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EXAMINATION OF CHEMICAL REPRESENTATIONS IN TURKISH HIGH SCHOOL CHEMISTRY TEXTBOOKS

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Abstract. *The aim of this research was to examine the chemical representations that are present in Turkish high school chemistry textbooks. Content analysis was the method of analysis. Four chemistry textbooks, which were commonly used in Turkey, for each grade (i.e., from 9th to 12th), were selected. When evaluating the representations, a rubric including five main criteria was used: (1) type of representation, (2) interpretation of representations' surface features, (3) representations' relatedness to text, (4) properties of representations' caption, and (5) degree of correlation between subordinates comprising a multiple representation. The results of the research revealed that the chemical representations used in the textbooks are mainly macroscopic, symbolic, and hybrid. Majority of the representations had explicit surface features and appropriate captions. Moreover, they were completely related to the text. Most of the multiple representations had sufficient links between their subordinates. Recommendations for textbook writers and future research are provided.*

Keywords: *chemistry textbooks, chemical representations, generic qualitative research, content analysis.*

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Introduction

In many high school chemistry courses, chemistry textbooks often lead teachers when they decide what chemical concepts they teach and the order of teaching these concepts (Justi & Gilbert, 2002; Drechsler & Schmidt, 2005). Relying on textbooks' influence on teaching, textbooks are written assuming that most students (Chiang-Soong & Yager, 1993) and teachers can comprehend them. On the contrary, researchers have shown that use of vague language in textbooks can cause student misconceptions in chemistry (e.g., for electrochemistry see Sanger & Greenbowe, 1999; for chemical equilibrium see Pedrosa & Dias, 2000; for chemical bonding see Bergqvist, Drechsler, De Jong, & Rundgren, 2013). In addition to language used, how the information is presented is of crucial importance in students' learning. When information is presented with text only, students have difficulties in remembering (Mayer, 2002) and comprehending the material (Carney & Levin, 2002).

Chemistry as a discipline of science is both abstract and multi-representational (i.e., macroscopic, submicroscopic, and symbolic) in nature (Johnstone, 2000a, 2000b; Talanquer, 2011; Taber, 2013). However, multi-representational nature of chemistry compensates the limitations of its abstract nature. Research evidences have clearly indicated that using multiple representations when presenting information increases conceptual understanding (Ainsworth, 2006), comprehension, and remembering (Carney & Levin, 2002). Representations also have become "…one of the most pervasive and visible elements of the modern-day science textbook" (Lee, 2010, p. 1099) and chemistry textbooks (Gkitzia, Salta, & Tzougraki, 2011). More importantly, well-designed textbooks in terms of visuals are beneficial for students to understand the difficult concepts as well as to avoid misconceptions (Khine, 2013). However, representations have potential to create confusion (Stern & Roseman, 2004) and might limit students' learning when excessively used (Woodward, 1993). Therefore, representations should be used in caution. Bearing these issues in mind, the aim of this research was to investigate the types and characteristics of representations (i.e., interpretation of surface features, relation to the text, the properties of captions, and degree of correlation between representations) in high school chemistry textbooks (i.e., from 9th to 12th) in Turkey.

Theoretical Framework

Representations in Chemistry

Chemistry is abstract in nature (Taber, 2013) and "understanding chemistry relies on making sense of the invisible and the untouchable" (Kozma & Russell, 1997, p. 949). By the use of representations, "…chemists are able to visualize, discuss, and understand the molecules and chemical processes that account for the more perceivable reagents and phenomena they observe…" (Kozma & Russel, 2005, p. 130). Although termed differently, macroscopic, submicroscopic, and symbolic representations have been pointed out as major levels in chemistry (Johnstone, 1993, 2000a, 2000b; Gabel, 1999; Gilbert & Treagust, 2009; Justi & Gilbert, 2003; Liu & Taber, 2016; Taber, 2013; Talanquer, 2011). Johnstone (2000a) explicitly argued that these three forms of representation could be thought as corners of a triangle. He elaborated his argument by advocating that any form is not superior to another rather each complements the other forms. Even though it might seem that chemists and chemistry educators agreed upon the levels to represent chemical knowledge, all components have been subject to different interpretations (Talanquer, 2011).

Macroscopic level is the level of chemistry, which can be observed and studied (Gabel, 1999). It is also defined as the form of subject, which is tangible: what can be seen, touched, and smelt (Johnstone, 2000b). That is, macroscopic level is accessible to human sense and chemistry is experiential at this level. Gilbert and Treagust's (2009) definition also points out "experience" and "sense" properties for macroscopic representations. For example, the disappearance of solid sodium chloride in water is an example of macroscopic level for dissolving (Tan, Goh, Chia, & Treagust, 2009). Some differentiated macroscopic level from other levels by defining macroscopic as real and visible in terms of perception (Davidowitz & Chittleborough, 2009). They defined submicroscopic as real but too small to be seen with the naked eye. While Davidowitz and Chittleborough (2009) described macroscopic and submicroscopic as real, they defined symbolic as representation instead of real. In terms of perception, submicroscopic and symbolic levels are perceived via mental images and models. Different than those, others described macroscopic representations as the observable bulk properties of matter such as heat energy, pH and colour changes, and the formation of gases and precipitates (Treagust & Chandrasegaran, 2009). There has been a definition for macroscopic representations combining the aforementioned descriptions (i.e., observable and bulk properties). They advocated that macroscopic level includes both the actual phenomena and the concepts used to describe them (Dori & Hameiri, 2003; Hinton & Nakhleh, 1999).

Submicroscopic is defined as the level of representation where the behaviour of substances is interpreted in terms of the unseen and molecular (Johnstone, 2000a, 2000b). For example, using models of sodium ions, chloride ions, and water molecules to represent how water molecules hydrate these ions refers to submicroscopic level of dissolving. Atoms, molecules, ions, and structures are given as examples although structures are not explicitly defined. Differently, Treagust and Chandrasegaran (2009) emphasized the explanatory nature of submicroscopic representations at particulate level where matter is described as being composed of atoms, molecules, and ions. Taber (2013) also highlighted this by advocating that learners can give meaning to macroscopic concepts through submicroscopic theoretical models. Gilbert and Treagust (2009) stressed that submicroscopic representations seek to support a qualitative explanation for the phenomena experienced with senses, which refers to macroscopic (Gilbert & Treagust, 2009). Although Bucat and Mocerino (2009) agreed with others on what submicroscopic representations include (e.g., atoms, ions, and molecules), they focused on its imaginative nature similar to Taber (2013) who used the term "submicroscopic theoretical entities". On the contrary, Davidowitz and Chittleborough (2009) defined submicroscopic as real, similar to macroscopic level, but too small to be seen. Also, Wu and Shah (2004) advocated that submicroscopic representations portray the structure and movement of the real particles of matter (e.g., atoms, molecules, ions, and electrons), which are too tiny to be observed. Examples of models representing particles at submicroscopic level are given as ball and stick-, the space filling- and the stick-structures (Gkitzia et al., 2011). However, stick structures especially the ones representing molecular geometry have also symbolic representations in nature, which will be explained in the next paragraph.

Johnstone (1993, 2000a, 2000b) gave examples of symbolic representations as symbols, formula, equations, molarity stoichiometry, mathematical manipulation, and graphs. Gilbert (2005) elaborated mathematical expressions as mathematical equations such as the universal gas law and the reaction rate laws. Gilbert and Tragust (2009) defined symbolic level as seeking to support a quantitative explanation of macroscopic phenomena. Gabel (1999) gave only chemical symbols, chemical formulas, and chemical equations as examples of symbolic level representations without mentioning mathematical ones. Some scholars have also examined symbolic system in two

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levels, which are chemical and algebraic (Nakhleh & Krajcik, 1994). At chemical level, substances and processes are symbolized using chemical language and drawings. Relationships between the properties of matter are expressed using formulas and graphs in algebraic level. Different than the aforementioned scholars giving popular examples of symbolic representations (e.g., element symbols [Fe] and chemical formulas [H_2O]), Taber (2009) gave specific examples of symbolic representations in chemistry (e.g., reaction mechanisms, Lewis structures, the letters used for atomic number (A), and constants such as K_{sp}). Although signs are used to symbolize chemical substances and processes in some occasions, the signs have both symbolic and iconic nature (Hoffmann & Laszlo, 1991). For instance, structural formulas are utilized to represent molecular geometry. These formulas include the types of atoms and bonds represented as symbols. However, the drawing of structural formulas gives an iconic impression as it purposes to portray the three-dimensional structure of the molecule. Consequently, Talanquer (2011) defined these kinds of representations as hybrid since they have both semi-symbolic and semi-iconic nature.

Literature Review

Studies about High School Chemistry Textbooks in Turkey

Research studies conducted about high school chemistry textbooks in Turkey could be examined under two headings: (1) teachers' use of textbooks and (2) content analysis of textbooks with respect to several aspects.

Researchers in the first category mostly used scales and interviews to examine how chemistry teachers use textbooks (Akkuş, Üner, & Kazak, 2014; Aydın, 2010; Eroğlu, Akarsu, & Bektaş, 2015; Nakiboğlu, 2009). Major findings of these studies revealed that chemistry teachers utilize textbooks when they plan their instruction and choose experiments and activities. However, experienced teachers prefer to use textbooks less because of the state-wide examinations for university entrance (Nakiboğlu, 2009). In terms of their opinion, chemistry teachers find the number and quality of representations not satisfactory (Akkuş et al., 2014; Eroğlu et al., 2015). Nevertheless, chemistry teachers expressed that they use visuals and representations in chemistry textbooks during instruction (Eroğlu et al., 2015).

Scientific process skills (Koray, Bağçe-Bahadır, & Geçgin, 2006; Şen & Nakiboğlu, 2014), nature of science (NOS) (Aydın & Tortumlu, 2015), inscriptions in chemical reactions (Aydın, Sinha, izci, & Volkmann, 2014), nature of questions in gas laws (Nakiboğlu & Yıldırır, 2011), and semantic mistakes in the amount of substance (Pekdağ & Azizoğlu, 2013) were the aspects that have been taken into consideration during content analysis of chemistry textbooks. In terms of scientific process skills, activities and experiments in chemistry textbooks engage students in basic skills such as observation and measurement (Koray et al., 2006; Şen & Nakiboğlu, 2014). A recent research, which investigated the inclusion of NOS in chemistry textbooks, indicated that the number of NOS aspects mentioned decreased from ninth to twelfth grade (Aydın & Tortumlu, 2015). Chemistry textbooks mostly focused on the tentativeness, the empirical-based, and the difference between observation and inference. When focusing on these aspects, chemistry textbooks employed the implicit approach to teach NOS. Another research investigating high school chemistry textbook questions in gas laws chapter revealed that most of the questions were algorithmic (63%) and there were lower number of conceptual questions (33%) than algorithmic (Nakiboğlu & Yıldırır, 2011). Conceptual questions did not include representations in submicroscopic level, whereas laboratory and demonstration questions were more prevalent in textbooks. There have been only two studies considering representations in high school chemistry textbooks in the topic of chemical reactions (Aydın et al., 2014) and amount of substance (Pekdağ & Azizoğlu, 2013). In the amount of substance, researchers found that chemistry textbooks included concepts that are missed at some levels of chemistry and used representations mistakenly. In the chemical reactions (Aydın et al., 2014), chemistry textbooks included symbolic representations the most (47%). Percentages for macroscopic (35%) and multiple representations were lower (12%) than symbolic. Although there have been attempts to investigate representations in chemistry textbooks, they are limited to certain topics. With these considerations, the importance of this research lies in the scope since it examines representations utilized in commonly used high school chemistry textbooks in all grade levels (i.e., from ninth to twelfth).

Studies about Representations in Chemistry Textbooks

This literature review focuses on the ones investigating representations in chemistry textbooks either in high school or college level. When the studies in the literature from this perspective were reviewed, three categories emerged under which these studies could be grouped: (1) representations used in chemistry textbooks, (2) representations used in some chemistry topics, and (3) representations used in questions.

Studies in the first category focused on analysing representations either in high school (Chiappetta, Sethna, & Fillman, 1991; Gkitzia et al., 2011; Harrison, 2001; Shehab & BouJaoude, 2016) or in college chemistry textbooks (Kumi, Olimpo, Bartlett, & Dixon, 2013; Nyachwaya & Gillaspie, 2016; Nyachwaya & Wood, 2014). Chiappetta et al. (2011) were interested in number of pictures/diagrams in seven high school chemistry textbooks. Analysis results showed that average number of pictures/diagrams per chapter ranged between 10 and 25. Harrison (2001) investigated models used in Australian high school chemistry textbooks and found that iconic and symbolic models were used mostly. Two of the studies in high school chemistry category were interested in the same features of representations (e.g., type of representation and representations' relation to the text) and used same rubric including criteria for evaluation (Gkitzia et al., 2011; Shehab & BouJaoude, 2016). Gkitzia el al. (2011) analysed tenth grade Greek chemistry textbooks and found that macroscopic, submicroscopic, symbolic, and multiple representations were frequently used. In the research conducted by Shehab and BouJaoude (2016) with the tenth, the eleventh, and the twelfth grade Lebanese high school chemistry textbooks, it was revealed that Lebanese chemistry textbooks were focused on macroscopic, submicroscopic, and symbolic levels. In terms of other features analysed, both studies found similar results. Nearly two thirds of the representations were problematic since interpretation of surface features were left to the readers and one third of them had explicitly mentioned surface features. In terms of relation to the text, majority of the representations were completely related to the text. Also, most of the representations were appropriately captioned. With respect to a degree of correlation, more than half of the multiple representations did not indicate the equivalence between subordinate representations. Nyachwaya and Wood (2014) also evaluated representations in physical chemistry textbooks in college level by utilizing the same rubric developed by Gkitzia et al. (2011). Symbolic representations were used the most and it was followed by submicroscopic representations in physical chemistry textbooks. Moreover, the use of macroscopic representations were the least while mixed and hybrid representations did not exist. Vast majority of all representations had explicit surface features and were completely related to the text. Captions of all representations were appropriate for students to comprehend. In a recent research, Nyachwaya and Gillaspie (2016) examined representations in general chemistry textbooks with regard to number of representation, physical integration to the text, figure indexing, extended captions, labelling, representation function, and conceptual integration. Majority of the representations were representational, which presents the information in a new way. Also, 80% of representations in all textbooks were directly integrated and had captions. In terms of indexing, high proportion of representations were either indexed on a different page or not indexed at all. Another research in college level used a self-designed rubric to evaluate whether Newman (NPs) and Fischer Projections (FPs) are accurately introduced, constructed, and represented in seven frequently used organic chemistry textbooks (Kumi et al., 2013). Findings indicated introduction of both NPs and FPs were average. Construction of diagrams for NPs was better than it was for FPs. Success of representation of NPs throughout the text was mediocre while FPs were more successively represented.

Researchers investigating representations in some chemistry topics mostly focused on whether representations cause misconception (Bergqvist et al., 2013; Pedrosa & Dias, 2000; Sanger & Greenbowe, 1999). They were interested in type of representations in the topic less (Aydın et al., 2014; Pekdağ & Azizoğlu, 2013). Sanger and Greenbowe (1999) analysed the language and representations used in electrochemistry and oxidation-reduction chapters in college chemistry textbooks. Their findings revealed that macroscopic and symbolic representations might lead students to have misconceptions in electrochemistry. For instance, macroscopic drawing of cells and cell notation depicted by symbols imply that the anode and cathode depend on the physical placement of the half-cells. Another research focusing on chemical equilibrium advocated that high school and university chemistry textbooks' approaches to chemical equilibrium have potential to prevent students to reach conceptual understanding since they reduce it to a world of symbols and equations (Pedrosa & Dias, 2000). Similarly, representations of chemical bonding models might cause students to have alternative conceptions and difficulties in understanding chemical bonding (Bergqvist et al., 2013). For instance, for ionic and covalent bonding, upper secondary school chemistry textbooks use representations showing interactions between discrete atoms while the reactants actually are composed of molecules or lattice structure.

Studies in the third category were either interested in the use of representations in questions of a particular chemistry topic (Gillette & Sanger, 2014; Nakiboğlu & Yıldırır, 2011) or end of the chapter questions in all topics (Davila & Talanquer, 2010). Gillette and Sanger (2014) examined the distribution of representations used in questions in gas law chapters of four high school and four college chemistry textbooks. They found that quantitative

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questions (N=1573) only used symbolic representations, whereas distribution of qualitative questions (N=740) in these textbooks was not significantly different based on representation types used in these questions. The percentage for the use of macroscopic representation was 37, whereas it was 33 and 30 for submicroscopic and symbolic representations respectively. Different than this research, Davila and Talanquer (2010) investigated types of questions at the end of chapter in three most used general chemistry textbooks in America. A total of 19.844 questions were analysed. Questions that require students to translate between representations or to represent and interpret information in graphical or symbolic form were few (i.e., percentages of these kind of questions ranged between .4 and 1.3).

The Present Research

"In discussing chemical education, the analysis of textbooks is of pivotal importance because they are the most widely and frequently used teaching aid at all educational levels" (Justi & Gilbert, 2003, p. 57). Teachers utilize textbooks as a principal reference when they think about the content and choose activities (Sánchez & Valcárcel, 1999). Moreover, textbooks may act as an alternative source of information when the teacher is unavailable (Harrison, 2001) and students perceive textbooks as a very important part of their science education (Tulip & Cook, 1993). Hence, it is important to analyze textbooks to see the degree to which they can act as an alternative source.

Based on the available data suggesting that textbooks are important for both teachers and students, authors write textbooks assuming that most students at a given grade level can comprehend them (Chiang-Soon & Yager, 1993). Even though textbooks including various types of representations are an important source for both learners (Devetak & Vogrinc, 2013) and teachers (Carvalho & Clement, 2007), the reading of these representations is not at all trivial for students (Stylianidou, 2002). Moreover, students may have misconceptions if they are left with the task of interpreting representations (Chittleborough & Treagust, 2008). Consistently, it is suggested that teachers need to put effort explaining the meaning of the representations to students (Stylianidou, 2002) since the meaning of a representation is not rooted in the representation itself instead is ascribed to the use of representation in practice (Kozma & Russel, 2005). For increasing the contribution of textbooks to the use of representation in practice, research suggested that linked referential connections should be made visible and information should be made explicit for decreasing students' cognitive load (Wu & Shah, 2004). With these considerations, this research attempted to analyze the quality of captions, relation to the text, interpretation of surface features, and degree of correlation between subordinate representations to see the degree to which they ease students' cognitive load.

Finally, there have been some efforts in analyzing representations in high school chemistry textbooks with respect to some chemistry topics (e.g., chemical reactions, Aydın et al., 2014; amount of substance Pekdağ & Azizoğlu, 2013) and questions in a particular topic (i.e., gas laws, Nakiboğlu & Yıldırır, 2011) in Turkey. This research fulfills the lack of studies investigating representations used in Turkish high school chemistry textbooks. Moreover, this research focuses on the analysis of four chemistry textbooks (i.e., one chemistry textbook for each grade; from 9th to 12th) assigned by the National Ministry of Education (NME) as the primary textbook in all high schools. In other words, millions of students use these four textbooks as the primary source of nearly all information about chemistry. Also, analyzed chemistry textbooks include all chemistry topics that students are expected to learn during their high school education. Therefore, this research provides information about how Turkish chemistry textbooks including chapters about all topics contribute to Turkish students' learning through the use of representations. By doing so, it tried to respond Han and Roth's call (2006) that was "because of possible contextual factors, more research is therefore required focusing on science textbook inscriptions in different cultures and subject matters" (p. 176).

There are possible limitations inherent in this research. First, this research was interested in representations present in four Turkish chemistry textbooks (i.e., one textbook from each grade), used throughout 2015-2016 school semester. However, chemistry textbooks are distributed to schools by NME and utilized across the Turkey. That is, millions of students utilize these four textbooks as the main source of almost all information about chemistry. Hence, the conclusions drawn from this research are beneficial to all students and chemistry teachers. Nevertheless, it would be valuable to analyze chemistry textbooks of other Turkish textbook publishers to reach conclusions that have a high generalizability degree. One can think this research is a first attempt for this kind of research. Second, representations were analyzed from chemical education researchers' perspective on representations. Both the way teachers used and the way students see these representations are important factors influencing pedagogical contribution of these representations to chemistry teaching. As a next step, investigating students' and teachers' perspective would be worthwhile to provide a bigger picture.

Problem of Research

This research aimed to examine chemical representations used in high school chemistry textbooks (i.e., from 9th to 12th) in Turkey. This aim was addressed through the following research questions:

1. What types of representations are included in commonly used high school chemistry textbooks?
2. What is the degree of interpretation of surface features in commonly used high school chemistry textbooks?
3. About the representations commonly used in high school chemistry textbooks, what is the degree of relatedness to text (i.e., existence and clarity of any statement in the textbook for direct students to the representations)?
4. What are the properties of captions in commonly used high school chemistry textbooks?
5. What is the degree of correlation between representations in multiple ones commonly used high school chemistry textbooks?

Methodology of Research

Research Design

This research is qualitative in nature (Marshall & Rossman, 2011) and specifically recognized as "basic or generic qualitative research" (Merriam, 1998). Basic or generic qualitative studies have the essential characteristics of qualitative research (e.g., eliciting meaning, researcher as data collection and analysis instrument, and rich description). However, this type of research "simply seek to discover and understand a phenomenon, a process, or the perspectives and worldviews of the people involved" (Merriam 1998, p. 11). Accordingly, this research aimed to elicit the meaning of representations and understand the type and characteristics of chemical representations in Turkish high school chemistry textbooks. This research could be categorized as a descriptive generic qualitative research (Caelli, Ray, & Mill, 2003). Objective of this research was to obtain descriptive information about representations. For getting descriptive information, content analysis of high school chemistry textbooks with regard to representations was conducted. During content analysis, written content of human communications (e.g., textbooks, essays, and pictures) is studied. Content analysis also includes quantitative aspects. Types and characteristics of representations were interpreted through the use of frequencies and the percentages, which is a common way to interpret content analysis data (Fraenkel & Wallen, 2006).

Sample of Research

Developing a sampling plan and specifying the units of analysis are important for content analysis (Fraenkel & Wallen, 2006). Among various sampling techniques, purposive sampling was implemented to select four high school chemistry textbooks. Each of four textbooks was used by students in different grades (i.e., ninth to twelfth) across Turkey (see references for the selected books). Two main criteria were determined for judging whether the sample of chemistry textbooks is representative. First, NME must approve high school chemistry textbooks. Second, the textbooks must be widely and currently used in high schools. In Turkey, NME distributes the approved textbooks to schools for teachers to use during the semester, which in turn ensures wide usage of the books. By considering those, an approved and distributed chemistry textbook for each grade level in 2015-2016 school year was selected. Before analyzing the data, the unit of analysis was specified (e.g., word, sentence, and painting) (Fraenkel & Wallen, 2006). All the images labelled as "figure or picture" and images shown in frames in activity, teaching, and assessment parts of the textbooks were selected as visuals, which formed the unit of analysis in this research. Symbols are used extensively in teaching and learning chemistry (Taber, 2009) to avoid painstaking of writing. Therefore, symbolic visuals (e.g., element symbol, compound formulae, and letter for measurable quantities such as "P" for pressure), which imperatively appear in the course of assessment, activity, and teaching parts, were excluded from data analysis. Data analysis was conducted during 2016-2017 fall semester.

Instrument and Procedures

After identification of facet of the content to be investigated (i.e., visuals identified as unit of analysis in this research), an existing rubric was utilized (Gkitzia et al., 2011) during formulating categories that are relevant to

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the examination of representations (Fraenkel & Wallen, 2006). The rubric includes criteria for analysis of representations in school textbooks. Moreover, there has been evidence for the applicability of this rubric in evaluating the chemical representations in science (Kapıcı & Savaşçı-Akalın, 2015), chemistry (Gkitzia et al., 2011), and physical chemistry textbooks (Nyachwaya & Wood, 2014). The rubric aims to evaluate chemical representations with respect to several aspects, which are type of representation, interpretation of surface features, relatedness to the text, properties of caption, and degree of correlation between representations in multiple ones.

1st criterion (C1) - Type of representation: This criterion examines the type of each representation and categorizes them as macroscopic, submicroscopic, symbolic, multiple, hybrid, and mixed (see Appendix for examples).

Macroscopic representations portray phenomena directly accessible to human visual sense. Visuals representing tangible, observable, and touchable objects and concepts are macroscopic in their type. On the contrary, submicroscopic representations depict the structure and movement of atoms and their derivatives such as ions, molecules, electrons, protons, neutrons, orbitals, and etc. (Bucat & Mocerino, 2009). These constitute the unobservable world, which is only accessible with imagination. Submicroscopic representations may emerge as molecular models (i.e., the space filling and ball and stick), pictures, and computer animations. Symbolic representations are the mediators between macroscopic and submicroscopic representations (Taber, 2009). They refer to letters, numbers, signs, and symbols that are used to symbolize atoms, molecules, ions, substances, measurable quantities, units for measurements, constants, and oxidation states in systematic compound names (Gkitzia et al., 2011; Taber, 2009). The chemical symbols (e.g., H), the chemical formulas (e.g., NaCl), reaction mechanisms, Lewis structures, graphs, the letters of A and Z for atomic number and mass respectively, letters standing for various measurable quantities (e.g., V for volume), units (e.g., mol, kg, and mol dm^3), constants (e.g., Ka), letters indicating mathematical relations (e.g., pH), letters pointing structural features of crystals, (e.g., f.c.c.), and numbers showing oxidation states in systematic compound names (e.g., iron (II) chloride) are examples of symbolic representations. Multiple representations include two or three levels of representations to depict chemical phenomena and hence each representation complements one another. Hybrid representations also include coexistence of two or three levels of chemical representations in order to form one representation. The basic difference between multiple and hybrid representation lies in the number of representations used to depict the phenomena. Multiple representations show the phenomenon at two or three levels by combining two or three levels of representations while hybrid representations combine the characteristics of two or three levels to form one representation (Gkitzia et al., 2011).

Chemical substances and processes are represented by both icons and symbols, which comprise the visual language of chemistry (Talanquer, 2011). Moreover, the signs used in chemistry combine both symbolic and iconic values (Hoffmann & Laszlo, 1991) in many cases. Structural formula representing molecular geometry is a typical example for these kinds of cases. The types of atoms and bonds are represented using symbols while the drawing has an iconic value since it aims to depict the three-dimensional structure of the modelled molecule. Therefore, "[t]he semi-symbolic, semi-iconic nature of many visual representations in chemistry gives them a hybrid status between signs and models…" (Talanquer, 2011, p. 184). Thinking them as mere signs may result in classifying them as symbolic representations, whereas thinking them as models which has descriptive, explanatory, and predictive power may lead someone to classify them as part of the explanatory (submicroscopic) level. With these considerations in mind, structural formulas as hybrid representations in addition to those are defined by Gkitzia et al. (2011). The last type of representation proposed by Gkitzia et al. (2011) is mixed, which includes coexistence of a chemistry level (i.e., macroscopic, submicroscopic, and symbolic) and another type of depiction (e.g., analogy). During analysis two new categories were added, which are "scientist" and "microscopic". Scientist was used to categorize photo or picture of a scientist (e.g., picture of Robert Boyle). Microscopic was utilized for some visuals including microscopic views of substances or processes (see Appendix for examples of scientist and microscopic categories).

2nd criterion (C2) - Interpretation of surface features: This criterion is related to what degree students understand the correct meaning of representation (Gkitzia et al., 2011). It examines whether the meaning of a representation is clear, and specifically to what extent surface features are clearly labelled. Clarity of surface features is important since students have difficulties in interpreting the correct meaning of representations (de Vos & Verdonk, 1996). More importantly, students try to understand the textbook pictures when they know the codes to interpret them (Pinto & Ametller, 2002). To enhance learning, textbook authors should point out the important features of a representation to both teachers and students (Gkitzia et al., 2011). Explicit, implicit, and ambiguous were used as labels when coding interpretation of surface features. If the interpretation and meaning of surface features are clearly mentioned either in the text or in the caption including internal ones, it is coded as explicit. A representation is coded as implicit when the meaning of some surface features is clearly mentioned. When there is no indication for the meaning of any surface feature it is coded as ambiguous (see Appendix for examples).

3rd criterion (C3) – Relatedness to the text: This criterion examines not only to what degree a representation is coherently related to the text but also the existence of the direct link from the text to the representation. There has been empirical evidence indicating that students have difficulty in connecting representations with the corresponding text (Garnett, Garnett, & Hackling, 1995). If students are expected to make sense of the phenomenon depicted in the visual, related concepts and information with appropriate reference to representation should be mentioned in the text (Pozzer & Roth, 2003). Completely related and linked, completely related and unlinked, partially related and linked, partially related and unlinked, and unrelated were used as labels while coding the relatedness of visuals to the text. If a representation depicts the text content exactly, it is called completely related. In other words, if a representation depicts the text content exactly, that representation together with the text has the potential to contribute to build the concepts and to foster the learning. The representation becomes partially related if it depicts some of the text content or familiar subject to the text instead of the exact one. If a representation is irrelevant to the text, then it is coded as unrelated. When analyzing the link of representation to the text, the phrases like "as shown in the figure or picture" and "the following model", and explicit reference to the visual in brackets were examined. If those existed, the representation is linked to the text (see Appendix for examples).

4th criterion (C4) – Existence and properties of a caption: This criterion is related to the existence and appropriateness of caption. The caption is essential since it guides the reader what to look and how to understand (Pozzer & Roth, 2003). Moreover, captions have potential to make both the content and message of representations clear (Ardac & Akaygun, 2005). Captions were labelled as appropriate, problematic, and no caption when examining the properties of the caption. An appropriate caption should be explicit, brief, and comprehensive so that it can provide autonomy to representation. Also, an appropriate caption should explain the exact content of the visual. Problematic captions do not provide an accurate description of the visual. They are also implicit and long so that a reader cannot comprehend the representation. Visual is coded as no caption when there is none.

5th criterion (C5) – Degree of correlation between the components (subordinate representations) comprising a multiple representation: This criterion examines the degree to which correlation between subordinate representations forming multiple one is clearly indicated. That is, it investigates the sufficient and clear link between macroscopic, microscopic, and symbolic representations so that students can understand the three levels. Transforming representations into one another and correlating three levels of chemistry are challenging tasks for students (Chittleborough & Treagust, 2008). Although challenging, the ones who can transform are able to reach conceptual understanding (Treagust, Chittleborough, & Mamiala, 2003). Therefore, examining the links between representations is important. Sufficiently linked, insufficiently linked, and unlinked were used to categorize the multiple representations with regard to the links between subordinates. A multiple representation is coded as sufficiently linked when links between different levels and equivalence of subordinates are clearly indicated. Use of arrows or signs that link different levels of representations provides sufficiency to the links. A multiple representation is coded as insufficiently linked when equivalence of subordinates and links between different levels are implicit and not explicitly indicated by a sign or arrow. Unlinked multiple representations include subordinates as placed next to one another and no indication of equivalence of them (see Appendix for examples).

Data Analysis

For ensuring reliability, 100 visuals were randomly selected and coded by two independent coders. Also, coders consulted the opinions of three experts, who had masters or PhD degree in chemistry education, during coding when there is a disagreement between coders. The discrepancies between the coders were discussed and resolved. Based on this consensus, the remaining data were analyzed by the researcher. The inter-coder reliability was 82% in the type of representations, 76% in the interpretation of surface features, 78% in the relatedness to the text, 90% in the properties of caption, and 75% in the degree of correlation between subordinates comprising multiple representations. These reliability values indicate substantial and perfect agreement (Cohen, Manion, & Morrison, 2000) and were considered as acceptable (Gwet, 2014) since they are above 75%

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Results of Research

Results revealed that high school chemistry textbooks (i.e., from 9th to 12th) include 1701 visual representations in total.

Types of Representations Included in Commonly Used High School Chemistry Textbooks

The eleventh grade chemistry textbook had the highest number of representations (30%; 513 representations). Frequencies of representations in the tenth and twelfth grade chemistry textbooks were almost the same (25%; 420 representations and 25%; 426 representations respectively). The number of representations in the ninth grade chemistry textbook was the lowest (20%; 342 representations). Distribution of representations across different units in all chemistry textbooks (see Appendix) indicated that "Modern atom theory" (i.e., a unit in the eleventh grade) included the frequent number of representations (10%; 170 representations), whereas the lowest number of representations was used in "Calculations with chemical formulas and equations" (i.e., a unit in the eleventh grade) (1%, 17 representations). A closer look to how representations placed in different parts of the textbooks (i.e., assessment, activity, and teaching) revealed that the vast majority of the representations took place in the teaching part (85%; 1436 representations). Activity part included 175 representations (10%), whereas 90 representations (5%) were used in the assessment part of the textbooks.

With regard to the type of representations, most common type of representation in high school chemistry textbooks was macroscopic (34.4%; 585 representations). It was followed by symbolic and hybrid representations, which have almost the same frequency of use (23.3%; 396 representations and 23.2%; 395 representations respectively). A closer analysis of symbolic representations indicated that some of symbolic representations (236) were used to symbolize to lab safety (57.6%; 136 representations), graph (30.1%; 71 representations), hazardous chemicals (8.9%; 21 representations), and recycling (3.4%; 8 representations). Multiple representations were the third in the order of frequency (10.4%, 177 representations). There were 107 submicroscopic representations (6.3%) following multiple ones. The lowest number of representations belonged to the mixed ones (1.2%; 20 representations) according to Gkitzia et al.'s (2011) typology. The frequencies for researcher created categories, which are microscopic and related to scientists, were lower than the mixed representations. There were 16 visuals (.9%) related to scientists and 5 visuals (.3%) depicting microscopic level.

Distribution of different type of representations in chemistry textbooks across grade levels is shown in Figure 1. The number of macroscopic representations was almost the same for both tenth and twelfth grade chemistry textbooks (45%; 187 representations and 46%; 196 representations respectively). The eleventh grade chemistry textbook came after the tenth and twelfth grade books in the use of macroscopic representations (21%; 109 representations). The least frequent use of macroscopic representations was observed in the ninth grade chemistry textbook (27%; 93 representations). Nevertheless, ninth grade chemistry textbook included symbolic representations the most (38%; 130 representations). Tenth (22%; 92 representations) and eleventh (27%; 136 representations) grade textbooks followed ninth grade textbook in the use of symbolic representations. Interestingly, twelfth grade textbook utilized the least frequent number of symbolic representations (9%; 38 representations). With regard to prevalence of hybrid representations across grade levels, the most frequent use was observed in the eleventh and twelfth grade chemistry textbooks (26%; 133 representations and 28%; 117 representations respectively). It was followed by tenth grade chemistry textbook, which had nearly the same frequency of inclusion (24%; 100 representations). Ninth grade chemistry textbook utilized hybrid representations the least (13%; 45 representations). Multiple representations were used mostly in the eleventh grade textbook (20%; 104 representations). Preference for the utilization of multiple representations was nearly the same for ninth (8%; 28 representations), tenth (6%; 23 representations), and twelfth grade (5%; 22 representations) chemistry textbooks. The frequencies for the use of submicroscopic representations were similar for ninth (9%; 31 representations) and twelfth (9%; 38 representations) grade textbooks, and it was higher than for their use in tenth (4%; 17 representations) and eleventh (4%; 21 representations) grade chemistry textbooks. Most frequent use of mixed representations was observed in the ninth grade chemistry textbook (4%; 12 representations), whereas the frequencies were 6 (1%) and 2 (.4%) for the twelfth and eleventh grade chemistry textbooks respectively.

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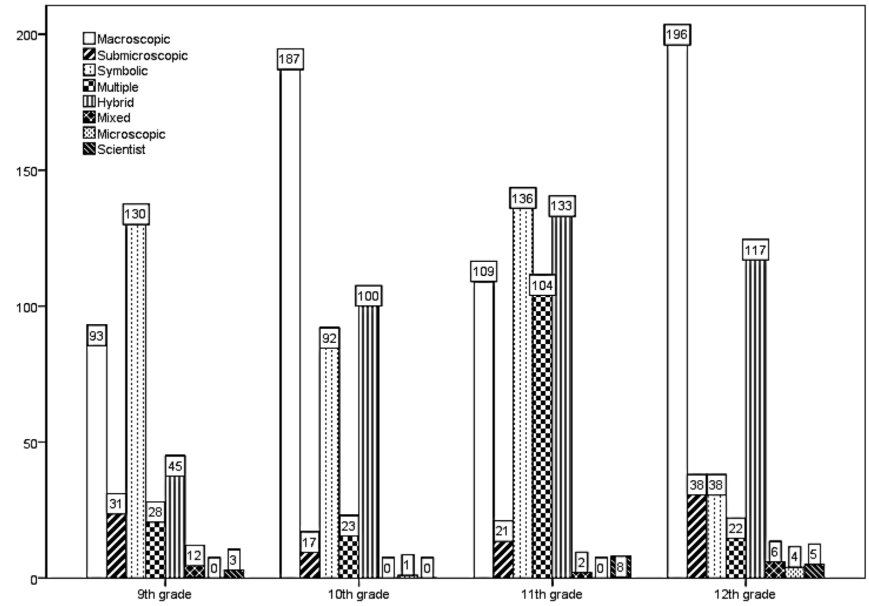

Figure 1: Distribution of representation types (in frequencies) in high school chemistry textbooks with respect to grade levels.

How different types of representations were distributed to different parts of the textbooks was also identified (Table 1). Vast majority of representations in each category was included in teaching part of the book. For instance, there were 543 (93%) macroscopic representations in teaching part, whereas activity and assessment parts utilized 35 (6%) and seven (1%) macroscopic representations respectively. Activity parts did not include any submicroscopic representation while there were only three (3%) submicroscopic representations in the assessment part. The use of symbolic representations was prevalent in the activity part (128 out of 396) when compared to other types of representations. Symbolic representations were also utilized in the assessment part (10%; 39 representations) of which majority of them refers to questions about graphs. The use of hybrid representations was also high in the assessment part (9%; 34 representations).

Table 1. Distribution of representation types in high school chemistry textbooks with respect to parts.

Type of representation	Part		
	Assessment	Activity	Teaching
Macroscopic	7	35	543
Submicroscopic	3		104
Symbolic	39	128	229
Multiple	7	10	160
Hybrid	34	1	360
Mixed		1	19
Scientist			16
Microscopic			5

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Degree of the Interpretation of Surface Features in Commonly Used High School Chemistry Textbooks

After excluding 16 visuals about scientist from the data (N=1701), analysis of 1685 representations indicated that more than half of the representations had explicit surface features (63%; 1068 representations). Thirty-nine percent of the representations had implicit surface features (520 representations). There were 97 representations (6%) that were ambiguous for students to understand the meaning of representation.

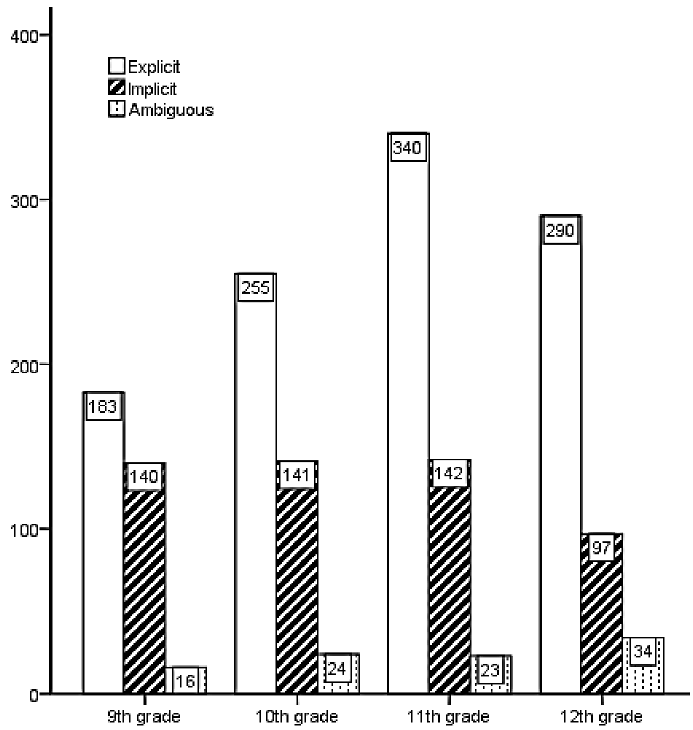

Figure 2: Distribution of interpretation of representations' surface features (in frequencies) in high school chemistry textbooks with respect to grade levels.

Examining how interpretation of surface features changes (Figure 2) with regard to grade levels showed that the percentage of representations with explicit surface features decreased from twelfth to ninth grade: for twelfth (69%; 290 representations), for eleventh (67%; 340 representations), for tenth (61%; 255 representations), and for ninth (54%; 183 representations). On the contrary, the percentage of representations with implicit surface features diminished from ninth to twelfth grade: for ninth grade (41%; 140 representations), for tenth grade (34%; 141 representations), for eleventh grade (28%; 142 representations), and for twelfth (23%; 97 representations). Ambiguous representations were almost homogenously distributed in ninth (5%; 16 representations), tenth (6%; 24 representations), eleventh (5%; 23 representations), and twelfth (8%; 34 representations) grade chemistry textbooks.

A closer look at how different type of representations were differed in terms of interpretation of surface features (Table 2) revealed that majority of the symbolic (86%), microscopic (80%), mixed (75%), hybrid (62%), and macroscopic (60%) representations mentioned surface features explicitly either in the text or in the caption. However, percentages of multiple representations with explicit (57%) and implicit (42%) surface features did not differ to a certain degree. When the percentage of ambiguous ones is considered (2%), nearly half of the time multiple representations (i.e., implicit and ambiguous ones) left students alone when interpreting the meaning of features of representation.

Table 2. Frequencies of interpretation of surface features for different type of representations.

Type of representation	Interpretation of surface features		
	Explicit	Implicit	Ambiguous
Macroscopic	350	198	37
Submicroscopic	13	49	45
Symbolic	340	56	
Multiple	100	74	3
Hybrid	246	138	11
Mixed	15	5	
Microscopic	4		1

Degree of Relatedness of Representations to Text in Commonly Used High School Chemistry Textbooks

After excluding 16 visuals about scientist from the data (N=1701), analysis of 1685 representations showed that above half of the representations were completely related and linked to the text (64%; 1083 representations). Although completely related, 17% (293) of representations were not linked to the text. The frequency for partially related and linked representations was 200 (12%). Partially related and unlinked (4%; 66 representations) and unrelated (3%; 43 representations) ones were the lowest characteristics that representations exhibit in terms of their relation to the text.

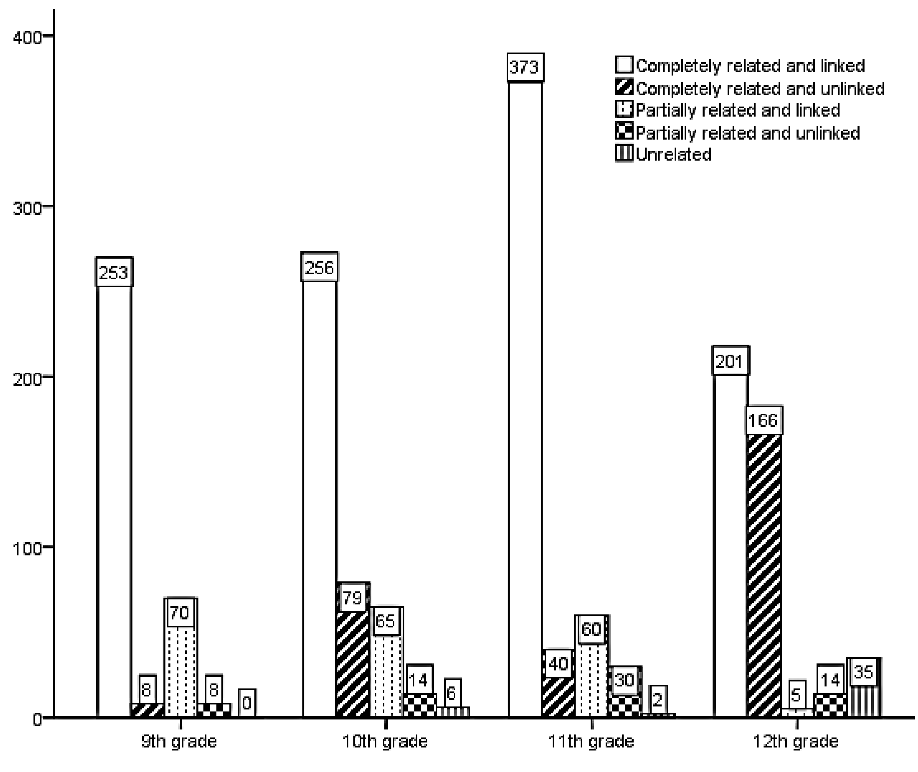

Figure 3. Distribution of representations' relatedness to the text (in frequencies) in high school chemistry textbooks with respect to grade levels

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Majority of the representations in ninth (75%; 253 representations), tenth (61%; 256 representations), and eleventh (74%; 373 representations) grade textbooks were completely related and linked to the text. However, nearly half of the representations' relation and link to the text was complete in twelfth grade textbook (48%; 201 representations). Although completely related, the most frequent unlinked representations were observed in twelfth grade textbook (39%; 166 representations) when compared to ninth (2%; 8 representations), tenth (19%; 79 representations), and eleventh (8%; 40 representations) grade textbooks. Percentages of partially related and linked representations decreased from ninth to twelfth grade textbooks: for ninth grade (21%; 70 representations), for tenth grade (16%; 65 representations), for eleventh grade (12%; 60 representations), and for twelfth grade (1%; 5 representations). Although partially related the prevalence of unlinked representations in eleventh grade textbook (6%; 30 representations) was higher than the ones in ninth (2%; 8 representations), tenth (3%; 14 representations), and twelfth (3%; 14 representations) grade textbooks. Unrelated representations appeared mostly in twelfth grade textbooks (8%; 35 representations). The frequencies for this type of representations were lower for both tenth (1%; 6 representations) and eleventh (.4%; 2 representations) grades.

Degree of relation and link to the text is important for students' meaningful understanding of what the representation depicts. Therefore, representations' relation and link to the text was also examined (Table 3). Microscopic (100%), and symbolic representations had the highest frequency (85%; 336 representations) with respect to their complete relation and link to the text. Following this, multiple representations were the second most frequent representation type (71%; 125 representations) that is completely related and linked to the text. Mixed representations were the third in the degree to which their complete relation and link to the text (65%; 13 representations). Chemistry textbooks ensured students' complete understanding of majority of the symbolic, multiple, and mixed representations. However, nearly half of the submicroscopic (58%; 62 representations) and hybrid (57%; 223 representations) representations are problematic for students to understand since either their relation is incomplete or there is no link to the text.

Table 3. Frequencies of different type of representations' relatedness to the text.

	Relatedness to the text				
Type of representation	Completely related and linked	Completely related and unlinked	Partially related and linked	Partially related and unlinked	Unrelated
Macroscopic	319	135	61	32	38
Submicroscopic	62	11	21	9	4
Symbolic	336	29	23	8	
Multiple	125	19	31	2	
Hybrid	223	97	59	15	1
Mixed	13	2	5		
Microscopic	5				

The Properties of Captions in Commonly Used High School Chemistry Textbooks

When analyzing the existence and properties of caption, 378 representations were excluded from the data (N=1685) since these representations are placed in the text and not caption applicable. Most of the representations' captions (78%; 1019 representations) were appropriate in the sense that they were explicit, brief, and comprehensive. Twenty percent of representations (264 representations) had problematic captions, whereas very few representations (2%; 24 representations) did not have a caption for students to understand what the visual depicts.

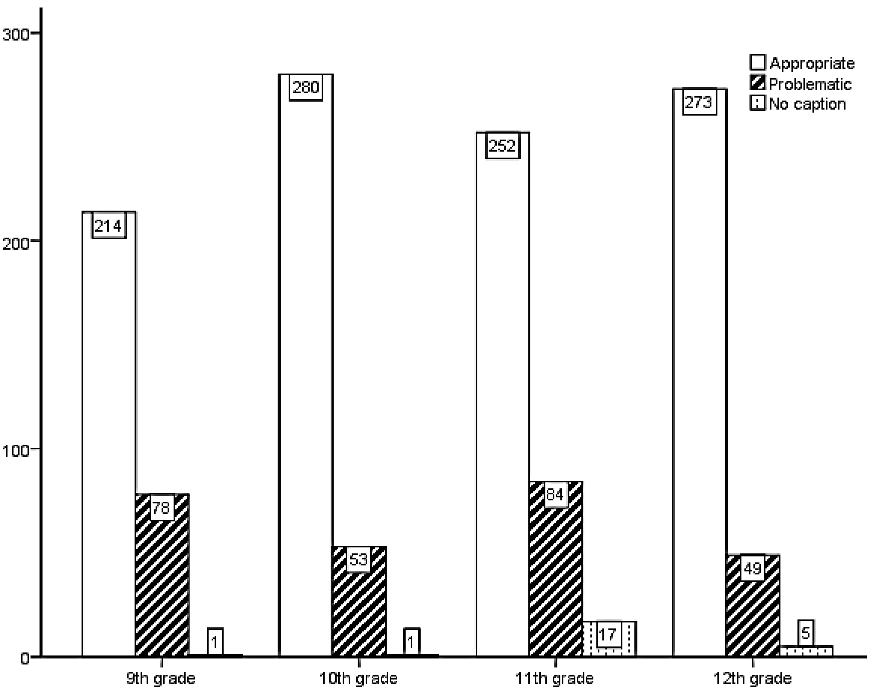

Figure 4. Distribution of caption properties (in frequencies) in high school chemistry textbooks with respect to grade levels

Representations in chemistry textbooks across all grades were similar in the sense that majority of them have appropriate captions (Figure 4): for ninth grade (73%; 214 representations), for tenth grade (84%; 280 representations), for eleventh grade (71%; 252 representations), and for twelfth grade (84%; 273 representations). Percentages of captions that are implicit or incomprehensive or lengthy ranged between 15% (49 representations in twelfth grade) and 27% (78 representations in ninth grade). Prevalence of problematic captions was nearly the same for both tenth (16%; 53 representations) and twelfth grade textbooks, and ninth and eleventh (24%; 84 representations) grades.

Table 4. Frequencies of different type of representations' caption properties.

Type of representation	Existence and properties of caption		
	Appropriate	Problematic	No caption
Macroscopic	307	82	3
Submicroscopic	60	32	1
Symbolic	269	23	17
Multiple	105	49	
Hybrid	262	73	3
Mixed	12	5	
Microscopic	4		

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Existence of an appropriate caption for a representation, especially for the ones that students have problems to understand (e.g., submicroscopic and multiple), is important to ensure that students clearly receive the message of representation. With this consideration, analysis of data revealed that most of the representations in each type had an appropriate caption (Table 4). Representations with problematic captions ranged between 7% and 34% whereas representations with no caption were merely encountered. Data revealed that representations emerged either in teaching or in assessment or in activity parts. All the representations in assessment part, 86% of the representations in activity part, and 77% of the representations in teaching part were captioned appropriately. However, 262 representations in teaching part (23%) had problematic caption and 17 representations in activity part (12%) had no caption.

Degree of Correlation between Representations in Multiple Ones in Commonly Used High School Chemistry Textbooks

Multiple and hybrid representations bring at least two types of representations together to make the content understandable. There was total amount of 572 multiple and hybrid representations. Submicroscopic-symbolic representations were the most frequent combination used in representations (52%; 299 representations). It was followed by macroscopic-symbolic combination (37%; 209 representations). Macroscopic-submicroscopic combination was the third in order regarding frequency of use (.7%; 39 representations). Another type of binary combination that emerged in this research was macroscopic-microscopic and it was used four times in all textbooks. There were 21 (4%) ternary (i.e., composed of three parts) representations that bring macroscopic, submicroscopic, and symbolic representations together.

Table 5. Frequencies of different type of representation combination in each grade chemistry textbook.

Type of representation	Grade level			
	9th grade	10th grade	11th grade	12th grade
Macro-submicroscopic	21	12	6	
Macro-symbolic	2	18	178	11
Submicroscopic-symbolic	41	87	49	122
Macro-micro		4		
Macro-submicroscopic-symbolic	9	2	4	6

Table 5 shows how chemistry textbooks in different grade levels include different combinations of representations. Use of macroscopic-submicroscopic representations was not so prevalent across textbooks. However, macroscopic-symbolic representations were used frequently in the eleventh grade chemistry textbook (75%). Contrarily, twelfth (88%) and tenth (71%) grade textbooks included the submicroscopic-symbolic representations the most. Ternary representations were seldom in their preference by all chemistry textbooks. A closer analysis revealed how different type of representation combinations are distributed in different units (Figure 5). Some of the salient features of this distribution were related to the use of a particular representation in some units than others. For instance, macroscopic-submicroscopic representations were used in phases of matter (56%; 15 representations) and mixtures (37%; 11 representations) more frequently than their use in other units. Ternary representations were more encountered in chemistry as a science (25%), phases of matter (19%), and atom and periodic table units (12%). Macroscopic-symbolic representations and submicroscopic-symbolic representations were used more often than other representation combinations in most of the units.

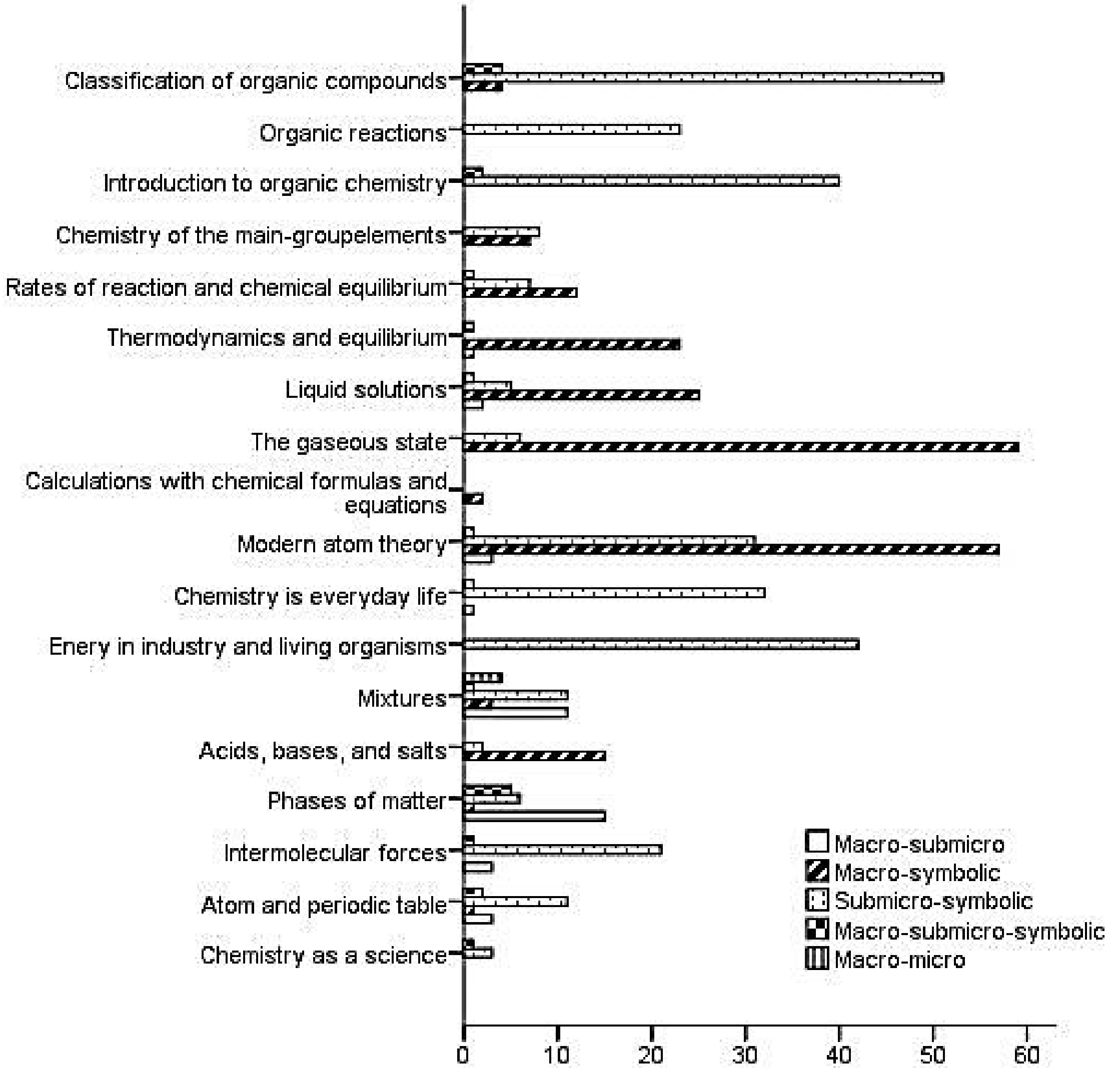

Figure 5: Distribution of different type of representation combination in high school chemistry textbooks with respect to units in each grade.

According to Gkitzia et al.'s typology (2011), only multiple representations can be analyzed in terms of their degree of correlation since different representations in hybrid ones already overlap. Chemistry textbooks analyzed in this research included total 178 multiple presentations. Most of them had sufficient links between their subordinates (68%; 121 representations). Twenty-nine percent (52 representations) of multiple representations lacked of some sufficient links, which make them insufficient in terms of the links they should include. Very few multiple representations (3%; 5 representations) did not include links between their subordinates.

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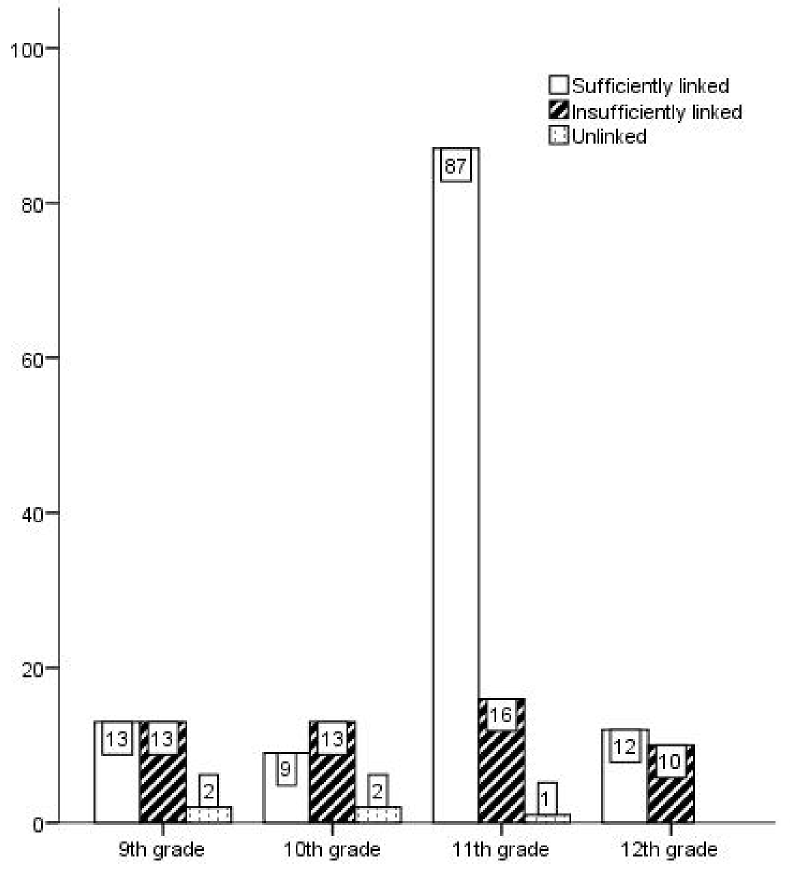

Figure 6: Distribution of degree of correlation between representations in multiple ones (in frequencies) in high school chemistry textbooks with respect to grade levels.

Among all chemistry textbooks, eleventh grade had the most frequent (84%; 87 representations) number of sufficiently linked multiple representations (Figure 6). Nearly half of the multiple representations in ninth (46%; 13 representations) and twelfth (55%; 12 representations) grade chemistry textbooks included sufficient links. Tenth grade chemistry textbook had the lowest frequency of sufficiently linked multiple representations (38%; 9 representations). The number of insufficiently linked multiple representations was the same for ninth (46%; 13 representations), tenth (54%; 13 representations), and twelfth (10%; 46 representations) grade chemistry textbooks. However, eleventh grade textbook included insufficiently linked multiple representations the least (15%; 16 representations). There were just two unlinked multiple representations in ninth and tenth grade chemistry textbooks.

Discussion

This research examined types and characteristics of representations in high school chemistry textbooks in Turkey. Findings of the research will be discussed under five sections using each criteria in Gkitzia et al.'s (2011) rubric for evaluating representations: (1) types of representations, (2) interpretation of representations' surface features, (3) relatedness of representations to the text, (4) properties of representations' captions, and (5) degree of correlation between subordinates comprising multiple representations.

First, chemistry textbooks used in different grades were different from each other with regard to percentages of visuals included. Eleventh grade had the highest frequency. It was followed by tenth and twelfth. Ninth grade had the lowest number of visuals. To take a closer look, number of objectives in each grade's curriculum was examined considering the fact that high number of objectives requires students to learn more chemistry content when compared to low number of objectives. Moreover, more chemistry content supports the use of high number of representations with various kinds. It was revealed that eleventh grade curriculum had the highest number of objectives (N=42) and concurrently eleventh grade textbook had the frequent number of representations. Tenth and twelfth grade curricula were second in order regarding number of objectives (N=39 and N=40 respectively). Therefore, they were also second in order of frequency of representations. Ninth grade curriculum had the lowest number of objectives of all (N=33) and it had the lowest frequency of representation. Among different chemistry units in textbooks analysed, the highest number of representations were used in "Modern atom theory" whereas the lowest number of representations was observed in "Calculations with chemical formulas and equations". When the nature of these topics is considered, it is expected. Representations of atom models in history, orbitals, and modern atom were prevalent in the unit of "Modern atom theory". However, the topic of chemical calculations is perceived more algorithmic in nature and presented with more problems and calculations to students without using so many visuals to teach the topic. Among different parts of the textbooks (i.e., assessment, activity, and teaching), the vast majority of the representations took place in teaching part (85%). Although chemistry curricula in Turkey are based on a learning environment where teachers are expected to utilize hands-on activities, chemistry textbooks analysed in this research seem to achieve this task by using representations that make abstract concepts concrete. Also, there has been no extra class hour for conducting laboratory experiments in chemistry classes. Therefore, textbook authors may spend less time for activities and more time for teaching in their books. With regard to type of representations, most common types of representation in high school chemistry textbooks were macroscopic, symbolic, and hybrid representations. Although used, the number of multiple and submicroscopic representations were low. Few representations were mixed in their type. These findings are similar for Greek and Lebanese chemistry textbooks in the sense that they included macroscopic and symbolic representations the most (Gkitzia et al., 2011; Shehab & BouJaoude, 2016). It was different for hybrid representations. Hybrid representations were low in their use for Greek and Lebanese textbooks, however it was one of the mostly used representations in Turkish textbooks. Possible explanation might be related to differences of representations counted as hybrid. Different than those studies (Gkitzia et al., 2011; Shehab & BouJaoude, 2016), I coded structural formulas representing molecular geometry as hybrid. Distribution of different type of representations in chemistry textbooks across grade levels revealed that macroscopic representations were mostly used in tenth and twelfth grade, symbolic representations were observed mostly in ninth grade, hybrid representations were preferred by eleventh and twelfth grade the most, and multiple representations were used mostly in eleventh grade. Nature of the topics in each grade might explain the differences in the use of different representations in each grade. Ninth grade chemistry textbook includes topics as "symbolic language of chemistry" and "atom and periodic system" and hence they are more appropriate for the use of symbolic representations. Gases and modern atom theory in eleventh grade and organic chemistry in twelfth grade are suitable for utilization of hybrid representations. Solutions, chemical equilibrium, and rate of reaction topics are included in eleventh grade and therefore they support the use of multiple representations more. All types of representations appeared in teaching part mostly. This finding is congruent with others indicating that quantitative questions include symbolic representations and conceptual questions do not include submicroscopic representations (Nakiboğlu & Yıldırır, 2011).

Second, majority of the representations had explicit surface features while 40% of them left the students alone while interpreting what representation means. This characteristic of representations puts Turkish chemistry textbooks in a better position than Greek (Gkitzia et al., 2011) and Lebanese textbooks (Shehab & BouJaoude, 2016) of which most of the representations are implicit and ambiguous. Although the differences between grades are not considerable, the percentage of representations with explicit surface features decreased from twelfth to ninth grade (i.e., from 69% to 54%). It would be more reasonable to expect a decrease from ninth to eleventh grade considering students' psychological development and learning level. This difference may stem from differences in each grade's textbook writers' approach to representations. When each representation type considered, majority of the representations except multiple ones were explicit in terms of their surface features. However, nearly half of the time multiple representations left students alone when interpreting the meaning of features of representation. Differences between grades and representations were expected considering the finding that the structural elements of representations differ both across the textbooks and within the same book (Pozzer & Roth, 2003). This feature of chemistry textbooks is problematic in terms of contribution of multiple representations into students' learning since students have difficulty in both understanding and transforming representational levels (Al-Balushi & Al-Harthy, 2015; Chittleborough & Treagust, 2008).

Third, regarding representations' relation to the text, data indicated that vast majority of the representations were completely related to the text, which is similar to Greek (Gkitzia et al., 2011) and Lebanese textbooks (Shehab & BouJaoude, 2016). However, the most problematic chemistry textbook was twelfth grade of which nearly half

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of the representations were incomplete and unlinked in their relation to the text. Although degree of relation is important in students' meaningful understanding of what the representation depicts, it would be more problematic if ninth grade chemistry textbooks have this percentage of relation when students' chemistry knowledge and psychological development level are considered. In terms of representation type and relation to text, Turkish high school chemistry textbooks assured students' complete understanding of the majority of symbolic, multiple, and mixed representations. Nevertheless, nearly half of the submicroscopic and hybrid representations are problematic for students to understand since either their relation is incomplete or there is no link to the text. This feature of submicroscopic and hybrid representations might increase students' cognitive load (Wu & Shah, 2004) and lead misconceptions in students' understanding of the concepts (Kumi et al., 2013). Emergence of representations with different surface features within the same grade is compatible with research revealing that the structural elements of representations differ within the same book (Pozzer & Roth, 2003).

Fourth, high percentage (80%) of representations had appropriate captions while the remaining were problematic in nature (i.e., lengthy, implicit, not comprehensible, and absent). When compared with Greek (Gkitzia et al., 2011) and Lebanese textbooks (Shehab & BouJoude, 2016), Turkish chemistry textbooks were better in making the content and message of representations clear (Sanger & Greenbowe, 2000). With regard to examination of the association between type of representation and property of caption, data revealed that most of the representations in each type had an appropriate caption, which increases the clarity of representations (Sanger & Greenbowe, 2000).

Fifth, among various representation combinations, submicroscopic-symbolic and macroscopic-symbolic were the most frequent combination used in representations, which is similar to Greek chemistry textbooks (Gkitzia et al., 2011). Macroscopic-symbolic representations were used frequently in eleventh grade chemistry textbook, whereas twelfth and tenth grade textbooks mostly included submicroscopic-symbolic representations. This may be related to the chemistry topics covered in different grades. Gaseous state and thermodynamics topic in eleventh grade are more inclined to use macroscopic-symbolic representations. However, organic chemistry (i.e., a unit in twelfth grade), acids and bases, and mixtures (i.e., units in tenth grade) are more suitable for the use of submicroscopic-symbolic representations. Of all the multiple representations, most of them had sufficient links between their subordinates. This finding is compatible with the ones found for Lebanese textbooks (Shehab & BouJaoude, 2016) and incompatible with the ones found for Greek chemistry textbooks (Gkitzia et al., 2011). Across the grades, eleventh grade chemistry textbook had the most frequent number of multiple representations of which their subordinates are sufficiently linked. Based on this features of chemistry textbooks, I can conclude that multiple representations in Turkish chemistry textbooks have potential to increase students' understanding in the related concepts, as also supported by others (e.g., Hilton & Nichols, 2011; Yakmaci-Guzel & Adadan, 2012). Also, students' cognitive load decreases when interpreting multiple representations in Turkish chemistry textbook, since their subordinates are sufficiently linked most of the time (Wu & Shah, 2004). Differences between grades in terms of links between subordinates comprising multiple representations could be explained with the fact, that the structural elements of representations differ across the textbooks (Pozzer & Roth, 2003).

Implications

This research has suggestions for chemistry educators, textbook writers, and teaching and learning of chemistry. Chemistry educators should benefit from categorization used in this research for the analysis of representations but in caution, since there have been some confusing issues regarding the definitions and examples of representations as discussed in theoretical framework part of this research. For instance, researcher had some challenges during categorization of structural formulas depicting molecular geometry. Since structural formulas also include symbols to represent formula of the compound, one might think it as symbolic. These structural formulas have also iconic in nature as they aim to represent the angles that atoms are bonded to each other in two dimensions. One is right to claim that these kinds of representations have both iconic and symbolic nature. Based on these considerations structural formulas were labelled as hybrid in this research. However, chemistry educators should conduct more research on the levels, definitions, and examples of representations used in chemistry. Are macroscopic, submicroscopic, symbolic, multiple, and hybrid levels enough to define representation levels in chemistry? As this research revealed the use of microscopic representation in chemistry textbooks, what is the appropriateness for the use of microscopic level representations in chemistry? What are the specific definitions and examples for each representation level? For instance, are submicroscopic representations real or theoretical entities? Are structural formula examples of submicroscopic or symbolic level? Could all of these representational levels be applicable when analyzing representations in different areas of chemistry (e.g., analytical chemistry and organic chemistry)? For instance, are definitions of representation levels the same for both analytical and organic chemistry? This research has also implications for science educators from other disciplines. What are the representation levels in other disciplines (e.g., physics and biology)? Are there similarities between the representation levels, used in different disciplines? Answers of these questions have potential to contribute both to our understanding about representations and use of representations in teaching and learning of science to enhance students' meaningful understanding.

In Turkey, NME evaluates the Turkish chemistry textbooks with respect to several criteria (e.g., number of visuals and scientific accuracy) and then approves them to be used in high schools throughout the country. Also, NME selects a number of chemistry teachers and educators to evaluate these books considering the criteria determined. However, textbook evaluators have not been specifically asked to take "representational levels in chemistry" into consideration specifically when evaluating the books. Regulations prepared by NME only emphasize that visual organization of the textbook should support students' learning and consider students' development level. There have been no specific regulations regarding how representation levels in chemistry (e.g., macroscopic, submicroscopic, and hybrid) should be used throughout the book. Therefore, differences exist between textbooks used in different grades in terms of properties of representations. NME and policy makers in other countries should determine criteria for textbooks about visuals and representations specifically for each discipline in science (e.g., chemistry and biology) since their nature are different from each other. Also, structural properties of representations (e.g., caption and interpretation of surface features), which increase representations' contribution to students' meaningful understanding, should be determined as a criterion. Since chemistry teachers are among the ones, who both evaluate and use textbooks, NME and policy makers in other countries should develop in-service training programs that increase teachers' both understanding and pedagogically relevant use of representations. Chemistry teacher educators should also integrate these issues in preservice chemistry teacher education programs.

Due to the fact that chemistry teachers have a crucial role in learning chemistry concepts, several suggestions are offered for teaching and learning of chemistry. Chemistry teachers should both integrate different levels of representations and explicitly emphasize those representations during chemistry teaching. For instance, chemistry teachers might utilize macroscopic, submicroscopic, and symbolic representations of a chemical reaction (e.g., precipitation reaction between potassium iodide and lead (II) nitrate) when teaching the types of reactions. Also, they explicitly define and name those representations. Hence, students' learning of the chemistry concept might be enhanced. Chemistry teachers could utilize representations in chemistry textbooks, the internet, and textbooks that they use as reference. For enabling students' transformation of representational levels into each other and use of representations to explain a chemical phenomenon, chemistry teachers might ask questions that require students to utilize different kinds of representations for both summative and formative purposes.

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Appendix

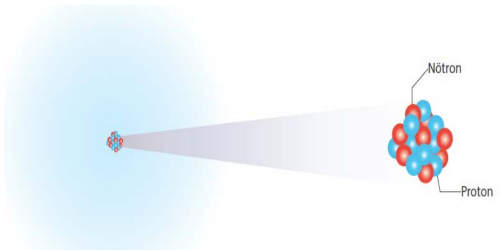
Table. Distribution of representations in high school chemistry textbooks with respect to units in each grade.

Grade Level	Unit	Frequency	Percentage
9th grade	Intermolecular forces	96	5.6
	Phases of matter	91	5.3
	Chemistry as a science	79	4.6
	Atom and periodic table	76	4.5
10th grade	Mixtures	135	7.9
	Chemistry is everyday life	134	7.9
	Energy in industry and living organisms	90	5.3
	Acids, bases, and salts	61	3.6
11th grade	Modern atom theory	170	10.0
	The gaseous state	104	6.1
	Liquid solutions	93	5.5
	Rates of reaction and chemical equilibrium	82	4.8
	Thermodynamics and equilibrium	47	2.8
	Calculations with chemical formulas and equations	17	1.0
12th grade	Classification of organic compounds	153	9.0
	Chemistry of the main-group elements	147	8.6
	Introduction to organic chemistry	82	4.8
	Organic reactions	44	2.6
	Total	1701	100

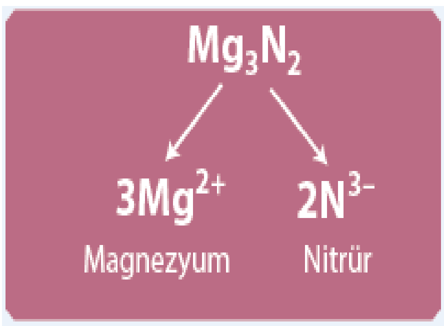
Examples of representations for criterion

1st criterion: Types of representation

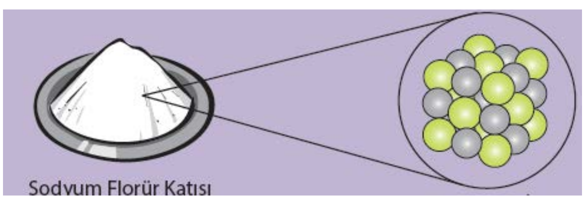
An example for macroscopic representation taken from 10th grade chemistry textbook. It was used to depict neutralization reactions between hydrochloric acid and ammonium hydroxide.



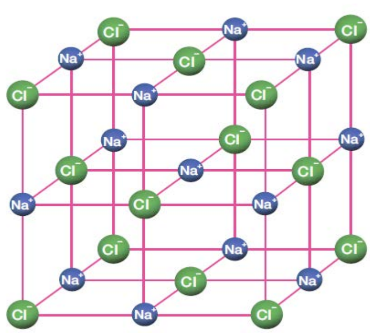
An example for submicroscopic representation taken from 11th grade chemistry textbook. It was used to portray an electron-cloud atom model.



An example for symbolic representation taken from 9th grade chemistry textbook



An example for multiple representation taken from 9th grade chemistry textbook. It portrays solid sodium chloride on the left macroscopically and lattice structure of sodium chloride on the right submicroscopically.



An example for hybrid representation taken from 11th grade chemistry textbook. It was used to represent lattice structure of sodium chloride.

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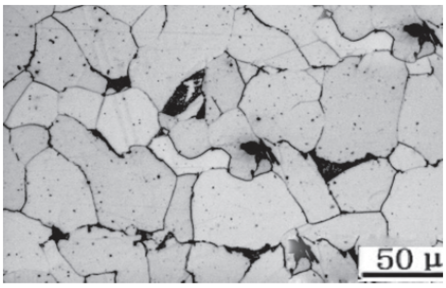
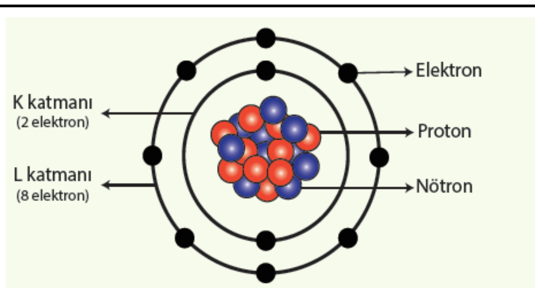
An example for mixed representation taken from 9th grade chemistry textbook. The visual was used to explain Thomson’s atom model analogically. Cake part represents the positively charged atom while raisins represent negatively charged electrons dispersed all over the atom.



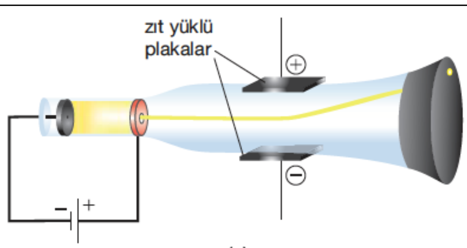
An example for microscopic representation taken from 12th grade chemistry textbook. It is the picture of heterogeneous alloys taken with optical microscope.

An example for representation categorized as “scientist” taken from 11th grade chemistry textbook. It is the picture of John Dalton.

2st criterion: Interpretation of surface features



An example for a representation (taken from 9th grade chemistry textbook) with explicit surface features. The visual depicts the Bohr atom model. With the use of internal captions it explicitly labels what elements in the picture mean.



An example for a representation (taken from 11th grade chemistry textbook) with implicit surface features. The visual how cathode rays react when confronted with charged plates. Although charged plates are shown on the visual, other parts of cathode ray tube are not indicated.

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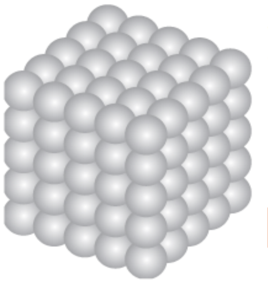


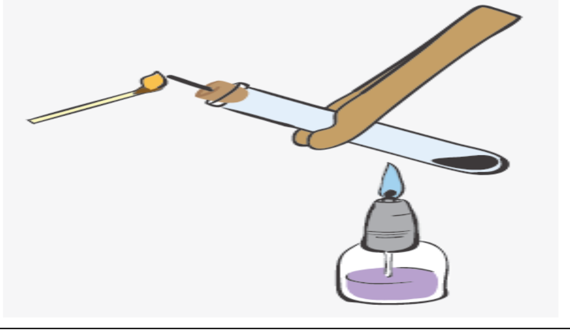
An example for a representation (taken from 12th grade chemistry textbook) with ambiguous surface features. The visual depicts the lattice structures in metals in submicroscopic level. However, there is no information regarding the type of the metal and what spheres represent.

3rd criterion: Relatedness to the text

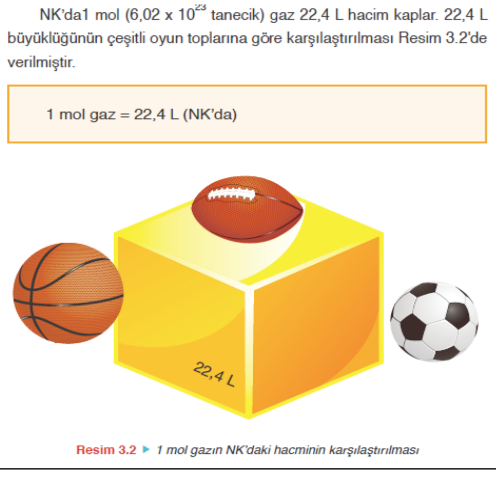
Bir başka örnek olarak **Şekil 2.2**'deki gibi bir altın külçesini ele alalım. Altın külçesinin fotoğrafını biraz büyüttüğümüzde görüntü netliğini kaybeder ve fotoğrafı meydana getiren pikseller ortaya çıkmaya başlar (solda). Altın külçesini de fotoğraf gibi büyütebilseydik onu meydana getiren altın atomlarını görebilirdik (sağda). Ancak, ünitenin başında da ifade edildiği gibi atomları görünür ışığı kullanarak gösterebilecek bir mikroskop henüz geliştirilmemiştir.

Şekil 2.2. Bir altın külçesinin fotoğrafını pikseller, altın külçesini ise atomlar meydana getirir.

An example for a representation (taken from 9th grade chemistry textbook), which is completely related and linked to the text. The beginning sentence of the text states that lets take gold block as an example shown in Figure 2.2. Therefore, it is completely linked. The text above the visual explains that when we zoom in the picture of gold block, picture loses its resolution and we see the pixels (on the left). It continues explanation by adding that if we could enlarge the gold block itself, we would have seen the atoms that made up gold block (on the right). Therefore it is completely related.



An example of a representation (taken from 10th grade chemistry textbook), which is completely related but not linked. The visual is placed in an activity and stands right next to the text that explains steps. Right next to the visual it states that light a match and hold it next to the edge of glass tube. However, there is no link to the visual like "as shown in the figure". Therefore, it is unlinked.



NK'da1 mol (6,02 x 10^{23} tanecik) gaz 22,4 L hacim kaplar. 22,4 L büyüklüğünün çeşitli oyun toplarına göre karşılaştırılması Resim 3.2'de verilmiştir.

1 mol gaz = 22,4 L (NK'da)

Resim 3.2 ▸ *1 mol gazın NK'daki hacminin karşılaştırılması*

An example of a representation (taken from 11th grade chemistry textbook), which is partially related and linked to the text. The text above the visual states that under standard conditions, one mole of gas (6.02x10^{23} particles) occupies 22.4 L. Comparison of amount of 22.4 L for different types of game balls are given in Picture 3.2. Since the text give reference to the number of the visual as "given in Picture 3.2." it is linked. However, there is no explanation related to cube in the text. Also, there is no explanation related to differences among the balls. Therefore, it is partially related.

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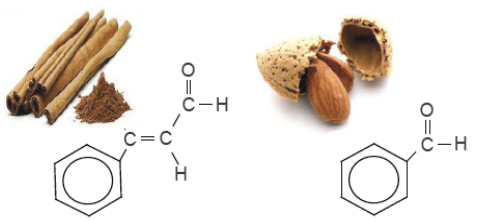
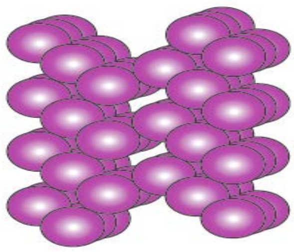
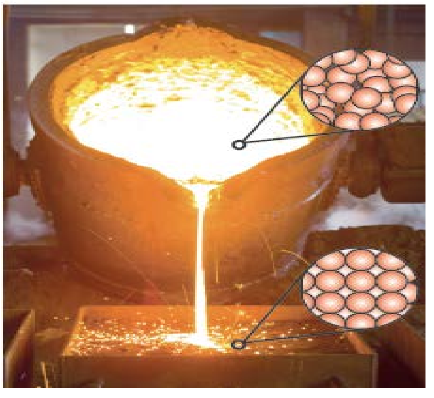
kokuları vardır. Tarçında sinnamaldehit, bademde benzaldehit bulunur.  *Sinnamaldehit (tarçın)* *Benzaldehit (badem)*	An example of a representation (taken from 12th grade chemistry textbook), which is partially related and unlinked to the text. The text above the visual states that cinnamon includes cinnamaldehyde and almond includes benzaldehyde. There is no link from the text to the visual like "as shown in following visuals". Also, visuals include both macroscopic and symbolic representations. There is no explanation in the text about those.
	An example of a representation (taken from 10th grade chemistry textbook), which is unrelated to the text. The text next to visual explains that cleaning materials, fertilizers, foods, construction materials, and drugs went through some processes before we use. The visual includes stationary materials not the ones mentioned in the text. Therefore, it is unrelated.
4th criterion: Existence and properties of captions	
 **Şekil 4.32.** Kapı ve pencere profillerinde PVC kullanımı.	An example of a representation (taken from 10th grade chemistry textbook), which has an appropriate caption. The caption explains that PVC is used in the construction of windows.
	An example of a representation (taken from 12th grade chemistry textbook), which has problematic caption. The caption explains that basic nature of equal amounts of K_2O and CaO solutions can be determined using universal pH indicators. However, caption does not point which one of the solution is K_2O and which one is CaO. It is not explicit. Also, there was no interpretation regarding the colour of pH indicator when put into basic solution.

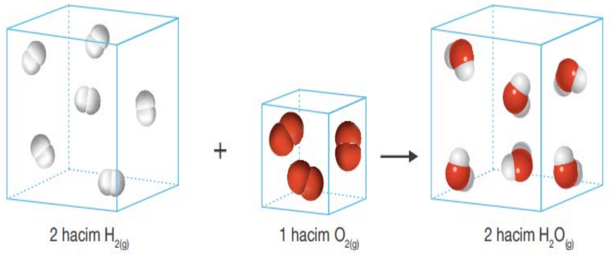


An example for a representation (taken from 9th grade chemistry textbook), which has no caption at all.

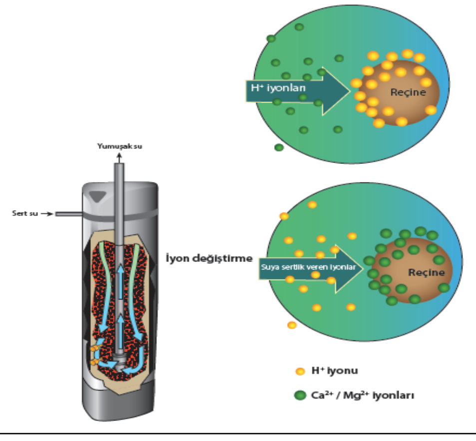
5th criterion: Degree of correlation between subordinates comprising multiple representations



An example for a multiple representation (taken from 9th grade chemistry textbook), which has sufficient links between its subordinates. It indicates solid and liquid metal both in macroscopic and submicroscopic levels. Equivalence between representations are indicated by lines.



An example for a multiple representation (taken from 11th grade chemistry textbook) that has insufficient links between its subordinates. It depicts the reaction between hydrogen and oxygen gas by using both symbolic and submicroscopic representations. However, symbolic and submicroscopic representations are placed in parallel so that students understand their link.



An example of a multiple representation (taken from 10th grade chemistry textbook), which has no links between its subordinates. The visual depicts cation-changing process during deionization of hard water. There is no link between the representations on the right and left side of the visual.

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