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Multi-representation Analysis of General Chemistry Books on Chemical Bonding Subject

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ABSTRACT

This research is a preliminary study that focuses on multi-representation analysis of the chemical bonding topic in three general chemistry of text books. The analysis was carried out to find out how concepts are explained based on the three levels of chemical representation, especially on ionic and covalent bonding, which are the basis for further research in developing intertextual-based learning strategies. Analysis was carried out at the macroscopic-symbolic and sub microscopic-symbolic levels usingmulti-representation analysis table that was adopted from Gkitzia et al., 201 for three general chemistry books, that are 1) Whitten, K.W, et.al. (2014). *Chemistry 10th edition.* English: Brooks/Cole Cengage Learning; 2) Chang, R. (2010). Chemistry 10th edition. New York : The McGraw-Hill Companies; and 3) Silberberg, M.S, and Amateis, P.G. (2021). *Chemistry: the molecular nature of matter and change 9th edition.* New York : The McGraw-Hill Companies. The analysis results show that book: Silberberg, M.S, and Amateis, P.G. (2021). *Chemistry: the molecular nature of matter and change 9th edition.* New York : The McGraw-Hill Companies has the most complete macroscopic-symbolic and sub microscopic-symbolic representation levels on the four main concept labels of chemical bonding, so that they can become standard reference material in developing chemical representations that will be used in intertextual learning strategies.

INTRODUCTION

Based on Minister of Education and Culture Regulation No. 69 Year 2013 concerning the Basic Framework and Curriculum Structure for Senior High Schools/Madrasah Aliyah, one of the subjects that must be studied by students in the mathematics and natural sciences specialization group is chemistry. Chemistry studies matter, the properties of matter, how and why substances combine or separate to form other substances, and the energy that accompanies these changes. Chemistry is the theoretical and practical study of the interactions, structure and properties of various materials. Investigation and understanding at the sub microscopic atomic level provides understanding of various macroscopic real world phenomena. Understanding of structure and process chemistry is used to adapt and innovate to meet the economic, environmental and social needs of an ever-evolving world. This includes overcoming the challenges of global climate change and energy limitations by designing processes to maximize the efficient use of the earth's limited resources (BSKAP, 2022). Studying chemistry makes students understand various things that happen around them and can influence attitudes in responding to problems in daily life both locally and globally, so that chemistry becomes an important branch of natural science to study.

The urgency of studying chemistry is in contrast to the facts on the ground. Most students find it difficult to study chemistry because chemistry topics are generally related to the structure of matter (Woldeamanuel, et.al, 2014). This statement is relevant to several research results which state that difficulties in studying chemistry are caused, among other things, by the abstract nature of chemical concepts (Pinarbasi, 2006; Sirhan, 2007; Wu, Krajcik & Soloway, 2001). Difficulty understanding these abstract concepts causes most students to develop alternative ideas that sometimes contradict the concept scientifically accepted. The development of students' alternative ideas is known as misconceptions (Suprapto, 2020). In research conducted by Rokhim, Rahayu & Dasna (2023), several chemical topics have been identified that often lead to misconceptions, including chemical bonding.

Johnstone (1993) stated that one of the causes of learning difficulties and misconceptions is students' inability to connect three levels of chemical representation, namely the macroscopic, submicroscopic and symbolic levels. The macroscopic level is the level that involves observable phenomena; submicroscopic level, which involves things that cannot be seen (small in size) such as atoms, molecules, ions and structures; and the symbolic level is a representation of atoms, molecules or ions which can be in the form of symbols, formulas or equations (Gilbert & Treagust, 2009). This is in line with Wu's statement (2003) where chemistry learning involves establishing conceptual relationships between macroscopic, microscopic and symbolic representations and using the idea of intertextuality to conceptualize the relationship. In addition, Bowen & Bunce (1997) stated that presenting chemical concepts with three levels of representation simultaneously is an important aspect that teachers need to pay attention to in the chemistry learning process. Research results show that learning chemistry by connecting the three levels of representation is effective in increasing students' understanding of chemistry material (Chandrasegaran, Treagust & Mocerino, 2009; Guzel & Adadan, 2013; Herawati, Mulyani & Redjeki, 2013; Madden, Jones & Rahm, 2011). Learning by linking these three levels of representation is known as intertextual.

Intertextuality is a central process for giving meaning to unfamiliar texts (Lemke, 1990). This means that we can create meaning through relationships between several texts, where these texts are sometimes difficult to interpret in a single text, so they need to be connected to other texts. According to Halliday & Hasan (1985), text is a functional language that expresses thoughts in the form of speech, writing or other media. The use of intertextuality in chemistry learning in the classroom will facilitate students in understanding the three levels of chemical representation which are viewed as a text and linked to other texts so that they can build meaning in chemistry learning. Meanwhile, Wu (2003) said that when students build an understanding of chemical concepts, they coordinate across various levels of representation and different types of experiences. The relationship between representations, real experiences and activities in class is known as an intertextuality relationship, so learning with this intertextuality strategy is believed to provide a complete and correct understanding of chemical concepts.

Before designing an intertextuality learning strategy, it is necessary to analyze several books that are used as the learning sources. One of them is a general chemistry textbook which is believed to be scientifically correct. So far, there has been no research that analyzes several chemistry textbooks in terms of multi- representations. Therefore, in this research three general chemistry books namely 1) Whitten, K.W, et.al, 2014. *Chemistry 10th edition.* English: Brooks/Cole Cengage Learning; 2) Chang, R. 2010. *Chemistry 10th edition.* New York : The McGraw-Hill Companies; and 3) Silberberg, M.S, and Amateis, P.G. 2021. *Chemistry: the molecular nature of matter and change 9th edition*. New York : The McGraw-Hill Companies, were analyzed which will produce results then this analysis will be used as a basis for further research. So, the aim of this research is to analysis chemical representation on the chemical bonding present in three chemistry textbooks. So far, there has been a lot of analysis research on school textbooks like previous research was conducted by Wulandari (2019) and Pratiwi, S (2020). Meanwhile, for general chemistry textbooks it is still very rare to analyze them.

The instrument that was used for evaluating the multi-representation in each book developed by Gkitzia, Salta and Tzougraki (Gkitzia et al., 2011). There are 5 criteria that can be used as multi-representation analysis, that are: 1) representation type level (C1), feature interpretation representational (C2), relationship with text (C3), representation and description properties (C4), the degree of correspondence between the representations achieved from various representations (C5).

METHODS

Research Design

In process of multi-representation analysis, A comparison table for each book was made based on the five criteria indicators from Gkitzia (2011), so that a general overview of each book could be obtained. After that, it can be generated as a descriptive analysis. The type of this research is descriptive with a qualitative approach. According to (Sugiyono, 2009) descriptive is a method that functions to describe or provide an overview of the object under study through data or samples that have been collected as they are without carrying out analysis and making conclusions that apply to the general public. In other words, descriptive analysis research takes problems or focuses attention on the problems as they exist. When the research is carried out, the research results are then processed and analyzed to draw conclusions. In this case, analysis was carried out on three general chemistry textbooks that are often used and used by prospective chemistry teacher students.

Research Target

The selection of three general chemistry books used a purposive sampling technique, namely selecting books with certain considerations, such as field observations of the frequency and number of book users as well as the ease and availability of existing books. So, among numbers of general chemistry book title, based on those considerations, it has been decided three general chemistry books that will be analyses that are: 1) Whitten, K.W, et.al, 2014. *Chemistry 10th edition.* English: Brooks/Cole Cengage Learning; 2) Chang, R. 2010. *Chemistry 10th edition.* New York : The McGraw-Hill Companies; and 3) Silberberg, M.S, and Amateis, P.G. 2021. *Chemistry: the molecular nature of matter and change 9th edition*. New York : The McGraw-Hill Companies. The results of the analysis are used to see the three levels of representation that emerge from each textbook so that they can later be used as a basis for developing learning strategies. Whether to adopt or modify the three levels of representation on the subject of chemical bonding.

Research Data

The data used in this research is qualitative data. The data was obtained through reading and comparing three books of general chemistry. Then, it was analyzed based on five criteria developed by Gkitzia, Salta and Tzougraki (Gkitzia et al., 2011) namely: representation type level (C1), feature interpretation representational (C2), relationship with text (C3), representation and description properties (C4), the degree of correspondence between the representations achieved from various representations (C5) that can be seen specifically in table 1. In this process, these criteria were adopted and modified to evaluate the essence of chemical representation. By making analysis data through table, and assessing those five criteria, it can get more information about multi-representations data for each book.

Table 1. Typology of Chemistry Multi- Representation

Criteria	Typology
C1: Representation type	i. Macroscopic ii Sub microscopic iii Symbolic iv Double/ Multiple

Criteria	Typology
	v Hybrid vi Mix
C2: Feature interpretation	i Explicit ii Implicit iii Ambiguity
C3: Relationship with the text	i Completed connected and related ii Completed connected but not related iii Some are connected and related iv Some are connected but not related v Not related
C4: representation and description properties	i The existence of appropriate information ii There is information accompanied by problems iii Without explanation
C5: the degree of correspondence between the representations achieved from various representations	i Quite related ii Not quite related iii Not related

Next, from each book we can get the concept label data. The concept labels analyzed were limited to five concept labels which those related to the material taught in high school chemical bonding. They are 1) Stability of element; 2) Ionic bonding formation; 3) Covalent bonding compound; 4) Ionic compound characteristic; and 5) Covalent compound characteristic. The representation analysis was carried out on three books of label concepts to see type representation level (C1) which are summarized in table 2.

Table 2. Data Analysis of the Three Levels of Chemical Representation in General Chemistry Textbooks

Concept Label	Level	Book I	Book II	Book III
Stability of element	Macroscopic-Symbolic	-	-	-
	Sub Microscopic-Symbolic	-	There is, completed with picture	-
Ionic bonding formation	Macroscopic-Symbolic	There is, completed with picture	There is, completed with picture	There is, completed with picture
	Sub Microscopic-Symbolic	There is, completed with picture	There is, completed with picture	There is, completed with picture
Covalent bonding formation	Macroscopic-Symbolic	There is, completed with picture	-	There is, completed with picture
	Sub Microscopic-Symbolic	There is, completed with picture	-	There is, completed with picture
Ionic compound characteristic	Macroscopic-Symbolic	-	-	There is, completed with picture

	Sub Microscopic-Symbolic	-	-	There is, completed with picture
Covalent compound characteristic	Macroscopic-Symbolic	-	-	There is, completed with picture
	Sub Microscopic-Symbolic	-	-	There is, completed with picture

A summary for each typology data can be seen in table 3.

Table 3. Typology Data from Three General Chemistry Books

Criteria	**Book**		
	I	**II**	**III**
C1			
i	2	1	4
ii	2	2	4
iii	4	3	8
C2			
i	√	√	√
ii	0	0	0
iii	0	0	0
C3			
i	√	√	√
ii	0	0	0
iii	0	0	0
iv	0	0	0
v	0	0	0
C4			
i	√	√	√
ii	0	0	0
iii	0	0	0
C5			
i	√	√	√
ii	0	0	0
iii	0	0	0

Research Instruments

In this research, the instrument used was a table of general descriptions of chemical representations on the subject of chemical bonding from each textbook, namely by classifying the presence or absence of macroscopic-symbolic levels and sub microscopic-symbolic levels that appeared and then analyzing the differences as mentioned in research data section.

Data Analysis

Data from the analysis of the three general chemistry textbooks in table 1 and 2 are analyzed based on typology, which can be seen in table 3. For C1, representations are widely used to describe several phenomena in chemistry simultaneously at two or three chemical levels. These three textbooks focus on symbolic representation which focuses on describing the structure of atoms and molecules. For C2, a representation is characterized as implicit when the meaning of each surface feature is clearly stated. For C3, it is fully related when it describes the exact content of the text. As mentioned, it is partially related when it describes the subject for the text but is less precise and unrelated, not relevant to the content in the text. For C4, appropriate captions must be explicit, concise and comprehensive, showing representation. Representation is important because it can clarify the content and message of the representation (Gudyanga, 2014). For C5, identified by first using and testing the extent to which correlations between surface features of separate 'subordinate' representations consisting of several, are clearly demonstrated.

RESULT AND DISCUSSION

This level of chemical representation on the subject of chemical bonding is focused on the analysis of the representation of ionic and covalent bonding from several General Chemistry textbooks used at several universities which are considered as a consensus mental model that is believed to be the truth of the concept. The analysis carried out on the breadth, accuracy and depth of the concepts analyzed in this textbook is adjusted to the concepts required in the independent curriculum. This analysis was carried out to determine the explanation of the concepts of ionic and covalent bonding based on the three levels of chemical representation which are the basis for determining intertextuality-based learning strategies which are summarized in table 2.

In the three general chemistry books mentioned above, the chapters that discuss the concepts of ionic bonding, covalent bonding and the properties of ionic and covalent compounds are found in the chemical bonding chapter. In all books, the concepts of ionic bonds are discussed, while the covalent bonding concept is just found in book I and III. Even, the concept of the properties of ionic and covalent compounds is only found in books III.

The concept of ionic bonding is presented in the three books, there are three levels of representation. At the macroscopic level, all three books almost equally mention examples of ionic bonding. All books are equipped with pictures with different compounds. Book II displays images of several ionic compounds including white NaCl; $CuSO_4.5H_2O$ is blue; $NiCl_2.6H_2O$ is green; $K_2Cr_2O_7$ is orange and $CoCl_2.6H_2O$ is red. Meanwhile, book I displays a picture of lithium fluoride (LiF), and book III shows a picture of the reaction between sodium and bromine, which is more clearly seen in Figure 1.


a b c

Figure 1. Macroscopic Representation in Forming Ionic Compound (a) Book I; (b) Book II; (c) Book III

In book I, it is equipped with a picture of the Born-Haber for the formation of 1 mole of solid LiF as in picture 2.

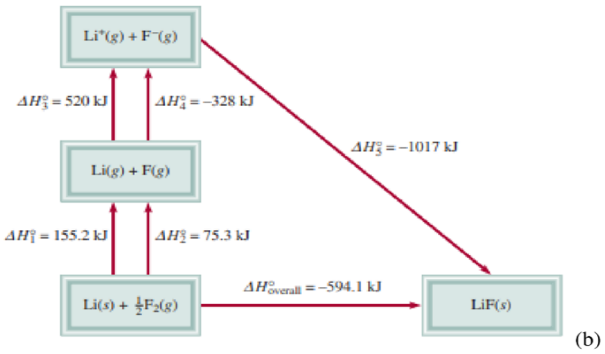

Figure 2. Macroscopic Representation of Ionic Bonding Formation with Born-Haber Cycle

The sub microscopic level of the concept of the process of forming ionic bonding, the three books are the same in explaining the process of forming ionic bonding, namely the electron transfer process in which electrons from metal atoms are transferred to non-metal atoms to form ions which join together in solid ionic compounds

The symbolic level of the concept of the process of forming ionic bonds, book II explains the process of forming ionic bonding with examples in the form of molecular formulas and ionization reactions, namely examples of forming ionic bonds from the elements lithium and fluorine, using Lewis symbols. The ionic bonding in LiF is an electrostatic attraction between positively charged lithium ions and negatively charged fluoride ions. This compound itself is neutral. The symbolic explanation of the concept of ionic bonding formation is in line with book III that showing only the molecular formula.

In the Born-Haber cycle the formation of 1 mole of solid LiF in book III, at the symbolic level is explained by describing the reaction stages as follows:

Converts solid lithium to gaseous lithium.

$Li(s) \rightarrow Li(g)$ $\Delta H_1 = 155.2$ kJ/mol

Dissociation of ½ mole of F2 gas into F gas atoms

$F_2(g) \rightarrow F(g)$ $\Delta H_2 = 75.3$ kJ/mol

Ionization 1 mole atom of Li gas

$Li(g) \rightarrow Li^+ (g) + e^-$ $\Delta H_3 = 520$ kJ/mol

Adds 1 mole of electrons to the gas F atom. The energy change in this process is the inverse of the electron affinity.

$F(g) + e^- \rightarrow F(g)$ $\Delta H_4 = -328$ kJ/mol

Combining 1 mole of Li^+ gas and 1 mole of F gas to form 1 mole of solid LiF.

$Li^+ (g) + F^- (g) \rightarrow LiF(s)$ $\Delta H_5 = -1017$ kJ/mol

At the submicroscopic and symbolic level, the same three books explain that the formation of covalent bonding between atoms will share electrons. To help track the whereabouts of valence electrons, a simple method called Lewis symbols or structures is used. book I are equipped with molecular pictures of the formation of covalent bonding from hydrogen atoms, which can be seen in Figure 6 below.

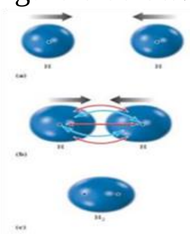

Figure 3. Submicroscopic Representation of Covalent Bonding in Book I

The final concept is the nature of ionic and covalent compounds. The nature of electrical conductivity is only explained in book I and III. Book I explains the macroscopic-symbolic level by displaying a tube containing a solution with a light and cable connected to the solution inside to see the electrical conductivity of three solutions, namely solutions of an acid, a strong base and a weak base at the same concentration and that is an example of a covalent compound. The first solution, that is HCl. While, in Book III still explains the macroscopic, sub microscopic and symbolic levels in one picture by showing a picture of a tube containing a solution with a light on top. However, the three compound phases are different, namely the first is an ionic compound in solid form, the second is an ionic compound in melt form, the third is an ionic compound that has dissolved in water.

The hardness of compound is only explained in book I. It explained the macroscopic level of the nature of hardness in covalent compounds only, through pictures of phenomena in the form of several types of crystals or covalent solids, namely diamond, graphite and quartz and at the same time links the molecular pictures.

Continued with the explanation at the sub microscopic-symbolic level of the concept of hardness properties of ionic compounds and covalent compounds. Book III are the same in explaining the nature of hardness in ionic and covalent compounds, namely that ionic compounds are hard and easily brittle, rather than bending when hit with sufficient force. The positive and negative ions in the crystal are arranged to maximize the attraction between the ions when an external force is applied, like charges move close together and repulsion breaks apart the part that the external force is applied to. This statement explains why ionic compounds are hard but easily brittle. The molecular picture can be seen in picture 4.

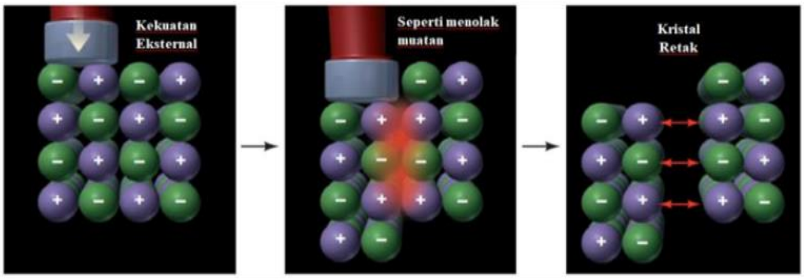

Figure 4. Sub Microscopic Level Example in Book III

Furthermore, the sub microscopic-symbolic explanation of book I is complemented by a molecular drawing of the diamond structure showing each carbon atom covalent bonded to four others at the corners of the tetrahedron. The statement represents a picture of a covalent crystal consisting of a solid whose lattice positions are occupied by atoms that are covalent bonded to other atoms in neighboring lattice sites. The result is a crystal that is essentially one giant molecule. These solids are sometimes called network solids because of the network of interlocking covalent bonding that extend throughout the crystal in all directions. Based on these findings and discussion, we found that Book III from Silberberg, M.S, and Amateis, P.G. (2021). *Chemistry: the molecular nature of matter and change 9th edition*. New York : The McGraw-Hill Companies has the most complete macroscopic-symbolic and sub microscopic-symbolic representation levels on the four main concept labels of chemical bonding, so that they can become standard reference material in developing chemical representations that will be used in intertextuality learning strategies. This is in line with Nikat (2021) who states that multi-representation can improve individual abilities in studying concepts.

CONCLUSION AND RECOMMENDATIONS

The results of the analysis show that of the three general chemistry textbooks the one with the highest completeness at three levels of representation is Silberberg, M.S, and Amateis, P.G. 2021. *Chemistry: the molecular nature of matter and change 9th edition*. New York : The McGraw-Hill Companies, with completeness at four concept labels, namely the formation of ionic bonding, covalent bonding, the character of ionic and covalent compounds. So, book III can be used as a reference for developing three levels of representation which will later be used in designing intertextuality learning strategies. Suggestions for further research are to adopt and modify the three levels of representation that appear in book IIII so that they are more contextual to the conditions of students in Indonesia.

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