INTRODUCTORY STUDY ON STUDENT'S MENTAL MODELS IN UNDERSTANDING THE CONCEPT OF ATOMIC STRUCTURE (Case Study on High School Students in Lampung Indonesia)

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Abstract: Several researchas indicated that mental models can affect the students' ability to perform reasoning on external representations encountered. Students' mental models are generally used to thinking in problem solving. Objective of this research is to look at the characteristics of initial mental models of students in understand the concept of atomic structure. Research subjects taken from students of high schools in Lampung Indonesia that have been selected as the sample. The number of samples involved as many as 119 people consisting of students of class XI. Diagnostic tests in the form of an essay used to see the emergence of a mental model of atomic structure that is tested in Class XI. The results of the research show that for all groups of students' early knowledge, initial mental models of the students in understanding the concept of atomic structure is dominated by verbal mental model of the category "very bad" and "bad," or the characteristics of "unformed" and "intermediate 1" mental models. This finding implies that students' mental models can be used as a reference in determining the instruction strategies that can help students in problems solving related to the phenomenon sub-microscopic, macroscopic, and symbolic.

Key Words: Introductory Study, Mental Model, Atomic Structure, understanding

INTRODUCTION

Various research on mental models have shown that learning with a variety of representations is very important to enhance the students' understanding of chemistry concepts, especially the use of visualization representations to explain the phenomenon of sub-micro (Herga, et al., 2014; Gkitzia, et al., 2011; Guzel & Adadan, 2013; Jaber & Boujaoude, 2012). Other studies consistently shows that students have difficulties in understanding and interpreting the representation (especially submicroscopic) in making the translation between the three types of representation and in building their representational abilities (Johnstone, 1993; Treagust, et al., 2003; Chittleborough, and Treagust, 2007). Chemistry instruction to build a deeper conceptual knowledge should be done by involving all three levels of the phenomenon. In reality the instruction of chemistry that has been taking place tends to prioritize only on the macroscopic and symbolic representations in a verbal manner (Chittleborough and Treagust, 2007; Liliasari, 2007; Sunyono, et al., 2011). Generally, submicroscopic representations are only represented verbally and models of molecules are less appreciated, whereas molecular models can facilitate instruction of chemistry on all three levels of the phenomena (macro, submicroscopic, and symbolic) which are shown through various representations.

The research that has been conducted by Tasker and Dalton (2006) showed that the use of concrete models, image representation, animation and simulation has proven beneficial for the students' process of understanding of chemical concepts, particularly the concept of molecular or submicroscopic level. According to Tasker and Dalton (2006) that "Chemistry involves interpreting observable changes in matter (e.g. color changes, smells, bubbles) at the concrete macroscopic or laboratory level and in terms of imperceptible changes in structure and processes at the imaginary submicroscopic or molecular level." These changes at the molecular level are then described in the symbolic level that is abstract in two ways, namely qualitatively: using a special notation, language, diagram, and symbolism, and quantitatively using mathematics (equations and graphs).

The statement from Tasker & Dalton (2006) is related to the transformation of the external representation into an internal representation (hereinafter expressed as a mental model). Cognitive psychology expert Johnson-Laird (in Solaz-Portoles and Lopez, 2007) formulated a mental model definition in an attempt to explain the processes of a person's reasoning in syllogizing and forming an internal representation in the form of a mental model in a working memory (WM) of the world and combine the information that has been stored in long term memory (LTM) with information on the characteristics of the task, and then extracted by perceptual processes in memory. Senge (2004) defines mental models as follows: "Mental models are deeply held internal images of how the world works, images that limit us to familiar ways of thinking and acting. Very often, we are not consciously aware of our mental models or the effects they have on our behavior."

Some research on mental models have found that many students have a very simple mental model of chemical phenomena, for example atomic and molecular models which are depicted as discrete and concrete structures, but do not have the skills to build more complex mental models (Chittleborough and Treagust, 2007; Coll, 2008; Guzel & Adadan, 2013). Guzel & Adadan (2013) utilized multiple representations in instruction to develop understanding of chemistry for teacher candidate students about the structure of matter. As a result, even though the student has been able to develop the representational abilities, but the image structure created is still very simple. Coll (2008) reported in a study of "*mental models of chemical bonding*" that high school, undergraduate, and graduate students prefer the simple and realistic mental model more. Chittleborough and Treagust (2007) in their study reported that students' mental models can be formed through interpretation, understanding, and an explanation of the submicroscopic representation phenomenon, but most students prefer to use their mental models in a representation phenomenon that is simple. One way to do it is to use visualization suitable for a particular instruction topic. A study conducted by Sunyono, et. al. (2011) reported that students' mental models still tend to be at the macroscopic and symbolic level, their submicroscopic level is still not well established. This is due to students having difficulty in making the interpretation of the submicroscopic phenomenon.

Referring to the research results of Sunyono, et. al. (2009), the instruction of atomic structure topic should be done by involving submicroscopic representation, because it is characteristically abstract and atomic theory or the nature of matter is a key concept in science and technology (Gkitzia, et al., 2011). Park, et. al. (2009) stated that the theory of the atom is the main concept in science instruction and its concepts are abstract, so the way to teach and learn about the atomic theory must be well considered, especially in choosing a strategy of utilizing visualization. Wang (2007) in his dissertation reported that instruction about the structure of atoms, especially the position of an electron in an atom, requires a visualization model that is designed in such a way so as to assist students in making the interpretation of the phenomenon of electrons in atoms and that students' mental models can be developed well. Hilton & Nichols (2011) reported that understanding the phenomena of more complex and abstract topics such as the structure of an atom, cannot be achieved by the students without involving the submicroscopic and symbolic representations. Similarly, research conducted by Guzel & Adadan (2013) reported that instruction designed by developing an understanding of the various representations (macro, submicroscopic, and symbolic phenomena) can produce a more representational in-depth understanding of the structure of the matter and can be maintained up to 17 months.

Researchers study a person's mental model by grouping it into several characteristics, for example: Norman (in Barsalou, 1992) divides the characteristics of mental models into 2 parts, the structural mental model and conceptual mental model. In research of the education field, researchers generally studied the mental model by focusing on the conceptual model. Associated with the study of mental models in education, Wang (2007) and Jaber & Boujaoude (2012) classify the characteristics of mental models (conceptual) into three categories based on students' scores to questions in a mental model test, namely: "high" mental model (students' correct answers reach $\geq 70\%$), "moderate" mental model (if

50%> of students' correct answers are <70%), and "low" mental model (students correctly answer ≤ 50%). However, Park, et. al. (2009) classify the characteristics of mental models into five parts, namely (1) the initial mental model that is not shaped or unclear,which is the mental model that is there since birth and emerges as a result of information from the environment that is incorrect, or the concept/ description and image structure that is made, is entirely scientifically unacceptable, or students do not have any concept whatsoever; (2) intermediate 1 mental model is a mental model that is beginning to be formed and is characterized by concepts/explanations given being scientifically closer to the truth and the image structure created is unacceptable or otherwise; (3) intermediate 2 mental model is the students' mental model characterized by the concept/explanation of the students being partially correct and the image structure being made is scientifically closer to the truth; (4) intermediate 3 mental model of is a mental model that can be categorized as a consensus mental model, namely characterized by the concept/explanation owned by students being scientifically acceptable and image structure being made is closer to the truth or otherwise the explanation/concept owned cannot be received well scientifically, but the image structure being created is right; and (5) target mental model is a mental model that is characterized by the concept/description and image structure created by the student being scientifically correct. This study was conducted to answer the question: "how are the characteristics of an initial mental model of students in understanding the concept of the structure of atoms?"

METHODOLOGY

Research Design and Research Sample

The research design is done through observation with the investigation, interviews, and a questionnaire completed by the teacher, as well as initial concept mastery test questions and initial mental model test filled by students. The research design conducted is a field observation aimed to obtain data on theinstruction model used by chemistry teachers and mental model of high school students in Lampung Province - Indonesia. Regions surveyed for this data collection is in three regencies / cities that are randomly chosen from the 14 regencies/cities in the province of Lampung. Afterwards, four high schools were randomly sampled. These four schools were selected from different regions, including: (1) a high school in the provincial capital (students with employee and entrepreneur environment), ie a high school of Utama 2 (SMA Utama 2) Bandar Lampung , (2) high schools near the capital (students in a farming environment),ie State high School 2 of Natar (SMAN 2 Natar) and State high school 1 of Negerikaton (SMAN 1 Negerikaton); and (3) a high school far from the capital (students with an industrial/agroindustry entrepreneur), ie State high school 1 of Terusan Nunyai (SMAN 1 Terusan Nunyai). The sampling of the schools was to get student respondents with different backgrounds. Furthermore, one class of XI grade students was taken randomly from every high school to test mastery of chemistry concepts of X grade and characteristics of mental model. Thus, there werea total of 119 students involved as respondents in the study.

Instruments and Data Analysis

The initial mental model of students as measured in this study is a conceptual mental model that emerged in response to the questions in a diagnostic test on the topic of atomic structure (especially the atomic model of Rutherford, Bohr, and wave mechanics). The instrument used to determine the appearance of the students'initial mental model is a form of a mental model diagnostic test or what is called an atomic structure model test (TMS). The test instrument was adapted from a model developed by Wang (2007) and Park & Light (2009), in the form of a written essay test that comes with submicroscopic image. There were 4 diagnostic test items in this study. Interviews were then done with 3 (three) selected students representing each group (school). Interviews with students were conducted to find out more about the responses of the students and the difficulties that arise in solving the problems.

Data obtained from the results of diagnostic tests and interviews were then analyzed through transcription and categorization, so initial mental models of students could be identified and common general difficulties that occur when dealing with the external representation of the submicroscopic level, especially in solving the problem of the atom model concept. A scoring system was implemented to categorize the emergence of mental models through the students' answers on diagnostic test questions. Scoring technique is performed by using a rubric, namely by assessing the students' answers on the test with description using labeling to determine the level of achievement of resolving the problem. The level of achievement in problem solving are then categorized as a mental model of "bad" (where a score = 1), "poor" (score = 2), "medium" or "moderate" (score = 3), "good" (score = 4), and "excellent" (score = 5). Based on the results of the scoring and categorization, students' mental models appearing are then characterized into 5 mental model characters (Park, et al., 2009), namely, the unclear, intermediate 1, intermediate 2, intermediate 3, and the target model.

RESULTS

Questions on the diagnostic tests to see the emergence of student initial mental models in understanding the topic of the structure of atoms are in the form of three questions, namely about the students' understanding of the notion of atoms and molecules in a chemical change process, followed by a question about the model of the atom nucleus (Rutherford), the Bohr model of the atom, and model of wave mechanics. The questions raised include the interpretation of the submicroscopic phenomenon through verbal explanations, visual images, and symbols. The research results showed that students from different backgrounds have similar mental model abilities, namely being in the category of "poor" and "bad." The results of the analysis of the emergence of initial mental model of students in response to the number 1 atomic structure model (TMS-01) diagnostic test question is shown in Figure 1 below.

Number 1 test problem (TMS_01) is a test that asks about physics and chemical changes to see the students' level of understanding toward the definition of atoms, elements, and molecules (see Appendix). Based on the students' answers to the TMS 01 question, it can be said that students from four schools (with differing backgrounds) provide responses that are not different, resulting in the same initial mental model, namely "poor" and "bad". The study provides information that class XI students, who have studied the structure of atoms, are still not able to read the submicroscopic diagram well enough to distinguish the structure of atoms and molecules, and also in recognizing the changes of molecules when turning into atoms, the change of compounds into elements, and changes in a substance that does not change the structure of the substance itself. It shows that the university students' initial mental models in understanding the physics and chemical changes are still dominated by the macroscopic level.

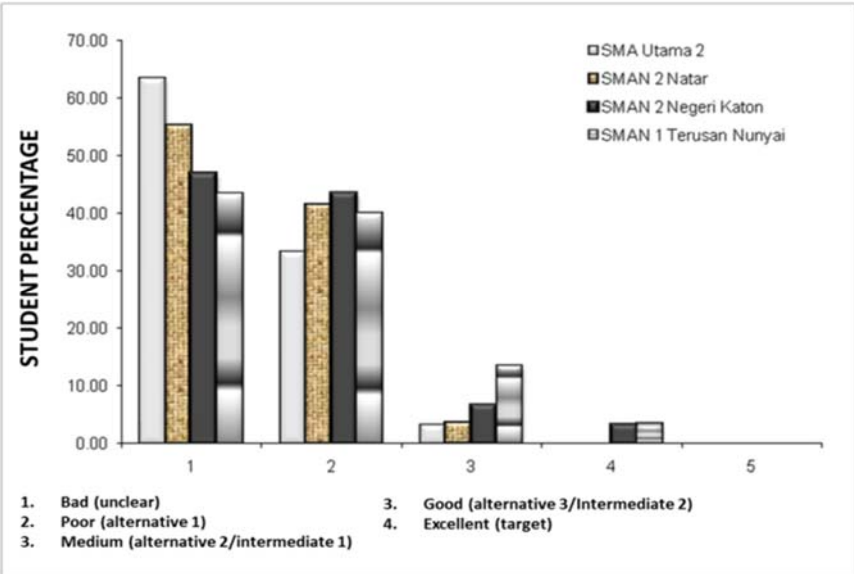

Figure 1. Percentage of Students with Initial Mental Model on Specific Characteristics for Question TMS-01

Based on Figure 1, the majority of university students (> 80%) assume that the phase 3 is the process of physics changes and only 3.57% who replied that the third stage is the process of chemical change. This means that students do not have sufficient understanding of the notion of atoms and molecules. This finding is in line with the statement of Park (2006) that the student's mental model of the chemical phenomena depends on the ability to distinguish between the submicroscopic structure of molecules and atoms. Therefore it is necessary to attempt to develop a university student initial mental model so that the hybrid mental model (Vosniadou, 1992) can be formed to reconcile the conflict between the conceptual definitions of experts, with the visual picture at the molecular level.

The question on test number 2 (TMS-02) shows that students are still experiencing difficulty in making the transformation from a verbal representation to a visual representation regarding the Bohr model of the atom (see Appendix). The difficulty is caused by the lack of imagination being used well by the university students because they did not practice in the instruction that took place. The question on TMS-02 is the question of student understanding on the atomic structure model according to the core model. The results of the analysis of students' answers to the TMS_02 test question showed that the majority of students are still not able to understand the atom core model, be they students from schools in cities or students from schools in areas far from cities (Figure 2).

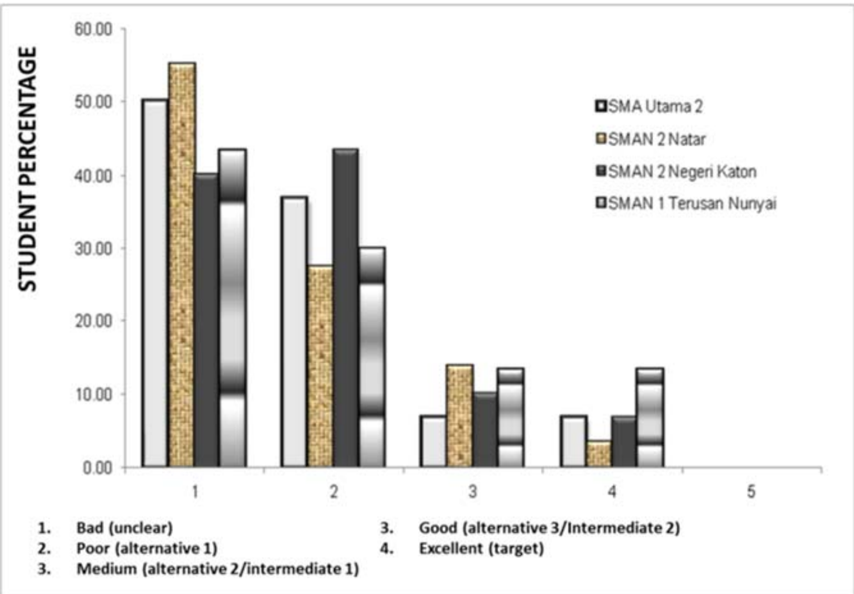

Figure 2. Percentage of Students with Initial Mental Model on Specific Characteristics for Question TMS-02.

Figure 2 shows a similar result with TMS-01. This result suggests that students with their knowledge of chemistry taught in class X were still not able to perform the transformation from the macroscopic (experimental phenomena of Thomson, Goldstein, Chadwick, and Rutherford) to the submicroscopic and symbolic phenomena. The transformation phenomenon is done through the imagination of the arrangement of particles in atoms then arranging a submicroscopic picture of the parts of the atom, then writing the symbolic arrangement of electrons, protons, and neutrons in an atom based on the visual image. Visual images that the students made were still very simple and most (41.67%) seem unable to distinguish between the Rutherford atomic model and the Bohr atomic model. Difficulties of the students may be caused because the students have not been involved with the submicroscopic phenomena in instruction. These results seem consistent with the statement by some researchers that the understanding of chemical concepts does not only involve rote verbal memorization alone, but also requires an understanding of the phenomena of submicroscopic representation of the structure of molecules or atoms (Ben-Zvi, et al., 1987; Coll and Treagust, 2003; Davidowitz, et al., 2010). Other studies, such as Coll (2008) stated that the ability of participant learners to operate or use their mental models in order to explain the events that involve the use of submicroscopic representations is very limited, so there is a need for training in interpreting submicroscopic visual images through instruction that involves 3 levels of chemistry phenomena. Furthermore Devetak, et al. (2009) found that students who have not trained with the external representation will have difficulty in interpreting the submicroscopic structure of a molecule or atom.

TMS-03 question is a question related to visual statement in which university students are asked to make the transformation from verbal to visual and symbolic representation or otherwise regarding the determination of electron orbit according to Bohr then create a visual image through an energy level diagram (see Appendix).
The result of the analysis of university student answers to the TMS-03 question is illustrated as Figure 3 below.

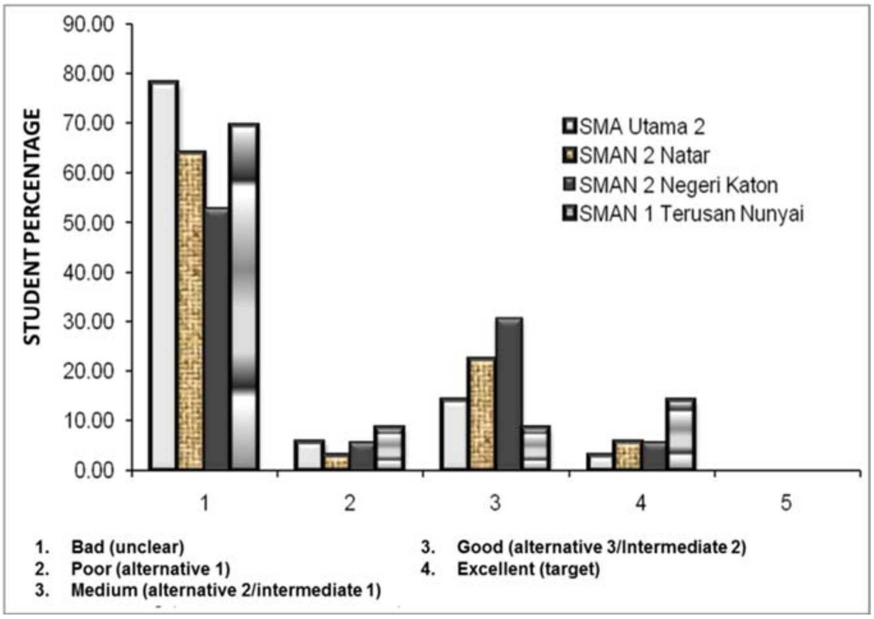

Figure 3. Percentage of Students with Initial Mental Model on Specific Characteristics for Question TMS-03.

Analysis of the students' answers to the TMS-03 question showed similar results with the results of the analysis of TMS-1. For all schools that were the subject of research, where the majority of students (> 66.00%) had an initial mental model in understanding the Bohr orbit model were in the category "poor" and "bad," or with the characteristic of a mental model "that are is not formed/unclear" and "intermediate 1”. This result indicates that class XI students who have studied the topic of the structure of atoms in class X are still experiencing difficulty in making the transformation of the verbal phenomenon to the visual phenomena of the Bohr model of the atom. Interviews showed that the difficulties faced by such students is more due to students not getting experience in making an interpretation of the electron orbit according to Bohr.

The results of the analysis of students' answers to the TMS-03 question shows that some of the students (25.00% and 20.83%) are actually able to interpret and make the transformation to a given phenomenon, but there are misconceptions in describing the flour and sodium atomic model. Students’ answers were interfered with the model of wave mechanics, namely by making the electron configuration use s and p orbitals, whereas what was being asked was the Bohr model that is not familiar with the orbital term. Due to that error in interpretation, the students' answers on the TMS-03 question produced an initial mental model in the category of "poor" and "bad." The interviews indicated that the ability to make such an interpretation, in distinguishing the Bohr model and the model of wave mechanics, were not provided as training in the instruction when they sat at high school. This is in line with the results of Wang & Barrow (2013) that instruction which does not involve the integration between submicroscopic and symbolic representations cause students to experience difficulties in describing and explaining the Bohr atom model in detail (and in a precise manner). According to students, the atomic model of wave mechanics was not studied in detail when they learned it in high school. Students are not given the experience in interpreting the Bohr electron orbit and the energy that accompanies the movement of such electrons, as well as how is the wave mechanics model in explaining the position and behavior of electrons in the atom.

The results of the analysis above, it seems, are in line with the findings of Park & Light (2009) that the student's difficulties in understanding concepts are characteristically abstract, can be caused by day-to-day experience that do not support problems solving involving submicroscopic representation phenomena. Furthermore, according to Park, et. al. (2009), the theory of the atom is a central concept in science, so how to teach and how to learn about the theory of the atom through models of atoms need to be considered well in choosing a strategy that can improve the ability of students' mental models from the "intermediate 1" mental model with the "poor" category to the "intermediate 3" mental model and with a "target" in the "good" and "excellent" category. Wang & Barrow (2013) reported that students with moderate mental model (medium) and very low scores have difficulty in visualizing the phenomenon of electrons in atoms and their energy transition. Wang (2007) in his dissertation reported that students with high, medium and low mental models scores have the same difficulty in terms of visualization of electrons in atoms. Similarly, Hilton & Nichols (2011) reported that the understanding of more complex and abstract phenomena cannot be achieved without the use of a variety of representations, especially the integration between submicroscopic and symbolic level representations. Using a variety of visualization tools for teaching and learning science and chemistry is very necessary because pupils better understand chemical phenomena and they can formulate appropriate mental models (Herga, et al., 2014**)**. Results of research conducted by Herga (2014) showed that the use of visual representation is more effective in improving knowledge acquisition rather than a class without using dynamic visualization elements. Based on these findings and support from previous research shows that instruction which does not provide experience and training to students in conducting interpretation, conceptual explanation, and transformation between the three levels of chemical phenomena will produce a low chemical problem solving, making it difficult to build a mental model in the category of "good" and "excellent".

SUMMARY OF MAJOR FINDINGS AND IMPLICATIONS

Based on the research results, we can conclude that (1) the initial mental models of students in understanding the concept of the structure of atoms is still dominated by verbal mental model with the category of "bad" and "poor" or with the characteristics of a mental model that is "unclear" and "intermediate 1" mental model. (2) the students' difficulties in interpreting the chemical phenomena in developing mental models, are among others:

a. identifying external representations (verbal and visual) about the position of electrons, protons, and neutrons in an atom according to each model of the atom (particle models, core models, and wave mechanics).
b. transforming the submicroscopic representation (visual) to verbal and symbolic or vice versa.
c. are not trained in the imagination of the submicroscopic representation phenomenon.

The results of this study have implications for the improvement of instruction practices, especially in setting instruction strategies in high school chemistry. One of the strategies that can be used to build a mental model is instruction by involving the three types of chemical representation (macro, submicroscopic, and symbolic phenomena). The goal is that students are able to provide explanations and gain a deep conceptual knowledge, so that students can more easily solve chemical problems associated with abstract concepts. The study of initial mental models is indispensable as a basis in determining the instruction strategy. Given that the mental model is an internal representation used by a person to think and thus affect the cognitive development of students (Chittleborough, and Treagust, 2007; Tasker & Dalton, 2006; Senge, 2004; Ben-Zvi, et al., 1987). Theories of mental models states that students' mental models are an internal representation that is constructed from experience, interpretation, and explanation of the concept which the university student received previously, then applied to the university students' understanding of the external representation of submicroscopic phenomena (such as Canas, 2001, Treagust, et al., 2003; Park, et al., 2009; Wang & Barrow, 2013; and Laird, 2013). Another statement was proposed by Norman (in Barsalou, 1992) that "people form mental models through experience, training and instruction," that a person forms a mental model through experience, training, and instruction.

The results of this study also indicate that the implementation of instruction in some schools in the province of Lampung - Indonesia are still incapable of facilitating students in using the ability of imagination to develop thinking skills and improve students' creativity. The difference in results between students from different schools, due to differences in learning strategies implemented by teachers in their respective schools. This is consistent with the findings of Min, Y.K. (2014) that the success of a student depends on many factors such as group chemistry, each member's psychological states, their disciplinary backgrounds, and their pedagogical foundation.

RECOMMENDATIONS

1. Initial mental model according to the results of this research is a preliminary picture of the student's ability to think about the concept of the structure of atoms. Information about the initial mental models can be used as the basis in determining the instruction strategies in high school chemistry to construct a meaningful understanding of the concept. Building a meaningful understanding of the concept requires development of a mental model packaging of instruction to produce systematic reasoning skills.
2. The instruction model that can develop students' mental models toward a mental model that is "good" and "excellent" is aninstruction model that is prepared involving the three levels of chemical phenomena (macro, submicroscopic, and symbolic) through cooperative and imaginative strategies.

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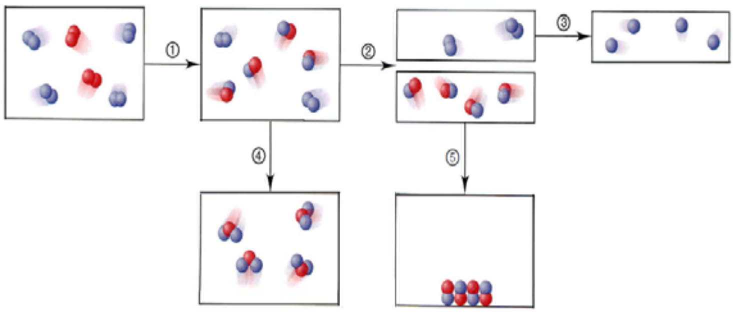
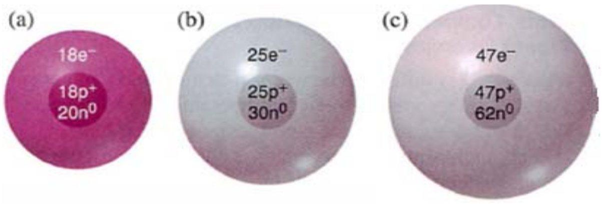
APPENDIX

TMS-01. Amongst these following stages, which one of these describe the process of physics change and which one describes a chemical change. Give your explanation!



TMS-02. a. Based on the experimental results of Rutherford, Thomson, Goldstein, and Chadwick. Give an explanation of the structure of atoms and draw an atomic model complete with its parts (protons, electrons, and neutrons) from the $^{23}_{11}Na$ and $^{14}_{7}N$!

b. Write the element with the symbol $^{A}_{Z}X$ for each atom notation as described below.



TMS-03. Based on the Bohr model of the atom, the number of electrons for each energy level follows the equation 2 n^2. Draw a picture the Bohr atomic model based on the results of your imagination of fluor atoms (Z = 9) and sodium atom (Z = 11), complete with energy levels according to Bohr! Explain your answer!