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THE MODEL OF EDUCATIONAL RECONSTRUCTION: STUDENTS' CONCEPTUAL KNOWLEDGE ON SOLID STATE CHEMISTRY DOMAIN

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ABSTRACT

Solid state chemistry (SSC) concept is abstract yet makes it difficult for students. Considering students' and scientist conception in designing a learning sequence, it is important to make scientific knowledge to be comprehensible for students. Model of Educational Reconstruction (MER) was adopted to define learning in order to develop students' Conceptual Knowledge (CK) of the SSC concept. A sequence of learning activities was designed based on the MER. The purpose of this study was to examine the use of MER in developing students' CK. One group pre- and post-test experimental design was employed in this study. CK on SSC structured essay test consisting of 26 items were developed to measure students' CK before and after their involvement in learning. Paired sample t-tests were employed and the results showed significant differences in the overall domain-knowledge ($p < .001$). In detail, students' CK categorized into complete (C), incomplete (IC), misconception (M), incorrect (I), and no answer (NA). After the intervention, the number of students that answered correctly increased (57,4% complete and 21% incomplete). This study showed that MER was an effective learning design to develop students' conceptual knowledge of chemistry concepts.

Keywords: Model of Educational Reconstruction, Conceptual Knowledge, Solid State Chemistry

INTRODUCTION

The abstract characteristic of solid state chemistry concept closely relates to real phenomena. This topic focuses on structure-property relationships and allows students to make connections between science and daily life. In order to enhance students' knowledge of structure-property relationships, chemical structures and chemical bondings- metallic, ionic and covalent- concepts should be well comprehended by students. However, most of these concepts are at the abstract molecular level in which students usually find it difficult to comprehend (Bergqvist et al., 2013; Croft & de Berg, 2014; Dhindsa & Treagust, 2014; Nimmermark et al., 2016).

There are many researchers and practitioners of chemistry education who study how to teach SSC concepts. The learning strategies used were: first, structure description using physics model such as plan view, 3D-picture, and analog (Battle et al., 2010; Cushman & Linford, 2015; Eymur & Geban, 2017; Karacop & Doymus, 2013; Pinto, 2012), and second, the use of software (Bennett & Rabe, 2012; Ganasen & Karpudewan, 2017; Linenberger & Bretz, 2012). Unfortunately, researchers still reported about students' misconceptions on chemical bonding as a base of SSC concept (Bergqvist & Rundgren, 2017;

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Bergqvist et al., 2016; Pérez et al., 2017; Sen & Yilmaz, 2017).

Students bring along their own conceptions to class. This should be a concern for teachers in considering instructional design. A teacher would find it difficult to teach a particular concept if misconceptions exist in the initial concept of students (Barke et al., 2009). Therefore, learning must be a bridge between students' and the scientist conception.

Model of Educational Reconstruction (MER) is a way to prepare contextual learning considering students' and scientists' concept (Duit et al., 2012). Learning reconstructions were done through three relevant phases: (1) analyzing the science content; (2) investigation on student conception; and (3) developing learning sequences (Duit et al., 2012; Niebert & Gropengiesser, 2013; Sam, 2017).

Considering student conception of learning sequences could promote a highly significant development of conceptual knowledge (Reinfried et al., 2015; Sam et al., 2015). Regarding the importance of considering students and scientists' concept in designing an SSC learning concept and many benefits of the MER-based interventions, the purpose of this study is to examine the use of MER in developing the students' conceptual knowledge toward scientist conception.

METHODS

This study was considered a one group pre-test and post-test pre-experimental design. 33 pre-service chemistry teachers in one of the state universities in Banten have participated in this research. The instruments of this study were the pre-test and post-test of on conceptual knowledge of SSC (26 essay structured questions).

There are three domain-knowledges of solid state chemistry concept that developed in this study: (1) metallic crystal and alloy structures; (2) covalent bonding and semiconductor network; and (3) ionic crystal structure and bonding. More than two questions examined each domain (Table 1). The instrument was validated by five experts in chemistry education and Content Validity Ratio (CVR). The CVR value was .99 (acceptable (Wilson et al., 2012)). Cronbach's alpha coefficient was computed to measure the reliability of questions. The coefficient was 0.77 (acceptable (Glynn et al., 2011). The primary data were students' responses to the tests of conceptual knowledge. Students' answers to each concept were also scored (Table 1).

Table 1. Question Criteria

Concepts	Domain knowledge	Question number	Score
Metallic bonding related to the melting point	Metallic crystal	1Aa	0-3
Metallic bonding model		1Ab	0-3
Metallic structure related to % occupancy		1B	0-3
Metallic structure related to density		1C	0-2
Metallic structure related to ductility		1D	0-2
The material conductivity and band theory		2B	0-2
		Total	13
Alloy criteria	Alloy	1Fb	0-2
Type Alloy structure		1Eb	0-1
Type of an alloy		1Ea, 1Fa	0-3
		Total	6
The conductivity of material	Covalent crystal	2Aa	0-3
The material conductive		2Ab	0-4
Covalent network structure		4A	0-2
Covalent network properties		4B	0-3
Polymer conductive		5A	0-2
Polymer conductive structure		5B	0-2
		Total	16
Type of a semiconductor	Semiconductor	2Ca, 2Cc	0-4
The conductivity of extrinsic semiconductor model		2Cb	0-2
Conductivity process in semiconductor		2Da	0-1

Semiconductor bonding model		2Db	0-1
		Total	8
Ionic structure	Ionic crystal	3A	0-2
Covalent bonding and ionic bonding		3Ba	0-3
Ionic crystal properties		3Bb	0-1
Ionic versus metallic crystal properties		3C	0-2
Ionic crystal defect properties		3D	0-2
		Total	**10**

To analyze the students' conceptual knowledge before and after the intervention, their answers in the pre-test and post-test were categorized into five categories (complete, incomplete, misconception, incorrect, and no answer).

The total score for each concept was different; it depended on the complexity of conceptual knowledge required to answer the questions. For example, the scoring guide for question number 1Aa are: (1) Complete, for students who answered in accordance with scientists conception, who mastered basic knowledge, and could relate their knowledge to explain the phenomena or question: score 3, also students who completely described the process of metallic bonding, comparing the parameter of metallic bonding in sodium, magnesium, and aluminum, and explaining the reason of the increasing melting point from sodium to aluminum; (2) Incomplete: score 1-2, for the students who knew the basic concept but could not connect it to a complete explanation; (3) Misconception: score 0, for students indicating misconceptions; (4) Incorrect: score 0, for students who were incorrectly or irrelevantly answering the questions; and (5) No answer: score 0, for students who did not provide answers on their answer sheets.

CK scoring was done for the pre-test and post-test. Paired sample t-tests adopted to analyze the differences between the pre-test and post-test results in students' CK. A test of hypotheses with p-value < .05 was considered as significant. The scores of each knowledge domain then have been converted to the n-gain to see the increasing domain-knowledge.

RESULTS AND DISCUSSION

Learning Design Based on the MER

MER considers students' and scientist conception in designing a learning sequence in order to bring student conception toward scientist conception. Learning sequences were designed based on MER. The conceptions that scientists and students have on SSC concepts were presented in the analysis section of selected data.

Scientist conception analysis was done in order to define and determine: 1) theories and conceptions; 2) function and meaning of science conception; 3) position of theories and concepts; and 4) field of applications. Inorganic books (Housecroft & Sharpe 2012; Miessler et al, 2014) were analyzed to determine scientist conception. The analysis of student conceptions was to clarify a scientific concept in students' perspectives. Therefore, the students were expected to translate their conceptions of SSC concept into a concept map and interviews.

Based on the characteristics of SSC, the topic was discussed based on the relationship among structures, properties, and applications. Regarding the criteria, the scientists' and student conceptions about SSC concepts-metallic, ionic, and covalent network crystal- are described in Table 2.

Table 2. The Student and Scientist Conception about SSC

No	Concept	Scientist Conception	Student Conception
1	Metallic Crystal structure	a. Generally, metals are known by students as a solid material at room temperature (25 °C) except mercury which is liquid, most have a silvery shine, are malleable and ductile, are good conductors of heat and electricity. The ability to conduct electricity in metals is explained by the "sea electron" model. Besides, the model can be used to predict the conductivity of polymers.	a. Valence electrons are bonded to metal atoms b. Friction between two metallic atoms causes valence electrons to form "sea electrons" c. The "sea electron" model differs from the metallic bonding d. Metal conduct electricity because of the friction between two metallic atoms to produce valence band

		b. Electric conductivity of conductors, semiconductors, and insulators are described using band theory (valence band and conduction band). Based on the band theory, we could explain the type of semiconductors. Pure materials that have semiconductor properties are called intrinsic semiconductor. Other elements that are not semiconductor purely can be modified by adding elements to make doped semiconductor, they are called extrinsic semiconductor (n-type and p-type). c. One of the applications of the extrinsic semiconductor is the diode. d. Other properties of metals: malleable and ductile. To determine these properties, the analysis of metallic structure such as FCC, HCP, BCC, and SC needs to be discussed.	
2	Covalent Network	a. Covalent network topic in this study is limited to diamond and graphite. Both are arranged by the same constituent components: carbon atoms. b. The structure differences cause them to have different optical, electronic, and mechanical properties. c. The invention of new applications of graphene provides challenges, opportunities and becomes an interesting study. Graphene is a layer of graphite, graphene properties of having electrical conductivity stronger than graphite are easily explained by understanding the bonds and structures of graphite and graphene.	a. Intra-molecular forces are stronger than others and there are electron shared b. Covalent bonds are formed by sharing pairs of electron and its strong bonding characters, because there are sigma and pi bonding
3	Ionic Crystal structure	a. Ionic solid conductivity differs from metals which can conduct electricity in a solid state. Salts conduct electricity in liquid or solution phase. b. Ionic solids are hard but very brittle – forces differ from the metal. Those properties are explained by different chemical bonding. c. In addition, the influence of covalent characters in ionic compounds also affects properties of ionic compounds such as melting point and solubility.	a. There are cations and anions in addition to Na atoms which have not become cations yet b. There are electrostatic forces, electron handover takes place c. There is an attraction between cation and anion and there is a force between positive and negative molecules d. Ionic solid conduct an electric current due to the electrostatic forces that cause free electrons to move

Table 2 shows that some students experienced misconceptions on the SSC concept, resulting in difficulties to explain properties of the material. Our task is to change their conception to the scientific conception. Scientists and student conceptions are considered to design learning sequences. Prior to knowledge of students about the SSC, the concept was the basis for designing interventions, media, experiments, and instrument test. Each intervention aimed to develop students' conceptual knowledge (Table 3).

Table 3. Learning Design Based on The MER

Concept	Scientist conception	Student conception	Reconstruction			
			Learning Design	Media	Experiment	Evaluation
Metallic bonding	Metallic bond explains the strong attraction of closely packed positive metal ions and a "sea" of delocalized electrons	a. Valence electrons are bonded to metal atoms b. Friction between two metallic atoms causes the valence electrons to form "sea electron" c. The "sea of electron" model differs from the metallic bonding	a. Analyzing metallic properties b. Illustrating the "sea of electron" model as metal bonding c. Predicting metallic properties based on structures	"sea of electron" model	-	Analyzing metallic bonding in a metal to predict its properties
Metal Conductivity	The conductivity of metals is due to the presence of delocalized electrons	Metals can conduct electricity because of the friction between two metal atoms to produce the valence band	a. Analyzing "sea of electron" model to explain electric conductivity of metals b. Band theory model to explain why a material can act as a conductor, an insulator, and a semiconductor	"sea of electron" model, Band theory model	Designing experiment to test conductivity of material	Predicting a certain conductivity of the material
Ionic Bonding and structure	Ionic bonding is a type of chemical bond that involves the electrostatic attraction between oppositely charged ions	a. There are cations and anions besides Na atoms that have not yet become cations b. There is an electrostatic force and an electron handover takes place c. There is an attraction between cations and anions and there is a force between positive and negative molecules	a. Analyzing the coulomb force that occurs in ionic compounds b. Describing ionic bonding (considering the size and charge of ions) c. Analyzing and differentiating ionic bonding d. Analyzing ionic crystal structure and discussing models	Ionic crystal structures and models	-	Analyzing ionic bonding in an ionic compound to predict its properties

Table 3 shows that students started learning from analyzing a daily life context, formulating questions related to the context, making hypotheses, planning laboratory activities to test the hypotheses, investigating laboratory phenomena, and using the theory to predict phenomena. The students were asked to evaluate the theories and predictions in more complex contexts.

In those activities, the mental model about the chemical structure like packing crystal structure and molecules is the big goal in order to make students connecting the structure to properties, for reaching this goal we need media to model chemical structures (physics and animation) to teach them successfully.

The Student Conception on the SSC

The patterns of student conceptions on each domain-knowledge before and after the MER-based learning categorized into 1) complete (C), 2) incomplete (IC), 3) misconception (M), 4) incorrect (I), and 5) not knowing concepts, not providing answers (N). The data are presented in percent form to know the results of students in each category (Table 4).

Table 4. Categories of the Students' CK on SSC Concepts

Domain Knowledge	Student Conceptions									
	Before Intervention (%)					After Intervention (%)				
	C	IC	M	W	N	C	IC	M	W	N
Metallic Crystal	17	22	14	22	24	48	22	11	12	6
Alloy	0	33	0	27	39	61	24	0	12	3
Covalent Network	1	11	6	7	75	71	10	0	9	10
Semiconductor	17	11	0	8	63	58	21	0	12	8
Ionic Crystal	6	4	7	24	60	49	28	4	14	4

Table 4 indicates that the learning design based on MER improved student conceptions almost on every topic that built domain-knowledge.

The percentages of students in complete and incomplete categories increased after the intervention. In contrast, the percentage of students with misconceptions, wrong, and no answer category decreased.

Solid state chemistry contains many abstract concepts such as chemical bonding and structure, molecular and crystal structure. It requires students to think at submicroscopic level. Unfortunately, most of the students at several educational levels find big difficulties. They are low in proficiency level to visualize structures and applications to chemical phenomena, they merely focus on memorizing submicroscopic and symbolic representation. So they cannot well imagine the process and structure of the phenomena and show misconceptions (Adadan, 2014; Adesoji & Omilani, 2012; Barke et al., 2009; Hand & Choi, 2010; Linenberger & Bretz, 2012; Luxford & Bretz, 2014; Madden et al., 2011; Ramnarain & Joseph, 2012; Stojanovska et al., 2017).

Considering students and scientist conception in designing learning topics gave students opportunities to examine and revisit their own conception, revise them and build scientific knowledge (Niebert & Gropengiesser, 2013; Sam et al., 2016). In addition, all media of molecular modeling or crystal structures are designed based on students' need. Therefore, it would make students easily recognize those models.

For example, before the intervention, most of the students answered incorrectly even were showing misconceptions about the differences in diamond and graphite properties. Both have very different properties: they are constituted of the same composition, carbon atoms – but the arrangements of C atoms are different. After the intervention, the students could answer correctly that both graphite and diamond have different chemical structures. A strong covalent bond makes them both have a high melting point. In graphite, each carbon atom bonds to three other carbon atoms, while in diamond one C atom bonds to four other C atoms. Therefore, there are free electrons in graphite. These free electrons cause graphite to conduct electricity while diamonds do not. The students described diamond and graphite structures well.

Almost all domain knowledge of students has increased. Unfortunately, in the domain of metallic and ionic crystal structures, misconceptions were found on some students. However, the numbers decreased after the intervention.

In the metallic crystal domain, some students still consider that the "sea electrons" model is different from the metal bonding model. This understanding had an impact on determining the physical properties of metals such as melting point. Six percent of the students in the post-test assumed that the increased melting point of sodium, magnesium, and aluminum metal were due to the distance of atoms. The periodic table shows that the nuclei and the last electron are far separated so that they do not relate to the ocean model of electrons as visualized in the learning process. Before the intervention, 27% of the students considered that the increased melting point from sodium to aluminum metal was due to intermolecular forces that make up the metal.

Some similar misconceptions occurred among the students who assumed that there is no bonding between metal atoms. They thought that metals are the electric conductor since metal atoms are conducting electricity. This indicates that the students had difficulties in distinguishing atoms and metal ions in metal structures (Barke et al., 2009; Bergqvist et al., 2013). Some researchers found that all the misconception occurred as students are lack to attribute the macro phenomena to the sub-micron level (Pérez et al., 2017). On the other hand, teachers may contribute to this misconception as they are not aware of the terms they use (Bergqvist & Rundgren, 2016). Normally, experts easily move from macro to particulate representation, but it is hard for students.

Explanations and visualizations of metal bonds were presented to help the students understand the bonds occurred in the metal and relate it to the physical properties of the metal including the melting point. Unfortunately, not all students were able to connect the structure and properties. Understanding the structure and relating it to nature is a challenge for the students. This is in line with the results of the study conducted by (Cheng & Oon, 2016; Pérez et al., 2017).

Misconceptions on the concept of metal structure and bonding also led 9 % of students to assume that metal bonds are stronger than ionic bonds. They applied this misconception to explain the fragility of ionic crystals over metal crystals. They assumed that ionic bonds are weaker than metal bonds. In fact, there are strong bonds that hold ions to stay in position in the crystal lattice. Changing the positions of these ions requires a strong force. If forces are applied to the ionic crystals, ions of the same charge will be closer to each other and the repulsion force will cause a sudden breakup of the crystals. To understand the connection between structure and properties, the students need a good understanding of chemical bonding. This is in line with Barke (2009).

Chemical bonding topic has been taught since high schools in Indonesia. Simplification of chemical bond concepts in high school causes students to use alternative concepts in the higher education level. This finding is in line with the previous research reported that chemical bonding is a difficult concept and gives many alternative concepts developed by students (Croft & de Berg, 2014; Dhindsa & Treagust, 2014; Nimmermark et al., 2016). The main point in the findings of this domain-knowledge is that the stabilized basic concept among students is important since one of the most important things in inorganic chemistry is the applied concepts.

Another research found that high school teachers always depend on school textbooks (Bergqvist et al., 2013); meanwhile, representation of chemical structures in school textbooks may cause students misconceptions without a scientific explanation from the teacher. There is also a need to fill the gap between researchers and textbook writers because books influence teachers' selection and use of representations for their lessons.

The Students' CK on the SSC Concept Improved Significantly

To identify whether or not there were significant differences between the pre-test and post-test scores, paired sample t-test was performed (Table 5). The results show that the difference between the pre-test and post-test scores in all domain knowledge ($p < .001$) improved significantly.

Table 5. Paired Sample T-Test between Pre-Test and Post-Test of theStudents' Domain Knowledge

Domain knowledge	Mean		Std. Dev.		Sig. (2-tailed)
	Pre-test	Post-test	Pre-test	Post-test	
Metallic crystal	2.93	8.12	1.99	2.89	p<.001
Alloy	0.82	4.30	1.01	1.75	p<.001
Covalent crystal	0.42	8.16	0.80	1.73	p<.001
Semiconductor	1.57	4.91	1.73	1.94	p<.001
Ionic crystal	0.42	5.37	0.75	2.48	p<.001

Table 5 tells that students' domain-knowledge increased and differed significantly in all domain-knowledge before and after interventions based on MER. Those results indicate that MER-based learning improves students' understanding of concepts significantly.

The results show that MER is a powerful strategy to develop student conceptions. This is in line with previous research results. It proves that MER-based learning develops students' conceptual knowledge, in which the knowledge increased significantly toward the scientist conception. It is also stable at a high level for some domains such as chemistry, physics, and geography (Reinfried et al, 2015; Sam et al 2016; Sam et al, 2015).

Barke et al, (2009) thought that students enter the classroom with their own conceptions of matter. Such conceptions can be obtained either from home or school. Unfortunately, not all of their conceptions are in accordance with the scientist conceptions, and even some of them are misconceptions. For instance, when students present questions about the fragility of ionic crystals compared to metallic crystals, they assume that metallic bonding is stronger than ionic bonding. In addition, some students believe that small cation sizes cause the fragility of ionic crystals. If the misconceptions are not detected early, then it would be difficult for teachers to teach other concepts.

The MER learning design focuses on the reconstruction of student conceptions. This helps students to understand the key concepts and to identify relationships between students' and scientist conceptions in order to decrease the gap between those two. Therefore, analyzing student conceptions before determining appropriate instructional designs contributed to conceptual understanding as well as the process of clarifying concepts by students (Sam, 2017).

Mastering the basic concepts clarifies that students are capable of using basic concepts to explain phenomena or properties of the material. In addition, students are able to use basic concepts to predict properties of other material. As an example, students who could predict well the conductivity of material based on the "sea electron" model would impact on their ability to design the steps for making glass and polymer conductive. Students are challenged to conduct glass and conductive polymer experiments. Both substances could be found in many modern applications such as touchscreens on mobile phones.

The Students' CK enhanced the SSC Concepts

To see clearly the increasing of each domain-knowledge, the scores of which then were converted to the n-gain (Figure 1).

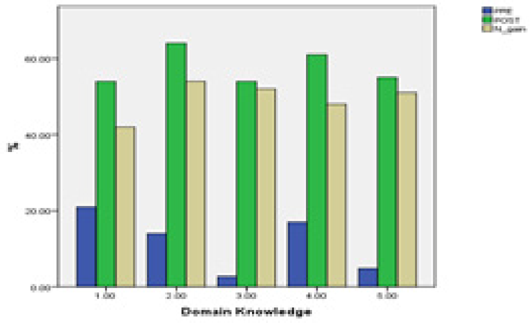

Figure 1. The Average Percentages of the Pre-test, Post-test, and N-gain Scores of Students on Each Domain-Knowledge.

The figure conveys that the percentage of the post-test scores of all domain-knowledge was higher than the pre-test with the middle n-gain category. MER had benefits for classroom learning design. The scientist-student content should be implemented to solve the assumption that knowledge cannot directly be transferred from scientist to students (Niebert & Gropingiesser, 2013; Sam et al, 2016). The open-ended discussion which posters conceptual knowledge is the best way to build up students the scientific knowledge and solve problems.

Criteria, properties, and structures of metal alloys were examined through group discussion. The discussion gave students the opportunity to get involved in thinking of the relationship between property and application of alloys with their structure. Structure visualizations presented through multimedia helped the students investigate the submicroscopic level. Correctly, most students were able to determine the types of alloys, as well as properly produce metal alloys. During the learning process, the students were very interested in discussing alloys, many of them wanted to create alloys to discover other properties such as color, strength, and conductivity.

Alloys are an application of metallic crystal concepts. Chemical science concepts in high school and basic chemistry courses do not emphasize the content of alloys in learning so that it is new for the students. The chemical content of solid state chemistry is studied in high school through chemical bonding topic. The topic focuses on comparing the process of ionic, metallic, covalent, coordination covalent bonding, and inter-molecular forces with the physical properties of the compounds. The analysis of several RPS in some of Indonesia's University of education also shows that the topic of alloys has not been studied in basic chemistry learning.

Meanwhile, students often find the application of metal alloys in everyday life such as precious metals, sculptures, household utensils, weapons and others. For example, sterling silver is a metal alloy consisting of 93% silver and 7% copper. It is considered as the precious metal. Its mechanical properties are strong and cheap, under than silver at 99% purity. The uniqueness made the students interested in learning other alloy properties such as their questions are: *"How is the electronic property of metal alloys? Is it still the same as its pure metal?; how to explain the alloy structure?; how to produce an alloy?"*. This became an opportunity for teachers to invite students to discuss this topic.

The students were able to determine both interstitial and substitution metal alloys. The alloy criteria required to determine alloys such as the size of the atoms, its electron structure, and metallic crystal structure. In this domain, alloys reached the highest n-gain (54 in middle category). This is parallel to the previous research suggesting that group learning with animation or media aid is more effective and provides students opportunities to improve their understanding–even through pleasant discussions between their friends (Eymur & Geban, 2017; Ganasen & Karpudewan, 2017; Karacop & Doymus, 2013). However, discussions and interactions between students and teachers would not occur if the discussed topic is not interesting and challenging for students.

The n-gain in understanding metallic crystals was the lowest (42 in middle category). This knowledge was measured by asking students to explain the reason of boiling and melting point increased of sodium to aluminum metal, different metal hardness between sodium and copper metal, different metal ductility between magnesium and copper metal, and comparing the conductivity of the aluminum metal with beryllium semimetal. To answer all these problems, students must be able to understand the basic concepts of metallic bonding, metallic crystal structure, and band theory.

To answer the increased melting and boiling points from the sodium to aluminum, students must be able to analyze the metallic bonding in the three metallic types. All three have metallic bonding, in which the positively charged ions bind to the delocalized valence electrons. From sodium to aluminum, ion charge increases and the number of delocalized valence electrons also. It causes the increasing metallic bonding strength from sodium to aluminum, resulting in high melting and boiling point. This understanding will affect students when they are asked to show metal bonding models of the three metals.

Although solid sodium metal can be cut using a ruler, copper metal should be cut by sharp scissors. The hardness of sodium metal compared to copper metal is explained by the metallic packing factor of metallic structures. Sodium metal adopts a body-centered cubic structure, the number of atoms per unit cell is two (one in the middle, 8 x 1/8 at eight corners), and the packing factor is 68%. While copper adopts a face-centered cubic structure, the number of atoms per unit cell is 4 and the packing factor is 74%.

The properties encountered in the case of copper and magnesium, both metals have similar properties in terms of "hardness" so that sharp scissors must be provided to cut metal plates. On the other side, copper metal can be made into sheets, while magnesium metal tends to crumble. Both magnesium and copper adopt a closed packing structure. Magnesium takes up a hexagonal close packing structure whereas copper adopts a cubic closed packing structure. In the case of the cubic closed structured crystal, there are glide planes within the atomic layers in all directions, thus, the mechanical attack can be repelled from many directions through the movement between atomic layers. The elementary cube itself allows the movement of smooth triangular layers in four directions, i.e. perpendicular to the four diagonal spaces. In comparison, the hexagonally closed structured crystal has only one direction of the triangular layer in the hexagonal unit cell.

A band shows a group of molecular orbitals. The energies of the resultant MO are very close together; in other words, there is a band of orbitals. The band occupies the valence electrons known as the valence band, and the empty one is so-called the conduction band. The difference distance between the valence band and conduction band (band gap) in some structures shows the conductors, insulators, and semiconductors material. Valence electrons in the valence band are moving freely in all directions, if the electric current is given then the electrons could move to the conduction band when it is able to pass the energy band gap.

Media, animation, and interesting discussions facilitate the students to see the relationship between structure and properties of metal crystals. However, media or animation is only tools, and observing the relationship between nature and structure requires spatial ability. If such ability is not controlled well by the students, it will result in difficulties. This is in accordance with Barke et al (2009) who stated that spatial ability is more important than simply writing down the structure and equation of chemical reactions.

CONCLUSION

The MER is a powerful strategy that could promote students' development of conceptual knowledge, and keep the knowledge stable. The results show that there were significant differences between the students' conceptual knowledge in all domains (metallic crystal structure, alloy, bonding network, semiconductor and ionic crystal) in the pre-test and post-test scores. This indicates that after the implementation of the MER-based learning in solid state chemistry topic, students' conceptual knowledge was close to scientist conceptions.

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