistry textbooks used in Lebanon. Specifically, the study aims at answering the following research questions:

1) Do the chemical representations used in the selected chemistry textbooks cover the basic elements required for their beneficial incorporation in school textbooks?
2) To what extent do the chemical representations used in the selected chemistry textbooks stress the links between the three levels of chemistry?

Implications for Practice

Chemical representations are essential components of chemistry textbooks and may enhance students’ conceptual understanding of chemistry concepts if presented properly in these textbooks. Recent studies and textbooks are promoting the explicit teaching of chemistry at the macro, micro and symbolic levels. Teaching practices should align with this direction. This study evaluated the chemical representations used in the current secondary chemistry textbooks and based on the results proposed specific recommendations for textbooks’ authors which may help them improve the current representations or choose the appropriate representations that may be used to design new chemistry textbooks.

CHAPTER II

Review of the Related Literature

Historical Overview

Different studies have mentioned that the macroscopic and microscopic approaches to chemistry have affected the development of chemical knowledge throughout history (e.g. Laugier & Dumon, 2000; Tsaparlis, 2000). Therefore, it is essential that one review the history of these approaches in order to gain a better understanding of their nature and origin. According to Laugier and Dumon (2000), the conflict between the macroscopic and microscopic approaches to chemistry has a long history which is revealed in the different perspectives of philosophers and scientists in their quest to acquire chemical knowledge. For example, Plato initiated a mechanistic point of view that presumes a microscopic approach to nature through an atomic, theoretical and mathematical method. On the other hand, Aristotle advocated an empiricist point of view that supported a descriptive and phenomenological understanding as revealed by the macroscopic approach (Laugier and Dumon, 2000). These discrete philosophical views influenced the work of chemists and their understanding of chemistry. Those who adopted the mechanistic point of view understood chemistry in terms of physical principles at the level of atoms and their interaction. On the contrary, those who fostered the empiricist point of view understood chemistry in terms of observations, properties of materials, and chemical reactions. According to Laugier and Dumon (2000), it was not before the work of Cannizaro (1860) and Mendeleev (1869) that chemists could resolve this conflict by underscoring the need to identify both the macro and the micro, and the shift between them in order to understand the transformation of matter.

It is certain that the dilemma between the macroscopic and microscopic approaches to chemistry found its way to schools. This was revealed through the topics that constituted the chemistry curriculum. In fact, by the early 20th century, the teaching of chemistry focused on the descriptive macroscopic domain. According to Johnstone (1982, p.702), “what was an offer in the chemistry curriculum was largely a catalog of preparations and properties of gases, a list of laws and definitions to be memorized, and a few industrial processes with details of temperatures and pressures for regurgitation.” This persisted until the Sputnik era during which a shift towards theories and principles was initiated. This formal microscopic approach emphasized a linear development of chemical concepts such as atomic structure, molecular structure, states of matter, chemical reactions, solutions, acid-base-salts, and oxidation-reduction. Nevertheless, such an abstract approach did not account for either students’ cognitive development and their conceptual difficulties, or the relationship of chemistry to everyday life (Tsaparlis, 2000). Hence, the introduction of new chemistry programs that focused on the interaction between chemistry, technology, and society was expected. These programs marked a backward shift towards the descriptive macroscopic approach.

The above discussion reveals that development of chemical knowledge requires the integration of both the descriptive macroscopic approach and the formal microscopic approach. This led Johnstone (1982) to propose that new chemistry has three basic components which can be represented by the corners of a triangle as shown in Figure 1. This multileveled model of thinking in chemistry has been recently identified by Gilbert and Treagust (2009) as “the triplet relationship” which constitutes three individual levels, the macroscopic, sub-microscopic and symbolic.

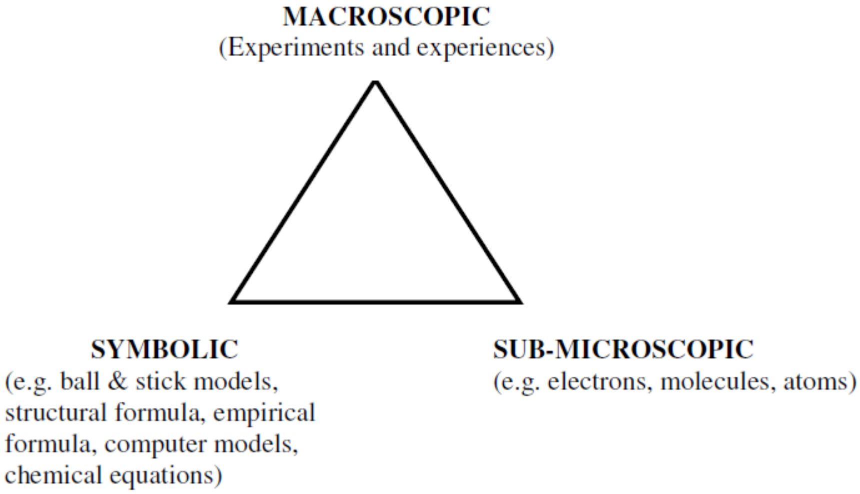

Figure 1. The triplet relationship in chemistry (Johnstone, 1991)

The macroscopic or macro level includes observable and sensory phenomena; it consists of representations of the empirical properties of solids, liquids, colloids, gases, and aerosols. These properties are detectable in everyday life and in chemistry laboratories; thus, they can be measured. Examples of such properties are mass, density, concentration, pH, temperature and osmotic pressure. The sub-microscopic or micro level involves entities that are too small to be seen using optical microscopes such as atoms, molecules, and ions. For example, the occurrence of solids can be described in terms of packed atoms or molecules, or colloids as assemblies of entities into micelles. The symbolic level comprises symbols, equations, signs, mathematical manipulations, graphs, etc. For example, the letters s, l, g, and aq. are used to indicate the physical state of the entity as being solid, liquid, gas, or aqueous respectively. An example that involves the three levels is presented by Rahayyu and Kita (2006) through the corroding nail example. At the macro level, a corroding nail is an observable phenomena where a solid iron nail has a brown flaky coating on it that comes out easily when touched; at the micro level, a corroding nail becomes a chemical process in which iron atoms of the nail react with oxygen molecules in the air and iron oxide molecules are produced; at the symbolic level, a corroding nail can be represented by the chemical equation $4Fe\ (s) + 3O_2\ (g) \rightarrow 2Fe_2O_3\ (s)$.

In the previous section, the historical origins of the macroscopic and microscopic approaches to chemistry have been reviewed. Moreover, the impact of these approaches on schools has been highlighted. In addition, the triplet relationship of chemistry and its three individual levels proposed by Johnstone (1982) have been described. In what follows, the link between the triplet relationship and students' difficulties in learning chemistry is discussed.

The Implication of the Triplet Relationship on Learning Chemistry

According to Talanquer (2010), the triplet relationship has served as a framework for many research studies in chemical education and guided the work of chemistry teachers, curriculum and software developers, and textbook writers across the world. It has offered researchers a new thinking model that can be used to precisely explain how students learn and understand chemical concepts. It can also be used to better identify and remediate students' misconceptions.

The triplet relationship reveals some concrete explanations about the nature of difficulties when learning chemistry. These explanations lie in the attempts of many researchers who tried to understand what difficulties students face while learning chemistry at the macro, sub-micro, and symbolic level.

Students’ learning difficulties at the macro level. As mentioned earlier, the macro level involves chemistry that is visible and tangible. It incorporates what students can perceive with the senses. According to Tsaparlis (2009), with the macro level, students will easily form new concepts through manipulating and interacting with chemicals and observing chemistry in action. Learning difficulties at this level arise from situations where students lack the ability to think scientifically and thus be motivated to value their observations and ask for explanations. Moreover, according to Bodner (1991), even after they graduate with a major in chemistry, students do not apply or extend their knowledge into the real world. Difficulties in learning chemistry at the macro level may lead to misconceptions. For example, in chemical reactions, the inability of students to identify substances based on their properties and their inability to differentiate between substances and mixtures are two major macroscopic misconceptions (Jaber, 2009).

Students’ learning difficulties at the sub-micro level. The sub-micro level explains the macroscopic phenomena in terms of the movement of particles such as atoms, electrons, and molecules (Treagust et al., 2003). Wu et al. (2001) stated that empirical studies have shown that learning at the sub-micro level is especially difficult for students because it is abstract and invisible “while students’ understanding of chemistry relies heavily on sensory information” (p. 1). Learning difficulties at this level arise specifically from the inability of students to visualize the sub-micro level; moreover, these difficulties have been attributed to several factors such as the perceptual nature of atoms and molecules and students’ incomplete or inappropriate mental models (Rahayu& Kita, 2006) and have fostered misconceptions at the particulate level of chemistry. For example, Shepherd and Renner (1982) found in their study that none of the high school students in their sample had a sound understanding of the particulate nature of gases, liquids, and solids, and that only 43% had a partial understanding.

Students' learning difficulties at the symbolic level. This level incorporates a wide variety of representations that are expressed in different forms. According to Taber (2009), the symbolic level mediates between the macro and the sub-micro levels. It is the language of chemistry that acts as a powerful facilitator of communication for discussing, teaching and learning chemistry. Nevertheless, the use of the symbolic representation in communicating chemistry to learners can be a source of learning difficulties (Taber, 2009). The learning difficulties arise from the inability of students to relate symbols to their corresponding chemical meaning or concept. For example, when a teacher labels a beaker of water as H_2O, some students may think that what is inside the beaker is one water molecule. Another example is when a teacher introduces the chemical equilibrium chapter by writing the symbolic representation of the Haber process as $N_2 + 3H_2 \rightleftharpoons 2NH_3$. The double-headed arrow ($\rightleftharpoons$) may be interpreted by a student as some of the reactants did not react.

Students' learning difficulties when shifting between the three levels. In addition to the difficulties that students face at each level, there is another critical learning impediment that students encounter when learning chemistry. This learning impediment is due to the lack of necessary skills that allow the integration and shift between the three levels (Johnstone, 2000). According to Sirhan (2007), real understanding of chemistry requires more than grasping key concepts at each level. In addition, it requires the establishment of meaningful links between the levels in order to bring the concepts into a coherent form. According to Johnstone (1982), professional chemists can easily blend the macro, micro and symbolic aspects of a chemical concept; however, this is a difficult task for novices. For example, when novices view snow as a white solid skiing material, professional chemists can shift easily from this macroscopic observation to the hexagonal shape of the solid water molecule which is represented as H_2O with a bond angle of 105^o.

The previous section highlights students' learning impediments in chemistry resulting from the triplet relationship perspective. This led many researchers to offer better explanations about how students learn chemistry and why they always view it as a difficult subject. Some researchers attributed difficulties to cognitive overload while others attributed them to the instrumental/relational level of understanding chemistry.

Cognitive Overload

For the last few decades, constructivism has been and continues to be a leading paradigm in science education. Students come to class with prior knowledge and experiences. They gradually integrate and reconstruct for themselves the conceptual structure of the academic discipline under study, such as chemistry (Jaber, 2009). However, this process is not simple; its complexity can be understood in terms of the information processing theory that mainly hypothesizes the existence of a working memory (WM) or short-term memory (STM) and a long term memory (LTM). According to Johnstone (1982), what we believe is worth to remember in addition to our knowledge and experiences are usually stored in the LTM. When students encounter a new concept, the WM holds it, draws related information from the LTM, and processes the new concept to make sense of it. The more the similarities between the new concept and the existing information in the LTM, the more it is understood and then retrieved. At this stage, it is important to keep in mind that the LTM has almost infinite capacity for holding information whereas, the WM or the STM has a very limited capacity and can be easily overloaded.

Looking at the learning of chemistry in light of the above theory and in terms of the triplet relationship helps us understand why chemistry is viewed by most students as a difficult and abstract subject. While students may come to class with vague macroscopic knowledge about certain chemical phenomena, chemistry teachers explain these phenomena at all three levels simultaneously. They expect that students can easily understand, switch, and shift between the three levels. For example, the concept element can be introduced by showing students some black carbon powder and yellow sulfur powder labeled as C and S respectively. Then, the teacher defines an element as atoms of the same kind. From a student’s perspective, this definition has no anchoring device in the LTM. Thus, the teacher is indirectly obliging the students to over process the given definition of “element”. Similar examples may result in the cognitive overload of the WM.

Instrumental/Relational Level of Understanding

Treagust et al. (2003) distinguished between two levels of understanding. The instrumental level reflects “rote-learning synopsis where the learner knows a rule and is able to use it (p. 1355)”; on the other hand, the relational level reflects “meaningful learning in which the student knows what to do and why they are doing it”. Moreover, Treagust et al. (2003) provide a framework, shown in Figure 2, which relates the instrumental and relational levels of understanding to the ability of integrating and shifting between the three levels.

As shown in Figure 2, moving easily and rapidly between the macro, micro, and symbolic corners of the triangle allows students to link meaningfully different chemistry concepts. Consequently, students learn at a relational level indicating the conceptual understanding of chemistry. On the other hand, when students learn chemical concepts at the three levels in a discrete manner, they learn at an instrumental level. At this level, students may solve algorithmic problems without a proper conceptual understanding of chemistry.

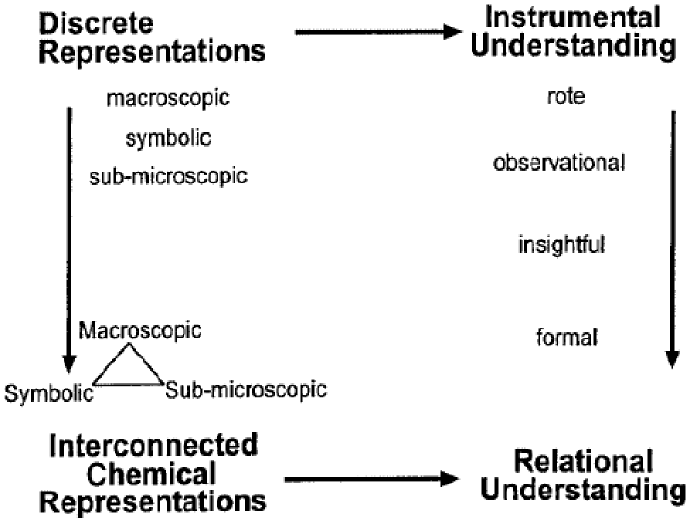

Figure 2. The relationship between the instrumental/relational levels of understanding the three levels (Treagust et al., 2003)

The above section can be used to explain why students view chemistry as a difficult subject. There are two main reasons for these views: a) the cognitive overload of the WM due to the simultaneous explanation of chemical phenomena at the three levels, b) learning at the instrumental level rather than the relational level due to the discontinuous learning of chemical phenomena at the three levels. Therefore, reducing the cognitive overload of the WM and learning at the relational level require improving the quality of teaching each element of the triplet but more importantly how to integrate these elements. This improvement should focus on teaching practices that can help students overcome their learning difficulties at each level and acquire the competence of shifting between the levels. According to Gabel (1999), such practices must be based on the idea that a full understanding of a chemical phenomenon involves the ability to move fluently between its representations. Therefore, in order to understand how learning occurs and thus identify and explain the proper and specific teaching practices that facilitate learning at each level, the role of representations in chemistry should be reviewed.

The Role of Representations in Chemistry

According to Gkitzia et al. (2011), chemical representations can be categorized in three types (macro, sub-micro, and symbolic representations) that are equivalent to Johnstone's (1993) chemistry levels shown in Figure 1. Macro representations depict phenomena according to human visual sense. These are direct experiences produced by laboratory experiments or by everyday life or by watching chemical phenomena through videos, pictures, or diagrams (Treagust et al., 2003). Sub-micro representations depict the structure and movement of the invisible particles such as atoms, ions, and molecules. The typical systems that are used for the creation of these representations are the molecular models such as the ball and stick and the space filling models (Wu & Shah, 2004). Symbolic representations include symbols, letters, numbers and signs that are used to represent atoms, molecules, ions, substances and chemical phenomena. Examples of symbolic representations include chemical formulas, chemical equations, reaction mechanisms, the Newman and Fisher projections, the Lewis structures, the graphs, and the algebraic equations. They express three dimensional particles in a two dimensional way (Wu & Shah, 2004). It is worth mentioning that, at the micro and symbolic levels, chemical representations are metaphors because they are describing real phenomena in terms of concepts that are more familiar to the learner (Chittleborough, 2004). However, the micro level itself is real and not a representation. Chittleborough (2004) suggests that the micro level is as real as the macro level; it is the scale that distinguishes them. The fact that the micro level cannot be seen easily makes it hard to accept it as real. This encourages chemists to use representations to explain and understand chemical phenomena at the micro level. The relationship of reality and representations to the triplet relationship is shown in Figure 3.

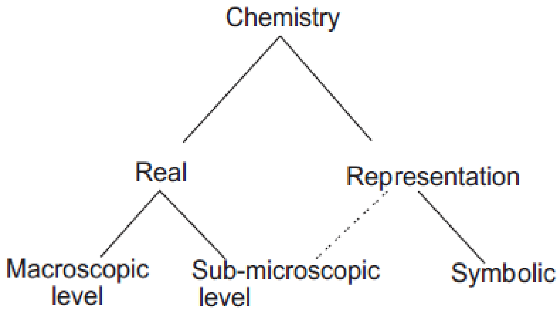

Figure 3. The relationship between the triplet relationship and reality and representations (Chittleborough, 2004)

The above section presented a review on the significance of chemical representations in chemistry. The next section will explain how learning can take place at each level and what specific teaching practices can be used to enhance learning at each level.

Learning at the Macro Level

According to Johnstone (2007), the proper learning of chemistry occurs when students form new concepts at the macro level followed by the gradual introduction of explanations at the micro and symbolic levels. First, students need to be familiar with “thinking in a scientific way through the use of macro and tangible experiences only”

(Johnstone, 2007, p.3). According to Tsaparlis (2009), the laboratory is the proper place for keeping chemistry tangible. Therefore, for students to learn at the macro level, it becomes essential for chemistry teachers to include laboratory and practical work as a main component in their instruction. However, to enhance learning at the macro level, it is not enough to only focus on expository laboratory experiences where students perform ‘cookbook’ experiments. Teachers should introduce inquiry and project-based laboratories and relate laboratory work to everyday life. Experiments about managing the chemistry of swimming pools or determining the percentage of ethanoic acid in vinegar are examples of these types of laboratories. Tsaparlis (2009) points out those such student-centered laboratories are relevant to real life and can promote genuine interest and motivation for practical work. According to Johnstone (2007), through these laboratories, students build chemical concepts based on tangible experience. These concepts can be easily stored in the long term memory and developed later to include inferred concepts. Other types of laboratories integrate technology in data collection, analysis, representation and interpretations processes and provide opportunities for students to work like scientists. The technological tools used in these laboratories function as “data grabbers” and consist of sensors or probes to collect physical data (such as temperature, humidity, etc.) in real time and another device connected to the sensor that digitizes and stores the collected data (BouJaoude & Jurdak, 2010). Hofstein and Lunetta (2004) suggest that the technological tools used in these laboratories empower students and help them conduct inquiry-based laboratories.

Learning at the Micro Level

Harrison and Treagust (2002) have shown that students' and science teachers' understanding of chemistry at the micro level is poor. Moreover, research has shown that learning at this level is a difficult task for the teacher and the student. Chittleborough (2004) proposes that explanations of chemical phenomena usually rely on the behavior at the micro level which is expressed as representations. Based on these representations, students construct their mental models that will help them understand chemistry at the relational level. Therefore, a better understanding of chemistry at the micro level requires learning experiences that align with and contribute to the development of mental models. Such learning experiences can be provided to students by teaching practices that depend on a process of visualization which involves the proper use of visuals that include models, photographs, virtual representations, diagrams, graphs, data arrays, etc. (Gilbert, 2008).

Gilbert (2008) defines visualization as the making of meaning of representations. It is a skill that is directly related to external and internal representations. External representation is the "systematic and focused public display of information in the form of pictures, diagrams, tables, etc.; whereas internal representation is the mental production, storage and use of an image that often is a result of external representation" (Gilbert, 2008). Based on this, visualization is concerned with the formation of an internal representation from an external one. According to Bucat and Mocerino (2009), visualizing chemistry at the micro level has its challenges. Teachers can overcome these challenges by designing instructional strategies that depend on different external representations such as chemical models, structural representations, virtual representations, photographs, diagrams, and graphs. Using these representations requires a series of cognitive operations in the spatial domain, such as recognizing the graphic conventions, manipulating spatial information provided by a molecular structure, and mentally tracking the constraints based on concepts (Wu & Shah, 2004). Thus, it is likely that learning chemistry involves students' visuo-spatial abilities that support students in performing certain cognitive operations spatially.

Learning at the Symbolic Level

As shown in Figure 3, chemistry at the symbolic level is completely related to representations. According to Taber (2009), this level provides a basic language for discussing, teaching and learning chemistry. Furthermore, he contends that this level, which includes graphs, equations, arrows, letters, diagrams, is very familiar to teachers who integrated and matched such symbols to their corresponding chemical concepts and subject knowledge. On the contrary, this level represents for students an additional learning demand which is already challenged by the abstract nature of chemical concepts. For example, chemical equations are symbolic representations of chemical reactions. When writing and balancing these equations, there are numerous assumptions that the student may not understand while teachers assume to be understood. Therefore, learning at the symbolic level requires the explicit introduction of the symbol system in a very careful sequenced way. This is possible (a) by giving students sufficient opportunities to consolidate one layer of symbolism before introducing the next and (b) by making explicit the differences and links between the different set of symbols (Taber 2009). Through this, students will learn chemistry at the symbolic level which will act as a facilitator of quick and effective communication about chemical concepts.

The above section provided a number of teaching practices that can be used to help students learn at the macro, micro, and symbolic levels. These teaching practices supported three main themes: (a) linking chemical concepts to real life observations, (b) emphasizing the role of visuals in developing mental models, and (c) introducing explicitly the symbol system that corresponds to specific chemical concepts. These themes should be implemented in chemistry classrooms in order for students to understand the correct message transferred by chemical representations present in textbooks, educational multimedia software, slides, video display, computer animation, and molecular models. However, the mere presence of chemical representations does not ensure that they sufficiently support students' understanding; moreover, when they do not fulfill certain requirements, they may cause misconceptions. Therefore, the next section will focus on the requirements that chemical representations should fulfill in order to enhance relational understanding.

Requirements of Chemical Representations that Enhance Relational Understanding

Chemistry studies abstract phenomena; thus, understanding chemical concepts is based on creating mental images of the unseen and untouched molecular phenomena. To represent such phenomena, chemists have invented specialized symbol systems which help them communicate and visualize chemistry. These systems are the chemical representations that teachers and students use at the macro, sub-micro, and symbolic level. Therefore, chemistry is a representative, symbolic and visual science (Gkitzia et al., 2011).

According to the previous sections of this review, chemical representations are an integral component of various teaching materials such as textbooks, educational multimedia software, slides, video display, computer animation, and molecular models. As mentioned earlier, the relational understanding of chemistry concepts requires students to interpret, translate between, and construct different types of representations. To address these requirements a lot of research has been conducted (Jaber, 2009; Justi et al., 2009) and the following suggestions for chemistry teachers, textbook writers, and curriculum developers arise: (a) chemical phenomena should be expressed using multiple representations, (b) the relations between different types of representations should be systematically taught to students, and (c) the meaning of symbols used in chemical representations should also be taught to students. However, in order for teachers, textbook writers, and curriculum developers to implement these suggestions, they must use the proper chemical representations that support learning at the three levels and help students overcome the difficulties in understanding chemical concepts. In other words, the presence of an image in a textbook or an animation on a slide does not necessarily ensure students' understanding. Chemical representations must fulfill certain requirements in order to enhance learning and not create misconceptions.

According to Wu and Shah (2004), understanding chemical representation requires the cognitive linkages between conceptual components that involve substantial content knowledge of underlying concepts, and visual components that involve encoding and interpreting the symbols and conventions (Wu et al., 2001). Because of the dual nature of chemical representations (visual and conceptual), chemical representations should be accompanied by a text, explanation, or other representations that show explicitly the connections between visual features and conceptual entities of a certain concept. Moreover, when multiple representations are presented, they must include clear instructions that allow students to identify the referential links among these representations. In addition, a chemical representation should carefully consider the accuracy of the content, the complexity of visual representations, and students' visualization capacities.

The above section reviewed the features that a chemical representation should attain in order for students to understand chemistry concepts at the relational level. The next section sheds light on research done on chemistry textbooks, mainly chemical representations present in textbooks.

Chemistry Textbooks

Previous research studies have examined chemical representations included in textbooks from various perspectives and classified them by different criteria depending on the purpose of each study. Two of these studies, Han and Roth (2004) and Gkitzia et al. (2011), are reviewed in this section as they directly relate to the purpose of this paper.

The purpose of Han and Roth's (2004) study was to investigate the function and structure of chemical representations in middle school science textbooks by drawing on a semiotic framework. According to Han and Roth (2004), reading chemical representations and thereby learning from them requires the interpretation of each representation as well as the text; furthermore, readers must link the two. This means that a chemistry concept could have both verbal and visual component. The process of reading scientific texts and thus the process of interpreting them (semiosis) necessarily include both components. Therefore, the semiosis process differs from reader to reader. To acquire a representation's intended sense; readers have to resort to various conventions used in representations and have to understand how the representations were generated to interpret them. As a result of this study, Han and Roth (2004) arrived at a semiotics of chemical representations to which they refer to as chemisemiotics. The chemisemiotics include a sign which stands for a referent. The relation between the sign and referent is never direct while the relation between the sign and the referent is mediated by interpretants. For example, if the sign is “a molecule of carbon dioxide”, a drawing containing two red circles standing for oxygen and one black circle standing for carbon constitutes an interpretant; other interpretants are the chemical formula (CO_2) or the structural representation $O = C = O$. The study presents the analysis of four concrete cases in which they use the framework of chemisemiotics to show what kind of work is required in reading chemical representations and how the semiotic models are applied to find chemical codes shared by the community of chemists. The analysis showed that reading of representations and texts requires several kinds of work: (a) structuring each representation and text (caption), (b) transposing representations, (c) linking representations with the text, and (d) interpreting the meaning of them. A main question arises from this study about the type of chemical representations that are efficient to include in textbooks to facilitate reading and learning.

In an attempt to answer the main question raised in the conclusion of Han and Roth’s (2004) study, Gkitzia et al.’s (2011) study focuses on the requirements that chemical representations should fulfill in textbooks in order to enhance understanding. Moreover, it identifies the kinds of chemical representations (regarding macro, sub-micro, and the symbolic level) that are used and points out whether they are properly incorporated in tenth grade Greek chemistry textbooks. The study started by analyzing the representations of five chemistry textbooks. This analysis generated five criteria that dealt with the quality of chemical representations and the specifications required for visual representations in text. In order to examine the utility of the five criteria, they were applied to evaluate representations in the tenth grade Greek chemistry textbooks'. To develop the five criteria further and identify the specific characteristics of each criterion, two researchers analyzed separately the representations present in five chemistry textbooks. Core characteristics of chemical representations, identified during the first reading, were revised after a second reading. The criteria and their relative typology were then constructed based on these core characteristics. Each researcher independently grouped the characteristics into individual criteria. Finally, to reduce bias issues, both researchers carried out additional analyses through discussion, reconstruction, and agreement. The outcome of the whole analysis is the development of a fully-fledged typology that is designed specifically for chemical representations in textbooks (Table 1). Each criterion was correlated to literature suggestions concerning both chemical representations and pictures in order to show their usefulness for teaching. The utility of this instrument lies in the fact that can guide textbook authors to successfully incorporate chemical representations, and it can also be used to evaluate chemistry textbooks.

This study focuses on the requirements that chemical representations should fulfill in textbooks in order to enhance conceptual understanding. Specifically, the purpose of this study is to evaluate the chemical representations that are present in the secondary chemistry textbooks used in Lebanon based on the criteria and typologies shown in Table 1. The analysis of the chemical representations present in the secondary chemistry textbooks will help in evaluating the textbooks in terms of the characteristics of the chemical representations present. Moreover, this analysis will reveal whether the current textbooks reveal the macro, sub-micro, and symbolic nature of chemical representations and the link between them.

Table 1

Criteria for the evaluation of chemical representations and their characteristics (Gkitzia et al. (2011)

Criterion	Typology for each criterion	
C1: Type of representation	i.	Macro
	ii.	Sub-micro
	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 un-linked
	iii.	Partially related and linked
	iv.	Partially related and unlinked
	v.	Unrelated
C4: Existence and properties of a caption	i.	Existence of appropriate caption (explicit, brief, comprehensive, providing autonomy)
	ii.	Existence of problematic caption
	iii.	No caption
C5: Degree of correspondence between representations comprising a multiple one	i.	Sufficiently linked
	ii.	Insufficiently linked
	iii.	Unlinked

CHAPTER III

Methodology

Research devoted to the analysis of texts has been conducted periodically throughout the history of education. According to Wang (1998), the common methodology applied by researchers to examine science textbooks has been a form of content analysis. However, the content analysis method had no standard set of rules or guidelines. In general, textbook studies claiming to apply content analysis were profoundly influenced by Berelson's (1952) emphasis on objectivity. These studies usually excluded qualitative considerations of what 'content' does the textbook includes and simply counted qualities of the representative 'content'. A central idea in content analysis is classifying words of a text into a smaller number of content categories. By contrast, users of textbooks do not use them in quantitative fashion. For learning to be effective, the quality of the content is crucial and not the quantity of words in the content category (Wang, 1998). To develop a more objective scientific and systematic approach for analyzing the quality of science textbooks, the analysis should depend on a clear set of conceptual guidelines to guide the investigation (Kippendroff, 1980). Accordingly, science textbooks studies conducted between 1989 and 1996 were generally based on two approaches to establish conceptual frameworks. The first approach was to generate a framework with a theoretical support prior to content analysis such as the scientific literacy framework generated by Chiappetta, Fillman, & Sethna. (1991) and later applied by Lumpe and Beck (1996). The second approach was to explore, construct and refine the conceptual framework during the process of content analysis such as the approach applied by Jeffery and Roach (1994) in their study of evolution proto-concepts.

In addition to the conceptual framework, another issue that emerges from the content analysis studies of science textbooks is the amount of texts selected for analysis. One trend is randomly selecting certain portions of the textbook and another is the whole textbook examination for a specific content.

Based on the above review, the methods of this study are mainly based on a conceptual framework developed by Gkitzia et al. (2011) to analyze the chemical representations present in school chemistry textbooks. The instrument developed by Gkitzia et al. (2011) is based on five criteria for the evaluation of chemical representations present in school chemistry textbooks which include the type of the representation, the interpretation of the surface features, their relationship to the text, the existence and the properties of a caption, and the degree of correspondence between the components comprising a multiple representation. Details about the instrument are presented in the section entitled “Instruments”.

The purpose of this study is to evaluate the chemical representations that are present in the secondary chemistry textbooks used in Lebanon using the instrument developed by Giktzia et al. (2011). Specifically, the study aimed at answering the following research questions:

1) Do the chemical representations used in the selected chemistry textbooks cover the basic elements required for their beneficial incorporation in school textbooks?
2) To what extent do the chemical representations used in the selected chemistry textbooks stress the links between the three levels of chemistry?

Textbooks to be Analyzed in the Study

In 1988, CERD developed and implemented a new curriculum for the general academic stream with a new set of instructional objectives. As shown in Figure 4, common content is provided for all students until Grade 10; then, in Grade 11 the student chooses to follow the Humanities Stream or the Science Stream. In Grade 12, the Humanities Stream is divided into Humanities and Literature or Social Sciences and Economics whereas the Science Stream is divided into General Sciences or Life Sciences. Students are obliged to complete a specific number of courses (no possibility for elective courses) in each stream. Up until Grade 6, Science is taken by all students. Starting in Grade 7, science is divided into three main subjects: Chemistry, Biology, and Physics.

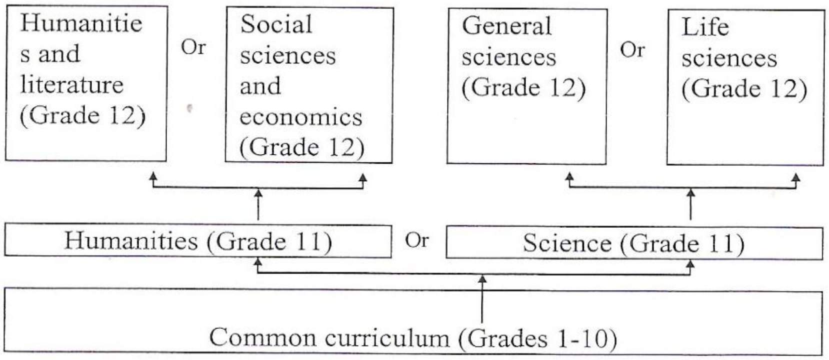

*Figure 4.*The structure of the academic educational ladder (CERD, 1995).

For every subject matter and at different levels, CERD prepared a suitable textbook. Unlike the old curriculum, the new textbooks tried to provide students with knowledge, skills, interest in the subject, analysis, and real-life examples and to emphasize concepts such as technology, national unity, and cooperation. For example, starting from Grade 7 till Grade 12, there is a separate book for chemistry, biology and physics. Each book is divided into units and chapters. Every chapter starts by listing a set of instructional objectives followed by several laboratory activities, analysis of activities, real-life examples, problem sets, pictures, tables, and graphs.

Choice of Grade Level

Current research has shown that the three levels approach for explaining chemical concepts such as the mole concept, atomic structure, kinetic theory, thermodynamics, electrochemistry, chemical reactions, and chemical bonding has a positive effect on students' conceptual understanding of chemistry (e.g. Jaber, 2009; Talanquer, 2010; Treagust et al., 2003). The results of these studies have shown that students were able to develop a better understanding of concepts such as the particulate nature of matter, chemical bonding, chemical equilibrium, chemical reactions, electrochemistry and the dissolution process. Therefore, textbooks of grade levels that deal with such topics are selected for analysis of chemical representations. According to the objectives of the Lebanese secondary level curriculum (Grades 10, 11 and 12), students should become knowledgeable about the particulate nature of matter, the language of chemistry that comprises symbols, formulas, equations and representations, chemical reactions, chemical bonding, chemical equilibrium, and aqueous solutions. This match between the concepts that requires a three levels approach for better understanding and concepts required by the Lebanese secondary level chemistry curriculum requires the analysis of the secondary chemistry textbooks.

Choice of Published Textbooks

There exists a diversity of schools in Lebanon. Schools are divided into three sectors: public, private and semi-private. While public schools are required to use the textbooks published by CERD, private schools are free to choose textbooks published by

CERD or private publishers which include American, French and local publishers. The selection and use of the textbook depends on each school's mission and philosophy. As a result of the variety of textbooks used in the Lebanese schools, the sample of this research will utilize only textbooks produced by Lebanese publishers.

In order to decide which Lebanese publishers are to be included in this research study and in the absence of formal statistics on the topic, the researcher contacted three major Lebanese bookstores LibraireHalim, Libraire du Liban, and Libraire Antoine to determine which Lebanese secondary chemistry textbooks are mostly used by Lebanese schools. The contacted bookstores are considered major bookstores in Lebanon with each having more than five branches across the country.

Another factor that is considered in the sample selection is the language used in textbooks. The language of science instruction in public, private or semi-private schools in Lebanon include French and English. The majority of the above mentioned publishers have the same chemistry textbook translated into different languages. The translated textbooks of each of the publishers share the same content and pedagogic approaches. Therefore, the English versions of each are used in this study.

As a result, the secondary chemistry textbooks that will be used for analysis in this research study are:

- Chami, S. , Chahine. B., El –Masri. M., El-Rifai, M., Kaoukabani, E., Sleiman, H. (1998). *Chemistry. Grade 10 basic education*. Educational Center for Research and Development, Sin-El-Fil, Lebanon.

- Helou, J., Abdallah, H., Chahine, B., Kaoukabani, E., (1998). *Chemistry. Grade 11 basic education*. Educational Center for Research and Development, Sin-El-Fil, Lebanon.
- Safa, A., Helou, J., Abdallah, H., Bachir, A., Chahine, B., Kawkabani, E., Zougheib, H, (1998). *Chemistry. Grade 12 basic education for life and general sciences*. Educational Center for Research and Development, Sin-El-Fil, Lebanon.
- Bachir, A., Zeitunlian, M., Matta, R., El-Khatib, F., Farah, E., (1998). *Chemistry: First Year Secondary Level. Scientifica Series.* Dar LibrairieHabib
- Matta, R., El-Khatib, F., Farah, E., (1998). *Chemistry: Second Year Secondary Level.Scientifica Series.* Dar LibrairieHabib
- Dagher, R., Haykal, T., Raad, J., Khoury, K., Helou, B. (1998). Chemistry: 1st Year Secondary. Edition Σ LibrairieKhoury, Beirut, Lebanon.
- Dagher, R., Haykal, T., Raad, J., Khoury, K., Helou, B. (1998). Chemistry: 2nd Year Secondary. Edition Σ LibrairieKhoury, Beirut, Lebanon.

Instruments

To conduct a detailed analysis of the chemical representations included in each of the above selected textbooks, an instrument developed by Gkitzia et al. (2011) is used. This instrument includes five criteria for the evaluation of chemical representations present in school chemistry textbooks. These criteria (C1-C5) are: the type of the representation (C1), the interpretation of the surface features (C2), their relationship to the text (C3), the existence and the properties of a caption (C4), and the degree of correspondence between the components comprising a multiple representation (C_5) .

Review of the Development of the Instrument

According to Gkitzia et al. (2011), to develop the chemical representation analysis instrument two researchers separately analyzed the chemical representations of two secondary Greek chemistry textbooks, two university Greek chemistry textbooks and a popular American chemistry textbook. The core characteristics of the chemical representations identified at the first reading were revised after the second reading. The criteria and their relative typology were then constructed based on the core characteristics as shown above in Table 1. Each researcher independently grouped the characteristics into individual criteria. Finally, to reduce bias, both researchers carried on several discussions, modifications, agreement, and further analysis. The outcome of the analysis was the development of a typology specifically designed to analyze chemical representations in textbooks. Each criterion was correlated to literature suggestions concerning both chemical representations and pictures in order to show their relevance to teaching chemistry. The developed criteria were independently implemented by two researchers to analyze the chemical representations of the second chapter of an American chemistry textbook titled as “Chemistry: The molecular nature of matter and change”(Silberg, 2008). Sixty nine chemical representations were selected to establish the reliability of the typology. The researchers used the typology and individually evaluated the representations twice. Later, they discussed their evaluations. After discussion, each researcher evaluated the representations again and carried out the necessary modifications. Finally, the inter-rater reliability value was 84% agreement among researchers which is above the 70% standard to establish reliability.

Description of the Each Criterion

The first criterion (C_1): type of representation. The first criterion examines the type of each representation included in the textbook. The following typology is used to characterize the representations: i) macro, ii) sub-micro, iii) symbolic, iv) multiple, v) hybrid, and vi) mixed. A representation is characterized as macro, sub-micro, or symbolic according to the corresponding level of chemistry presented by it. A representation is classified as multiple when it depicts the same chemical phenomenon at two or three levels. A representation is classified as hybrid when it depicts one part of a chemical phenomenon at one level and the other part of the same phenomenon at a different level. A representation is classified as mixed when the characteristics of one level and the characteristics of another type of representation such as an analogy coexist.

The second criterion (C_2): interpretation of surface features. The second criterion examines the clarity of the elements that compose the representation. For example, a representation of the Bohr's atomic model must include labeled features that will increase the probability that all students will understand its contents and create a proper internal mental model of the Bohr's model. The following typology is used to characterize the representations: i) explicit, ii) implicit, or iii) ambiguous. A representation is characterized as explicit when the meaning of each surface feature is clearly mentioned; it is characterized as implicit when the meaning of only some surface features is clearly mentioned and as ambiguous when there is no indication suggesting a meaning of any surface feature. The interpretation of the surface features can be mentioned either in the text or in the captions or in the representations by internal captions.

The third criterion (C_3): relatedness to text. This criterion examines the extent to which a representation is coherent and related to text content and whether there is a direct link which is represented by specific phrases that refer to the representation in the text such as “as can be seen in the representation”. The following typology is used to characterize the representations: i) completely related and linked, ii) completely related and unlinked, iii) partially related and linked, iv) partially related and unlinked, or v) unrelated. A representation is classified as completely related when it depicts the exact text content; it is partially related when it depicts a familiar subject to the text but not the exact one; it is unrelated when it is irrelevant to the text content. In addition, a representation is classified linked or unlinked when the text refers to it by using a direct link or not respectively.

The fourth criterion (C_4): existence and properties of a caption. This criterion examines whether a representation is accompanied by a caption and whether a caption is appropriate or not. An appropriate caption should be explicit, brief, and comprehensive providing autonomy to the representation.

The fifth criterion (C_5): degree of correspondence between components comprising a multiple representation. This criterion concerns only the multiple representations that were identified by using the first criterion. It examines to what extent the correspondence between the surface features of the components of the multiple representations are clearly indicated. The following typology is used to characterize the multiple representations: i) sufficiently linked, ii) insufficiently linked, or iii) unlinked. A multiple representation is classified as sufficiently linked when the equivalence of the surface features of the components is clearly indicated. A multiple representation is classified as insufficiently linked when the equivalence of only some surface features is indicated clearly. A multiple representation is classified as unlinked when the components of the representation are placed next to each other and there is no indication of the equivalence of their surface features.

Based on the above five criteria, the data sheet present in appendix A is completed for each chemical representation present in the selected textbook.

Textbook Analysis Procedures

The analysis of the chemical representations present in the above listed textbooks is carried out following the given steps:

Step one: general description of the selected textbooks in terms of chemical representations. Each of the selected textbooks is described based on unit titles and the number of pages. Then, a quantitative analysis is carried on to calculate the number of chemical representations per page. Furthermore, the chemical representations of each textbook are classified as photographs, photographs showing chemical phenomena, diagrams, and drawings. The types of representations are identified based on previous research (Pozzer & Roth, 2003; Roth et al, 1999). The above classification leads to calculating the relative prevalence of different types of representations across textbooks.

Step two: the analysis of chemical representations. All the chemical representations that deal with a certain chemical phenomena are analyzed based on the described instrument. These phenomena included description of microscopic particles, the mole concept, chemical reactions in dry and aqueous mediums, thermodynamics, electrochemistry, organic chemistry, chemical kinetics, chemical equilibrium, and environmental chemistry. Two raters, the researcher and another chemistry teacher independently analyzed the chemical representations of a 10% percent sample of each textbook after training on the process using the examples presented by Gkitzia et al. (2011). The analysis of the chemical representations is conducted using the data sheet presented in appendix A. The two raters met to compare their results. When discrepancies occurred, the raters reached consensus after discussing their choices with a science educator. The inter-rater reliability value (IRR) is calculated and compared.

Step three: the significance of the analysis. The calculation of the frequencies of chemical representations under each criterion allows an inter and intra comparisons of the chemical representations present in the Lebanese secondary chemistry textbooks. In other words, under each criterion, a comparison of chemical representations between different textbooks per one grade level was carried on; moreover, under each criterion, a comparison of chemical representations between different grade levels was carried out too. The latter comparisons led to significant answers to the following questions: what is the level of chemistry that chemical representations of different Lebanese secondary chemistry textbooks are focusing on?; what is the level of chemistry that each textbook emphasize?; are the current chemical representations capable of helping students understand their correct meaning?; is there an advantage of one textbook over another in terms of chemical representations?; are the chemical representations included in textbook adequately linked to the related concepts, principles, or phenomena described by the text?; are there sufficient links between macro, sub-micro, and symbolic components of a multiple representation so that students can fully understand the three levels of chemistry?

CHAPTER IV

Results

This study focuses on the requirements that chemical representations should fulfill in textbooks in order to enhance conceptual understanding. Specifically, the purpose of this study was to evaluate the chemical representations that are present in the secondary chemistry textbooks used in Lebanon. To accomplish this purpose, an instrument adapted from Giktzia et al. (2011) was used to classify and analyze the chemical representations of seven secondary chemistry textbooks published by three different publishers. This instrument includes five criteria for the evaluation of chemical representations present in school chemistry textbooks. These criteria (C_1-C_5) are: the type of the representation (C_1), the interpretation of the surface features (C_2), their relationship to the text (C_3), the existence and the properties of a caption (C_4), and the degree of correspondence between the components comprising a multiple representation (C_5).This chapter presents the results of the study.

Two raters independently analyzed a 10% sample of each of the seven textbooks based on the instrument developed by Giktzia et al. (2011) that includes five criteria for the evaluation of chemical representations present in textbooks. Both raters are current chemistry teachers at the secondary level. It is worth here to mention that differences between the two raters were significant when they categorized the chemical representations under the fourth criterion (C_4). Consensus was reached between the raters based on close follow-ups and comparisons with the examples presented by Giktzia et al. (2011)

Table 2 presents the inter-rater agreements for the analysis of the seven textbooks with regard of the five criteria. The inter-rater agreement ranges from 85% to 96% at the Grade 10 level with a mean of 91% and it ranges from 80% to 89% at the Grade 11 level with a mean of 84%. As for the Grade 12 level, the inter-rater agreement is 83%.

These percentages suggest a high degree of agreement among the raters in classifying the chemical representations under each of the five criteria.

Table 2

Inter-rater Agreement for the Classification of Chemical Representations of each of the Seven Chemistry Textbooks with Regard to the Five Criteria

	Percent agreement		
	Grade 10	Grade 11	Grade 12
CERD	96	80	83
Scientifica Series	85	89	
Dar Librairie Habib			
Librairie Khoury	91	84	
Mean	91	84	

Note. The percentage scores have been rounded off to the nearest whole number.

The chemical representations of each of the seven textbooks were classified based on the five criteria developed by Giktzia et al. (2011) and their corresponding typologies. The analyzed chemical representations include photographs (scientists, laboratory materials and glassware, and natural scenes), photographs of chemical phenomena (chemical reactions and separation techniques), diagrams (chemical equations, concept maps, graphs, structural formulas of organic compounds), and drawings (drawn figures of chemical reactions, electrochemical cells, and laboratory setups). Chemical representations which were categorized as photographs were later analyzed based on the third (C_3) and fourth (C_4) criteria only. All the other chemical representations were analyzed based on the four criteria (C_1 – C_4). Only the chemical representations that are classified as “multiple” under the first criterion (C_1) are subjected to further analysis under the fifth criterion (C_5).

Analysis of the Grade 10 Chemistry Textbook Published by CERD

This book included three units titled as the structure of matter, reactions and solutions, and environment. The last unit was omitted by CERD after one year of the implementation of the new Lebanese curriculum (1998). The analysis of the chemical representations of units one and two of this book showed 89 representations distributed over 215 pages with a mean of 0.4 representations per page. As shown in Table 3, the 89 chemical representations are categorized into 31 photographs, 16 photographs showing chemical phenomena, 34 diagrams, and 8 drawings.

Table 3

The Frequency of the Different Types of Chemical Representations in the Grade 10 Chemistry Textbook Published by CERD

Type of representation	Frequency
Photographs	31
Photographs showing chemical phenomena	16
Diagrams	34
Drawings	8
Total number of representations	89

As shown in Table 4, 48% of the included chemical representations are macro, 22% are sub-micro, 22% are symbolic, three percent are multiple, three percent are hybrid, and two percent are mixed. 9% of the included representations are explicit, 33% are implicit, and 58% are totally ambiguous. Forty two percent of the included representations are completely related to the text and linked, 32% are completely related to the text but un-linked, three percent are partially related to the text and linked, 10% are partially related to the text but un-linked, and seven percent are unrelated to the text and unlinked. Fifty three percent of the included chemical representations are accompanied by appropriate captions, 37% are accompanied by problematic captions, and 10% are with no captions. The surface features of the only two multiple representations present are un-sufficiently linked.

Analysis of the Grade 10 Chemistry Textbook Published by *Scientifica Series* Dar LibrairieHabib

This book included three units titled as the structure of matter, general chemistry, and environment. The last unit was omitted by CERD after one year of the implementation of the new Lebanese curriculum (1998). The analysis of the chemical representations of units one and two of this book showed 155 representations distributed over 202 pages with a mean of 0.8 representations per page. As shown in Table 5, the 155 chemical representations are divided into 26 photographs, 36 photographs showing chemical phenomena, 64 diagrams, and 29 drawings.

Table 5

The Frequency of the Different Types of Chemical Representations in the Grade 10 Chemistry Textbook Published by Scientifica Series Dar LibrairieHabib

Type of representation	Frequency
Photographs	26
Photographs showing chemical phenomena	36
Diagrams	64
Drawings	29
Total number of representations	155

Table 4

The Analysis of the Chemical Representations Present in the Grade 10 Chemistry Textbook Published by CERD with Regard to the Five Criteria Developed by Giktzia et al. (2011)

	C_1						C_2			C_3				
	M	SM	S	MU	H	MI	E	I	A	CL	CU	PL	PU	U
Number of representations that fit a specific criterion	58						58			89				
Number of representations under a specific typology	28	13	12	2	2	1	5	19	34	37	34	3	9	6
Percentage of representations under a specific typology	48	22	22	3	3	2	9	33	58	42	38	3	10	7

	C_4			C_5		
	AC	PC	NC	SL	IL	UL
Number of representations that fit a specific criterion	89			2		
Number of representations under a specific typology	47	33	9	0	0	2
Percentage of representations under a specific typology	53	37	10	0	0	100

Note. The percentage scores have been rounded off to the nearest whole number.
M = Macro, SM = Sub-micro, S = Symbolic, MU = Multiple, H = Hybrid, MI = Mixed
E = Explicit, I = Implicit, A = Ambiguous
CL = Completely related and linked, CU = Completely related and unlinked, PL = Partially related and linked PU = Partially related and linked, U = Unrelated
AC = Appropriate caption, PC = Problematic caption, NC = No caption
SL = Sufficiently linked, IL= Insufficiently linked, UL = Unlinked

As shown in Table 6, 49% of the included chemical representations are macro, 29% are sub-micro, three percent are symbolic, 10% are multiple, nine percent are hybrid, and none are mixed. Twenty nine percent of the included representations are explicit, 20% are implicit, and 51% are totally ambiguous. Twenty nine percent of the included representations are completely related to the text and linked, 53% are completely related to the text but un-linked, none are partially related to the text and linked, 10% are partially related to the text but un-linked, and eight percent are unrelated to the text and unlinked. Forty percent of the included chemical representations are accompanied by appropriate captions, 54% are accompanied by problematic captions, and six percent are with no captions. The surface features of eight percent of the multiple representations present are sufficiently linked, 67% are insufficiently linked, and 25% are unlinked.

Analysis of the Grade 10 Chemistry Textbook Published by LibrairieKhoury

This book included nine units titled as the atom, molecules, ions, reactions, water, acids and bases, quantitative analysis, chemical fertilizers, and atmospheric pollution. The last two units were omitted by CERD after one year from the implementation of the new Lebanese curriculum. The analysis of the chemical representations of the first seven units of this book showed 221 representations distributed over 246 pages with a mean of 0.9 representations per page. As shown in Table 7, the 221 chemical representations are divided into 55 photographs, 80 photographs showing chemical phenomena, 60 diagrams, and 26 drawings.

Table 6

The Analysis of the Chemical Representations Present in the Grade 10 Chemistry Textbook Published by Scientifica Series Dar LibrairieHabib with Regard to the Five Criteria Developed by Giktzia et al. (2011)

	C_1						C_2			C_3				
	M	SM	S	MU	H	MI	E	I	A	CL	CU	PL	PU	U
Number of representations that fit a specific criterion	129						129			155				
Number of representations under a specific typology	63	37	5	13	11	0	38	26	65	45	82	0	16	12
Percentage of representations under a specific typology	49	29	3	10	9	0	29	20	51	29	53	0	10	8

	C_4			C_5		
	AC	PC	NC	SL	IL	UL
Number of representations that fit a specific criterion	155			12		
Number of representations under a specific typology	62	84	9	1	8	3
Percentage of representations under a specific typology	40	54	6	8	67	25

Note. The percentage scores have been rounded off to the nearest whole number.

Table 7

The Frequency of the Different Types of Chemical Representations in the Grade 10 Chemistry Textbook Published by LibrairieKhoury

Type of representation	Frequency
Photographs	55
Photographs showing chemical phenomena	80
Diagrams	60
Drawings	26
Total number of representations	221

As shown in Table 8, 61% of the included chemical representations are macro, 19% are sub-micro, 11% are symbolic, five percent are multiple, four percent are hybrid, and none are mixed. 19% of the included representations are explicit, 18% are implicit, and 63% are totally ambiguous. One percent of the included representations are completely related to the text and linked, 62% are completely related to the text but un-linked, none are partially related to the text and linked, 17% are partially related to the text but un-linked, and 20% are unrelated to the text and unlinked. Twenty five percent of the included chemical representations are accompanied by appropriate captions, 17% are accompanied by problematic captions, and 58% are with no captions. The surface features of 29% of the multiple representations present are sufficiently linked, 71% are insufficiently linked, and none are unlinked.

Table 8

The Analysis of the Chemical Representations Present in the Grade 10 Chemistry Textbook Published by LibrairieKhoury with Regard to the Five Criteria Developed by Giktzia et al. (2011)

	C_1						C_2			C_3				
	M	SM	S	MU	H	MI	E	I	A	CL	CU	PL	PU	U
Number of representations that fit a specific criterion	166						166			221				
Number of representations under a specific typology	101	32	19	8	6	0	32	30	104	1	139	0	37	44
Percentage of representations under a specific typology	61	19	11	5	4	0	19	18	63	1	62	0	17	20

	C_4			C_5		
	AC	PC	NC	SL	IL	UL
Number of representations that fit a specific criterion	221			7		
Number of representations under a specific typology	56	37	128	2	5	0
Percentage of representations under a specific typology	25	17	58	29	71	0

Note. The percentage scores have been rounded off to the nearest whole number.

Analysis of the Grade 11 Chemistry Textbook Published by CERD

This book included eight units titled as thermochemistry, electrochemistry, industrial inorganic chemistry, metals and alloys, atomic orbitals, organic chemistry, petroleum and natural gas, and pollution. Industrial inorganic chemistry, metals and alloys, atomic orbitals, petroleum and natural gas, and pollution were omitted by CERD after one year of the implementation of the new Lebanese curriculum. The analysis of the chemical representations of the three remaining units of this book showed 115 representations distributed over 177 pages with a mean of 0.6 representations per page. As shown in Table 9, the 115 chemical representations are divided into 25 photographs, 34 photographs showing chemical phenomena, 33 diagrams, and 23 drawings.

Table 9

The Frequency of the Different Types of Chemical Representations in the Grade 11 Chemistry Textbook Published by CERD

Type of representation	Frequency
Photographs	25
Photographs showing chemical phenomena	34
Diagrams	33
Drawings	23
Total number of representations	115

As shown in Table 10, 59% of the included chemical representations are macro, 11% are sub-micro, 24% are symbolic, none are multiple, six percent are hybrid, and none are mixed. 30% of the included representations are explicit, 23% are implicit, and 47% are totally ambiguous. Seventy five percent of the included representations are completely related to the text and linked, 10% are completely related to the text but un-linked, eight percent are partially related to the text and linked, four percent are partially related to the text but un-linked, and three percent are unrelated to the text and unlinked.

Forty five percent of the included chemical representations are accompanied by appropriate captions, 51% are accompanied by problematic captions, and four percent are with no captions.

Table 10

The Analysis of the Chemical Representations Present in the Grade 11 Chemistry Textbook Published by CERD with Regard to the Five Criteria Developed by Giktzia et al. (2011)

	C_1						C_2			C_3				
	M	SM	S	MU	H	MI	E	I	A	CL	CU	PL	PU	U
Number of representations that fits a specific criterion	90						90			115				
Number of representations under a specific typology	53	10	22	0	5	0	27	21	42	86	11	9	5	4
Percentage of representations under a specific typology	59	11	24	0	6	0	30	23	47	75	10	8	4	3

	C_4			C_5		
	AC	PC	NC	SL	IL	UL
Number of representations that fits a specific criterion	115			0		
Number of representations under a specific typology	52	59	4	0	0	0
Percentage of representations under a specific typology	45	51	4	0	0	0

Note. The percentage scores have been rounded off to the nearest whole number.

Analysis of the Grade 11 Chemistry Textbook Published by *Scientifica Series* Dar LibrairieHabib

This book included five units titled as chemical reactions and energy, industrial chemistry and metallurgy, structure of matter, organic chemistry, and pollution. Industrial chemistry and metallurgy, structure of matter, and pollution were omitted by CERD after one year of the implementation of the new Lebanese curriculum. The analysis of the chemical representations of the two remaining units of this book showed 86 representations distributed over 164 pages with a mean of 0.5 representations per page. As shown in Table 11, the 86 chemical representations are divided into 18 photographs, 17 photographs showing chemical phenomena, 23 diagrams, and 28 drawings.

Table 11

The Frequency of the Different Types of Chemical Representations in the Grade 11 Chemistry Textbook Published by Scientifica Series Dar LibrairieHabib

Type of representation	Frequency
Photographs	18
Photographs showing chemical phenomena	17
Diagrams	23
Drawings	28
Total number of representations	86

As shown in Table 12, 68% of the included chemical representations are macro, 15% are sub-micro, 15% are symbolic, two percent are multiple, none are hybrid, and none are mixed. 32% of the included representations are explicit, 21% are implicit, and 47% are totally ambiguous. None of the included representations are completely related to the text and linked, 77% are completely related to the text but un-linked, none are partially related to the text and linked, 15% are partially related to the text but un-linked, and 8% are unrelated to the text and unlinked. Forty seven percent of the included chemical representations are accompanied by appropriate captions, fifty three percent are accompanied by problematic captions, and none are with no captions. The surface features of 50% of the multiple representations present are sufficiently linked, 50% are insufficiently linked, and none are unlinked.

Table 12

The Analysis of the Chemical Representations Present in the Grade 11 Chemistry Textbook Published by Scientifica Series Dar LibrairieHabib with Regard to the Five Criteria Developed by Giktzia et al. (2011)

	C_1						C_2			C_3				
	M	SM	S	MU	H	MI	E	I	A	CL	CU	PL	PU	U
Number of representations that fits a specific criterion	68						68			86				
Number of representations under a specific typology	46	10	10	2	0	0	22	14	32	0	66	0	13	7
Percentage of representations under a specific typology	68	15	15	2	0	0	32	21	47	0	77	0	15	8

	C_4			C_5		
	AC	PC	NC	SL	IL	UL
Number of representations that fits a specific criterion	86			2		
Number of representations under a specific typology	40	46	0	1	1	0
Percentage of representations under a specific typology	47	53	0	50	50	0

Note. The percentage scores have been rounded off to the nearest whole number.

Analysis of the Grade 11 Chemistry Textbook Published by LibrairieKhoury

This book included seven units titled as thermochemistry, electrochemistry, industrial inorganic chemistry, metals and alloys, the orbitals, organic chemistry and pollution. Industrial inorganic chemistry, metals and alloys, the orbitals, and pollution were omitted by CERD after one year of the implementation of the new Lebanese curriculum. The analysis of the chemical representations of the remaining three units of this book showed 130 representations distributed over 158 pages with a mean of 0.8 representations per page. As shown in Table 13, the 130 chemical representations are divided into 26 photographs, 17 photographs showing chemical phenomena, 36 diagrams, and 51 drawings.

Table 13

The Frequency of the Different Types of Chemical Representations in the Grade 11 Chemistry Textbook Published by LibrairieKhoury

Type of representation	Frequency
Photographs	26
Photographs showing chemical phenomena	17
Diagrams	36
Drawings	51
Total number of representations	130

As shown in Table 14, 73% of the included chemical representations are macro, 12% are sub-micro, 15% are symbolic, none are multiple, none are hybrid, and none are mixed. 25% of the included representations are explicit, 13% are implicit, and 62% are totally ambiguous. Five percent of the included representations are completely related to the text and linked, 71% are completely related to the text but un-linked, none are partially related to the text and linked, 16% are partially related to the text but un-linked, and eight percent are unrelated to the text and unlinked. Thirty seven percent of the included chemical representations are accompanied by appropriate captions, 25% are accompanied by problematic captions, and 38% are with no captions.

Table 14

The Analysis of the Chemical Representations Present in the Grade 11 Chemistry Textbook Published by LibrairieKhoury with Regard to the Five Criteria Developed by Giktzia et al. (2011)

	C_1						C_2			C_3				
	M	SM	S	MU	H	MI	E	I	A	CL	CU	PL	PU	U
Number of representations that fits a specific criterion	104						104			130				
Number of representations under a specific typology	76	12	16	0	0	0	26	14	64	6	92	0	21	11
Percentage of representations under a specific typology	73	12	15	0	0	0	25	13	62	5	71	0	16	8

	C_4			C_5		
	AC	PC	NC	SL	IL	UL
Number of representations that fits a specific criterion	130			0		
Number of representations under a specific typology	48	32	50	0	0	0
Percentage of representations under a specific typology	37	25	38	0	0	0

Note. The percentage scores have been rounded off to the nearest whole number.

Analysis of the Grade 12 Chemistry Textbook Published by CERD

This book included six units titled as the gaseous state, rate of reactions, chemical equilibrium, acids and bases, organic chemistry, and applied chemistry. The analysis of the chemical representations of the six units this book showed 146 representations distributed over 278 pages with a mean of 0.5 representations per page. As shown in Table 15, the 146 chemical representations are divided into 37 photographs, 28 photographs showing chemical phenomena, 71 diagrams, and 10 drawings.

Table 15

The Frequency of the Different Types of Chemical Representations in the Grade 12 Chemistry Textbook Published by CERD

Type of representation	Frequency
Photographs	37
Photographs showing chemical phenomena	28
Diagrams	71
Drawings	10
Total number of representations	146

As shown in Table 16, 34% of the included chemical representations are macro, 22% are sub-micro, 43% are symbolic, none are multiple, one percent is hybrid, and none are mixed. Five percent of the included representations are explicit, 34% are implicit, and 61% are totally ambiguous. Ninety one percent of the included representations are completely related to the text and linked, none are completely related to the text but un-linked, 8% are partially related to the text and linked, one percent are partially related to the text but un-linked, and none are unrelated to the text and unlinked. Fifty nine percent of the included chemical representations are accompanied by appropriate captions, 41% are accompanied by problematic captions, and none are with no captions.

Table 16

The Analysis of the Chemical Representations Present in the Grade 12 Chemistry Textbook Published by CERD with Regard to the Five Criteria Developed by Giktzia et al. (2011)

	C_1						C_2			C_3				
	M	SM	S	MU	H	MI	E	I	A	CL	CU	PL	PU	U
Number of representations that fits a specific criterion	109						109			146				
Number of representations under a specific typology	37	24	47	0	1	0	6	37	66	133	0	11	2	0
Percentage of representations under a specific typology	34	22	43	0	1	0	5	34	61	91	0	8	1	0

	C_4			C_5		
	AC	PC	NC	SL	IL	UL
Number of representations that fits a specific criterion	146			0		
Number of representations under a specific typology	86	60	0	0	0	0
Percentage of representations under a specific typology	59	41	0	0	0	0

Note. The percentage scores have been rounded off to the nearest whole number.

Comparing Grade 10 Textbooks

The 1st criterion (C_1). The chemical representations of the three Grade 10 chemistry textbooks were focused on the macro level with a mean of 53% (Figure 5) followed by the sub-micro level with a mean of 23%. Moreover, the three textbooks included few representations that can be classified as multiple, hybrid, or mixed with an average of 6%, 5%, and 1% respectively. These findings reveal the macro and sub-micro orientation of the textbooks.

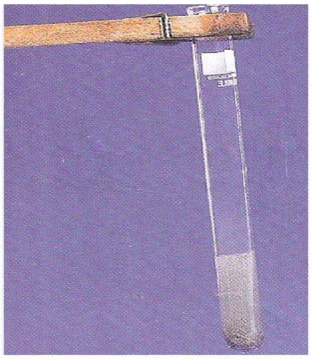

Fig. 4.5
Reaction between iron sulfide and hydrochloric acid solution.

Figure 5. An example of a photograph showing a chemical phenomenon at the macro level taken from the Grade 10 chemistry textbook published by CERD

The 2nd criterion (C_2). More than half of the chemical representations present in the three Grade 10 chemistry textbooks are totally ambiguous with a mean of 57% (Figure 6). Only few representations are labeled explicitly with a mean of 22%. For example, only 9% of the representations of the CERD book are labeled explicitly. These findings indicate that there is no systematic labeling for interpreting the chemical representations of the three textbooks.

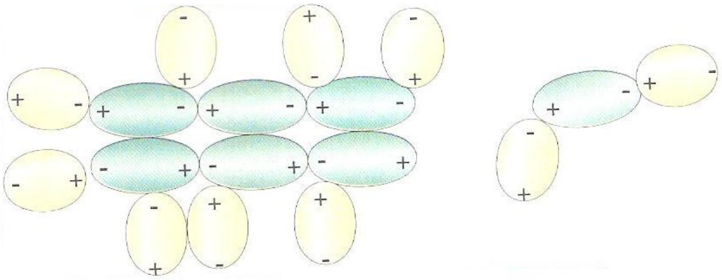

*Figure 6.*An example of a diagram with ambiguous surface features taken from the Grade 10 chemistry textbook published by Scientifica Series Dar LibrairieHabib

The 3rd criterion (C_3). Most of the representations of the CERD book were completely related to the text and linked (42%) or completely related to the text and un-linked (38%). More than half of the representations of LibrairieKhoury book and Dar LibrairieHabib were completely related and unlinked (62% and 53% respectively). These findings indicate that more than half of the representations of the three books lack a direct link between the text and the representation.

The 4th criterion (C_4). More than half of the chemical representations of the three textbooks have either a problematic caption (the content is not clear) or no caption with a mean of 61% (Figure 7).

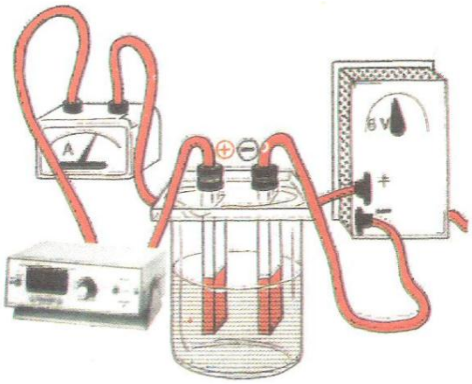

*Figure 7.*An example of a drawing with no captions taken from the Grade 10 chemistry textbook published by LibrairieKhoury

The 5th criterion (C_5). The majority of the chemical representations that are categorized as “multiple” in three books either do not reveal the equivalence between the surface characteristics at different levels or reveal insufficient indications for the equivalences with a mean of 88%. It is worth here to mention that 29% of the chemical representations of LibrairieKhoury book that are categorized as “multiple” reveal sufficient indications between the surface characteristics at different levels (Figure 8).

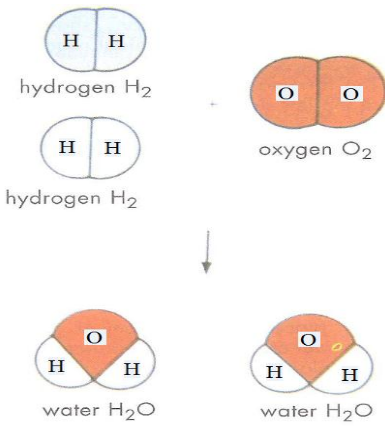

*Figure 8.*An example of a diagram showing the sufficient links between the sub-micro and symbolic level of the reaction of formation of water taken from the Grade 10 chemistry textbook published by LibrairieKhoury

Comparing Grade 11 textbooks

The 1st criterion (C_1). The chemical representations of the three Grade 11 chemistry textbooks were focused on the macro level with a mean of 67% followed by the symbolic level with a mean of 18% . Moreover, the three textbooks included few representations that can be classified as multiple and hybrid with an average of 1% and 2% respectively. The three books did not include any representation that can be categorized as mixed. These findings reveal the macro and symbolic orientation of the textbooks.

The 2nd criterion (C_2). More than half of the chemical representations present in the three Grade 11 chemistry textbooks are totally ambiguous with a mean of 52%. Only few representations are labeled explicitly with a mean of 29%. These findings indicate that there is no systematic labeling for interpreting the chemical representations of the three textbooks.

The 3rd criterion (C_3). Most of the representations of the CERD book were completely related to the text and linked (75%); a clear reference that connects the representation to the text was present. On the other hand, more than half of the representations of LibrairieKhoury book and Dar LibrairieHabib were completely related and unlinked (77% and 71% respectively). These findings indicate that more than half of the representations of the LibrairieKhoury book and Dar LibrairieHabib books lack a direct link between the text and the representation.

The 4th criterion (C_4). More than half of the chemical representations of the three textbooks have either a problematic caption (the content is not clear) or no caption with a mean of 57%.

The 5th criterion (C_5). Only one of the two chemical representations that are categorized as “multiple” in three books reveals sufficient indications between the surface characteristics at different levels. The other one reveals insufficient indications for the equivalences.

General Trends among the Seven Analyzed Textbooks

The above findings and comparisons suggest that the chemical representations of the secondary Lebanese chemistry textbooks are focused on the three levels (macro, micro, and symbolic) independently with a major emphasis on the macro level. The seven analyzed textbooks include few multiple, hybrid, or mixed representations. Moreover, most of the representations are completely related to the text; however, they are ambiguous and do not provide an explicit reference in the text that links the representation to the text. Only the CERD books were characterized by high percentages of representations that are linked to the text with a clear reference. Furthermore, many of the representations are not accompanied by proper captions. Finally, only few representations are characterized as “multiple” in the seven analyzed textbooks; nevertheless, many of them do not reveal the equivalence between the surface characteristics at different levels or reveal insufficient indications for the equivalences.

CHAPTER V

Discussion

Chemical representations are an integral component of various teaching materials such as textbooks, educational multimedia software, slides, video display, computer animation, and molecular models. As mentioned earlier, the relational understanding of chemistry concepts requires students to interpret, translate between, and construct different types of representations. For this reason, teachers, textbook writers, and curriculum developers must use the proper chemical representations that support learning at the three levels and help students overcome the difficulties in understanding chemical concepts. Therefore, chemical representations must fulfill certain requirements in order to enhance learning and not create misconceptions.

According to Wu and Shah (2004), understanding chemical representations requires the cognitive linkages between conceptual components that involve substantial content knowledge of underlying concepts, and visual components that involve encoding and interpreting the symbols and conventions (Wu et al., 2001). Because of the dual nature of chemical representations (visual and conceptual), chemical representations should be accompanied by a text, explanation, or other representations that show explicitly the connections between visual features and conceptual entities of a certain concept. Moreover, when multiple representations are presented, they must include clear instructions that allow students to identify the referential links among these representations. In addition, a chemical representation should carefully consider the accuracy of the content, the complexity of visual representations, and students' visualization capacities. According to Dimopoulos et al. (2003), modern science textbooks use many more visual images compared to the past in order to communicate their content to the students. Nevertheless, Styliandou et al. (2002) suggested that visual images could present additional problems for students' making it hard for them to understand the message of the specific topic explained in the textbook, so they emphasize that several factors should be considered when constructing visual images for textbooks such as encoding different meanings of similar symbols in different ways.

This study focused on investigating the requirements that chemical representations should fulfill in textbooks in order to enhance conceptual understanding. Specifically, the purpose of this study was to evaluate the chemical representations that are present in the secondary chemistry textbooks used in Lebanon based on an instrument adapted from Gkitzia et al (2011). Specifically, the study aims at answering the following research questions:

1) Do the chemical representations used in the selected chemistry textbooks cover the basic elements required for their beneficial incorporation in school textbooks?
2) To what extent do the chemical representations used in the selected chemistry textbooks stress the links between the three levels of chemistry?

Research Question I

Findings from this study reveal that most of the chemical representations used in the selected textbooks focused on the macro level followed by the sub-micro and the symbolic levels. According to Robinson (1998), chemical diagrams at the macro level can assist students to develop deeper understanding of chemical concepts. This view is supported by Dechsri et al. (1997) who reported improved student performance in the cognitive, affective, and manipulative domains as a result of including chemical representations at the macro level with the text of the laboratory manual. Nevertheless, it is worth here to mention that the presence of representations that cover different chemical phenomena at the macro level should not prevent teachers from demonstrating experiments or performing laboratory activities. Chemical representations of chemical phenomena at the macro levels are only 2D static images that cannot replace the educational impact of the real experiment. In addition, according to Chittleborough and Davidowitz (2008), the use of chemical representations at the sub-micro and symbolic levels is as important as those used at the macro-level. Chemical representations at the sub-micro level help students construct mental models that help them to understand concepts in more depth, whereas chemical representations at the symbolic level can help students understand the relation between the macro and sub-micro levels of different chemical phenomena.

Furthermore, findings show that the surface features or labels of most of the chemical representations used in the selected textbooks are implicit or ambiguous. Moreover, many of them are presented with problematic or no captions. According to Chittleborough and Davidowitz (2008), chemical representations at the macro, micro, or symbolic levels are tools that help students describe an idea, provide an explanation, present a visual image, make predictions, deductions, motivate and form hypothesis. However, to serve this purpose, textbook writers should take into consideration the quality of the chosen chemical representations. These representations should be supported by clear labels and explicit, brief, and comprehensive captions that will allow students to interpret and convey the correct message that the representation carry;

otherwise, students may consider the representations as simply pictures that are used to decorate the textbook or they receive false meanings from them which may cause misconceptions in learning.

Findings also reveal that most of the chemical representations used in the selected textbooks are completely associated to the text which supports the idea that the representations were chosen purposively to provide students with specific examples that will help them understand concepts at the relational level. Moreover, the findings reveal that CERD books were characterized by high percentages of chemical representations accompanied by a direct link or reference in the text. According to Giktzia et al. (2011) this characteristic helps students better understand the relationship of the representation to the textual context that explains the concept.

Research Question II

Studying chemistry is essentially about attempting to understand the nature of matter which itself is complex and abstract. Moreover, it includes studying concepts that are complicated by the levels at which they can be portrayed (Johnstone, 1993). Research shows that understanding is achieved when students are able to interrelate the macro, micro, and symbolic levels of representation of matter. Furthermore, research shows that many secondary and college students have difficulty transferring from one level to another (Boo, 1998; Gabel, 1998). According to Chittleborough and Treagust (2001), understanding chemical concepts mainly demands the development of mental models at the three levels. However, the development of such models is not an easy task. It requires students who are visually literate and have metavisual skills. Well informed teaching practices that reinforce the links between the three levels portraying chemical phenomena are needed to ensure that students do not develop alternative conceptions (Chittleborough & Treagust, 2001). Recent studies present examples of such teaching practices (e.g. Jaber, 2009; Justi et al., 2009). The findings of these studies indicated that students were able to understand chemical concepts at the three levels; moreover, they indicated that the use of model-based teaching practices enhanced students' metavisual skills and thus enriched their ability to develop mental models. In addition, recently published chemistry textbooks present chemical concepts at the three levels with more focus on the micro level which was neglected in old textbooks. The use of different chemical representations, which incorporate all three levels, as major tools of the new teaching strategies and recently published chemistry textbooks reveals the importance of these tools in enhancing students' metavisual skills and their ability to develop mental models at the three levels. Nevertheless, the findings of this study reveal that most of the chemical representations used in the selected textbooks focus on each of the three levels independently. This conclusion was supported by the low percentages of multiple, hybrid or mixed chemical representations. In addition, the different levels of multiple chemical representations are insufficiently linked or unlinked.

Limitations of the Study

A major limitation of this study is that it evaluates the chemical representations present in seven secondary Lebanese chemistry textbooks based on five specific criteria without taking into consideration the context through which the representation is used. For example, not all the chemical concepts that are presented by the Lebanese curriculum require a three levels approach. In some cases, the simple presence of a chemical representation may convey a clear message to the student. Moreover, the representations were analyzed from a science teacher's perspective ignoring the students' perspective and what they see or understand from a certain chemical representation. The textbook is essentially a tool that is used by teachers and students, the absence of the students' perspective while dealing with the chemical representation is an issue worth considering.

The selection of textbooks of specific publishers might affect the generalizability of the findings. The results of the present study do not reflect the chemical representations present in all secondary Lebanese chemistry textbooks. Textbooks of other Lebanese publishers must also be analyzed to draw general conclusions.

The two raters faced problems categorizing chemical representations under the fourth criterion (C_4). This is because the three indicators (explicit, brief, and comprehensive) of this criterion are very wide and subjective. Although consensus was reached, the availability or the development of other specific indicators would have made the classification task of these representations more accurate.

It is worth here to mention that the process of translating the book contents from French to English may have contributed in classifying some captions as problematic under (C_4).

Conclusion

In Lebanon, no attempt has been made to systematically analyze chemical representations in secondary chemistry textbooks where the objectives of the curricula require students' conceptual understanding of different chemical phenomena at the three levels. This study used an instrument developed by Giktzia et al. to analyze and evaluate the chemical representations used in seven secondary chemistry Lebanese textbooks of grade levels 10, 11, and 12. The results of the study revealed that the chemical representations used in the selected textbooks are focused on the macro level with either implicit or ambiguous labels. Moreover, the selected textbooks use very few multiple, hybrid or mixed representations. In addition, most chemical representations are accompanied by problematic or no captions. Since the chemical representations used in chemistry textbooks play a major role in chemistry education, the evaluation of whether these representations meet the basic requirements for conceptual understating of chemistry concepts will enrich the line of research and benefit the educational system in Lebanon with the hope that change will take place one day.

Recommendations for Further Research

The findings of this study indicate that multiple, hybrid, and mixed chemical representations are almost neglected by the seven analyzed textbooks. According to science education research, such representations support the conceptual understanding of different chemistry concepts such as chemical reactions, electrochemistry, thermochemistry, and acids and bases. Therefore, it is recommended to include more representations under these typologies with sufficient proper links between the different levels revealed by each representation. Moreover, it is recommended that chemical representations are accompanied by clear and explicit labels and explicit, brief, and comprehensive captions.

The analysis of textbooks in this study focused on secondary chemistry textbooks produced by Lebanese publishers. It is recommended that further research can be conducted to examine Lebanese chemistry textbooks belonging to the intermediate grade levels where chemistry is taught (Grade 7, 8, 9). Furthermore, the analysis could be extended not only to include textbooks designed by Lebanese publishers, but to textbooks designed by international publishers whose textbooks are used in the Lebanese schools.

As mentioned earlier, this study focused on the basic requirements that chemical representations must fulfill so that they help students understand major chemistry concepts. Future research may be conducted to investigate how teachers may use the current representations in explaining chemistry concepts and how students understand these representations when reading chemistry textbooks.

Furthermore, future studies should investigate the textbook’s writing process. The absence of specific guidelines for writing textbooks, choosing the suitable representations, and presenting them in textbooks makes it hard to understand why textbooks writers and publishers produced the textbooks in their current form. Consequently, investigating this process and the factors that might have influenced the decisions by writers and publishers might provide insights that have the potential to help in improving the textbook writing and publishing process. These studies can be of qualitative rather than a quantitative nature because of the need for in-depth understanding of the processes.

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APPENDIX I

DATA SHEET FOR CLASSIFYING CHEMICAL REPRESENTATIONS

Name of book:
Publisher:
Grade level:
Number of the page on which the chemical representation appears:
Type of chemical representation:

Criterion	Typology	Basic questions	Answer	Decision
C_1	i. Macro ii. Sub-micro iii. Symbolic iv. Multiple v. Hybrid vi. Mixed	• Does the representation reveal a chemical phenomenon at a single level? • Does the representation reveal a chemical phenomenon at multiple levels? • Does the representation reveal more than one level complementing each other to describe a chemical phenomenon? • Does the representation reveal the coexistence of one level with another type of depiction?		
C_2	i. Explicit ii. Implicit iii. Ambiguous	• Is the meaning of each surface feature clearly mentioned?		
C_3	i. Completely related and linked ii. Completely related and unlinked iii. Partially related and	• Does the representation reveal the exact text content? • Is there a direct link between the representation and the text?		

	linked iv. Partially related and unlinked v. Unrelated			
C_4	i. Appropriate caption ii. Problematic caption ii. No caption	- Is the representation accompanied by an explicit, brief, and comprehensive caption?		
C_5	i. Sufficiently linked ii. Insufficiently linked ii. Unlinked	- Are the surface features of a multiple representation linked clearly?		