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Supporting Students in Learning with Multiple Representation to Improve Student Mental Models on Atomic Structure Concepts

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ABSTRACT: The aim of this research is identify the effectiveness of a multiple representation-based learning model, which builds a mental model within the concept of atomic structure. The research sample of 108 students in 3 classes is obtained randomly from among students of Mathematics and Science Education Studies using a stratified random sampling technique. The same number of students formed the control group. In the experimental class, the learning was conducted by using multiple representations, whereas the control classes undertook conventional learning. Result of the research shows that (1) Learning with multiple representations is more effective in constructing students' mental models in understanding the concept of atomic structure compared with the conventional learning; (2) Learning with multiple representations is suitable for lessons in classes where the students have low capability level to keep up with those who have a medium and high capability level. These findings indicate that lessons, which involve the macro-sub-micro-symbolic phenomena using multiple representations, may improve their mental model and effectiveness of atomic structure studies. The learning model is discussed as an alternative in class lessons in order for the students with initially low capability to keep up with those of medium and high capability in constructing their mental models.

KEY WORDS: Mental Model, Multiple Representation, Atomic Structure, SiMaYang model

INTRODUCTION

Chemistry studies basically involve three types of chemical representations: macro, sub-micro and symbolic (Johnstone, 1993). Research consistently shows that the students encountered difficulties in understanding and interpreting these representations (especially sub-micro) and interpreting

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between the three types of representation so as to build their own representation (Johnstone, 1993; Treagust, et. al. 2003; Chittleborough & Treagust, 2007; Gkitzia, et. al. 2011). To construct a more in-depth conceptual knowledge of chemistry, lessons need to include all three types of representation.

In reality, current chemistry studies tend to give priority to the verbal macroscopic and symbolic representatives (Chittleborough & Treagust, 2007; Liliasari, 2007; Sunyono, et. al., 2011). Sub-microscopic representations are generally represented verbally, and molecular models often suffer from lack of appreciation, despite their function as a bridge between the three types of chemistry representations (macro, sub-micro and symbolic).

This research was undertaken to answer the following research question: "*how effective is the multiple representation based learning model (known as SiMaYang) in supporting students to construct mental models for atomic structure?*"

THEORETICAL FRAMEWORK

Mental Models

Research performed by Tasker and Dalton (2006) shows that the use of concrete models, image representation, animation and simulation has proven to be beneficial to understanding the concept of chemistry, especially in terms of the molecular or sub microscopic concept. According to Tasker and Dalton (2006), "*Chemistry involves interpreting observable changes in matter (e.g. colour changes, smells, bubbles) at the concrete macroscopic or laboratory level and in terms of imperceptible changes in structure and processes at the imaginary sub-micro or molecular level.*" Changes at the molecular level can be describes symbolically in two ways: qualitative (with specific notations, languages, diagram and symbolism), and quantitative (using mathematics, such as equation and charts).

Tasker & Dalton's (2006) statements relate to the transformation of external representations into internal representations (subsequently expressed as mental models). Cognitive psychology expert Johnson-Laird (cited in Solaz-Portolės & Loppez, 2007) formulated a definition of a mental model in his attempts to explain an individual's reasoning process in solving syllogism problems. This was through forming an internal representation in the form of a mental model in the working memory (WM) regarding the world and combining the information stored in the long-term memory with the information available in the problem's characteristics, to be extracted by the perceptual processes in the memory. Senge (2004) defined 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 behaviour."*

Several research studies regarding mental model show that many students have very simple mental models regarding chemistry phenomena, such as atomic and molecular models, described as discreet and concrete, but do not necessarily have the skills to construct a more complex mental model (Chittleborough & Treagust, 2007; Coll, 2008; Guzel & Adadan, 2013). Guzel and Adadan (2013) made use of several representations during a lesson to develop the understanding of chemistry among future chemistry teachers regarding the structure of matter. As a result, even though the students were able to develop a representational capability, the structure drawings they made were still very simple. Coll (2008) reported in his research regarding the "mental models of chemical bonding" that high school graduates and even post-graduate students prefer a simple and realistic mental model. Chittleborough and Treagust (2007), in their research, reported that a student's mental model can be established through interpretation, understanding and explanation of the phenomenon for sub-micro representation, but most students prefer using their mental model in a simple representation phenomena, one of which is by using a suitable visualization for a given topic. Studies performed by Sunyono et al. (2011) reported that a student's mental model tends to be at the macroscopic and symbolic levels, and that their sub-microscopic level mental model is not yet well developed due to difficulties in interpreting sub-micro phenomena. Chiras (2008) concluded that math achievement of students was a very good predictor of the quality of their mental models. Thus, the development of mental models in teaching chemistry needed to be undertaken through the representation of the three levels of learning science, as illustrated by Devetak et al. (2009).

According to research by Sunyono et al. (2009), the study of atomic structure, which needed to be performed by involving sub-microscopic representation, due to its abstract characteristics and atomic theory or material characteristic, was the main concept in science and technology (Gkitzia *el al*., 2011). Park et al. (2009) stated that atomic theory was the main concept in science studies and was abstract, requiring a careful approach, especially when selecting a visualization strategy. Wang (2007) in his dissertation reported that the study of atomic structure, especially the position of electrons in an atom, required a specifically designed visualization model, which could assist in interpreting the phenomenon of electrons in atoms and establishing a good mental model among students.

Hilton & Nichols (2011) reported that understanding a more complex and abstract chemical phenomena, such as atomic structure could not be achieved without involving sub-microscopic and symbolic representations. Similarly, research performed by Guzel and Adadan (2013) reported that a lesson designed to develop an understanding of various representations can result in a more in-depth representational understanding regarding the structure of matter and may be retained for up to 17 months.

Researchers study a person's mental model by grouping it, based on several characteristics; Norman (cited in Barsalou, 1992) divided mental model characteristics into 2 parts, a structural and a conceptual mental model. Research in the field of education generally entailed research studying a mental model, by focusing on its conceptual aspect.

As a component of mental model research in the field of education, Wang (2007), as well as Jaber and Boujaoude (2012), classified mental mode characteristics (conceptual) into three categories. These are based on students' reply scores to questions in a mental model test: "high" mental model (if the students gave ≥ 70% right answers), "moderate" mental model (if the students gave 50% > right answers < 70%) and "low" mental model (if the students gave ≤ 50% right answers). Meanwhile, Park et al. (2009) classified mental model characteristics into 5 categories:

1. Formless or unclear initial mental model, which exists since birth and arises out of an incorrect environment or concept/description and structural drawing, which cannot be accepted scientifically, and which have no concept at all;
2. Intermediate_1 mental model - a mental model, which is almost complete in terms of concept/description near to a representation of scientific facts, but without any acceptable structural drawing or vice versa;
3. Intermediate_2 mental model - a mental model partially correct with structural drawing nearing scientific facts;
4. Intermediate_3 mental model - classified as a consensus mental model with concept/description, which is scientifically acceptable and with an accurate structural drawing;
5. Targeted mental model- a mental model with a scientifically accurate concept/description and structural drawing.

Model of SiMaYang Learning (Learning Based on Multiple Representations)

The model of *SiMaYang* learning is a multiple-representations-based science learning method, which attempts to interconnect the three levels of a chemical phenomenon (macro, sub-micro and symbolic). The SiMaYang models have been developed by Sunyono (2013) by integrating interaction factors (based on the theory by Schönborn), which affect the students' abilities to represent a science phenomenon (Schönborn and Anderson, 2009) into the learning IF-SO framework (Waldrip, 2008, and Waldrip, 2010). The main focus of the IF-SO framework is its link to key issues in the study of physics. These include lesson planning (I and F), and the role of teachers and students through electoral representation (S and O), where:

I is the identification of key concepts, F is the focus on form and function of key concepts, S is sequence (order granting the challenge of representation), and O is the On-going assessment (Waldrip, 2010). The IF-SO framework has not been translated into a sequential learning syntax, so it needs to be developed further.

Results of research conducted by Shönborn and Anderson (2009) found seven factors that determine students' ability to interpret external representations (ER) of sub-microscopic phenomena. The 3 basic concepts are the reasoning ability available to the student within their ER (Reasoning; R), a student’s conceptual knowledge (Conceptual; C); and skills to select the mode of student representation (representation modes; M). Factor M can differ, based on factors C and R, because M does not depend on human intervention during the process of interpretation. It remains constant unless modified by ER (Shönborn & Anderson, 2009), or interactions of these three factors, namely factor R–C, a conceptual knowledge of oneself on the external representation (ER), factor R–M, the reasoning of the features of ER itself and factor C–M, which is an interactive factor that affects interpretation of ER. In addition, factor C-R-M is the interaction of these three initial factors (C, R, M), representing the ability of students to involve all of these factors in order to properly interpret ER.

Taking into account the Shönborn theory, learning steps within the IF-SO framework needs to be refined to produce a learning model based on multiple representations. Development of the learning model also needs to consider constructivist theory, the theory of information processing, and dual coding theory, as a foundation for developing the syntax of the SiMaYang model.

The learning theory for constructivism forms the basis for the orientation phase. According to the constructivist theory, students learn by building on prior experience (Slavin, 2006). Thus extracting the initial experience is necessary. The constructivist theory is premised on integrating the conceptual factor (C), reasoning (R), and modes of representation (M) (Schönborn and Anderson, 2009) with domain components for the issue (i) (identification of key concepts from Waldrip, 2010). This is needed at the stage where beginning teachers are required to explore the student’s experience; noting this experience in terms of reasoning, conceptual knowledge, and modes of representation that has been owned by the student.

Constructivist learning theory, information processing, and dual coding theory, formulate an integrating factor for the interaction of C – M and the interaction of reasoning, R – C in the framework of IF-SO associated with F (focus on the form and function of representation). This integration is used in formulating the exploration phase.

According to constructivist learning theory (Howe, 1996), knowledge is developed by students in a cultural context because of interaction with peers or other external factors.

There are several aspects that need to be considered in implementing the theory of constructivism, namely:

a. The student as the centre of learning.
b. Knowledge, which is presented systematically arranged and structured so as to be easily understood by students.
c. Taking advantage of good media (Bruner, 2001).

The information processing theory by Atkinson and Shiffrin (Solso, 2008) states that human behaviour such as speaking, writing, social interaction, and so on is the cognitive processing system which involves the function of working memory to be stored in long term memory and can then be activated in the process of reasoning and remembering (Woolfolk, 2008).

Dual coding theory states that a person's received information is processed through one of two channels, namely – a verbal channel such as text and sound, and a visual channel (non-verbal image) such as diagrams, pictures and animations (Solso, 2008).

Thus, the exploration phase is designed, with activities characterized by being collaborative, cooperative, and imaginative, through various representations (verbal, visual, symbolic / mathematical, and so on), so that the processing of information can take place optimally and the information obtained can be stored in terms of memory length to be used in the process of reasoning and remembering. Furthermore, the integration of the issue of S (sequence/series representational challenges of students) by the factors of interaction, R–M and C–R–M requires imagination activities. Thus the learning model developed involving the exploration phase, followed by the imagination, and is referred to as the exploration-imagination phase.

Integration of the interaction factors, R – M and C–R–M, with the issue of O (on-going assessment), based on the constructivism learning theory and information processing theory, is used as a reference in formulating the internalization phase. In this phase, students are invited to perform discovery through imagination, presentations, and activities of individuals in building mental models. To promote this imagination stage, in accordance with the advice of Tytler (1996) when implementing constructivism learning theory, instructional design should provide an opportunity for students to express their ideas in their own language and provide an opportunity for students to think about the experience to be more creative and imaginative, so an environment of conducive learning can be realized. The final stage of learning with models of SiMaYang is the evaluation phase. This stage aims to get feedback from the acquired learning.

Based on the above description, the multiple representations-based learning model, hereinafter called the SiMaYang model (Sunyono, 2013) has four phases of learning: orientation, exploration/ imagination, internalization, and evaluation. The syntax of the SiMaYang learning model is outlined in Table 1.

RESEARCH METHODOLOGY

Research Population and Sample

The population for this research was students in the Basic Chemistry class for Mathematics and Science Education Studies at a State university in Lampung Province, Indonesia. The research population consisted of 8 classes of 2012 students (every class had 38 – 42 students).

Student samples for the research were selected randomly using a stratified random sampling technique. The samples were classified, based on the students' initial chemistry knowledge through a pre-test related to their mastery level of the atomic structure concept. Based on the initial knowledge test, students from every study program were classified as having a high, moderate and low knowledge level. Then 9 students were taken from each study program and grouped, making a total of 36 research samples per class. The sampling was performed 6 times to obtain 6 mixed classes, out of which 3 experimental classes were chosen randomly (labelled Exp_1, Exp_2, and Exp_3) and 3 controlled classes (labelled Ctrl_1, Ctrl_2, and Ctrl_3) were assigned as replicas (labelled replication_1, replication_2, and replication_3). Thus, the number of samples in the experimental class was 108 students, divided into three classes. The same number also applies to the control class.

The outcome from student sampling for every experimental and control class is described in Table 2.

Table 2 Student sample for each Experimental and Control Class

Study program	**Student's Initial Capability**						**Total**	
	High		**Moderate**		**Low**			
	Exp.	Ctrl.	Exp.	Ctrl.	Exp.	Ctrl.	Exp.	Ctrl.
Mathematics Education	3	3	3	3	3	3	9	9
Physics Education	3	3	3	3	3	3	9	9
Chemistry education	3	3	3	3	3	3	9	9
Biology Education	3	3	3	3	3	3	9	9
Total	12	12	12	12	12	12	**36**	**36**

Table 1 Teaching phases for the SiMaYang Model

Phase	Teacher Activity	Student Activity
Phase I: Orientation	1. Delivering the purpose of study. 2. Motivating with various chemistry phenomena related with the students' experiences.	1. Listening to the lecture on the purpose of the study: questions 2. Answering questions and providing responses.
Phase II: Exploration– Imagination	1. Introducing the concept of chemistry by providing several different abstractions regarding chemistry phenomena (such as transformation of substance phase, chemical transformation, etc.) verbally, or through demonstrations and visualizations such as pictures, charts or simulation and/or analogy with the involvement students in listening and question & answer. 2. Guiding the students in establishing an imaginative representation of chemical phenomena through collaboration (discussion). 3. Encouraging and facilitating student discussion panels to establish mental models to interconnect different levels of chemical phenomena by implementing chemical transformation phenomena in the students' activity sheet.	1. Listening and participating in a question & answer session with the teacher regarding the introduced chemical phenomena. 2. Browsing information on web pages/blogs and/or textbooks. 3. Working in groups to conceptualise the chemical phenomenon provided on the students' activity sheet. 4. Discussing with group mates and practicing representational imagination under the teacher's guidance.
Phase III: Internalization	1. Guiding and facilitating the students in articulating / communicating their ideas through presentation of group work. 2. Encouraging other students to comment or respond to the presented group work. 3. Giving assignments to create individual activity on articulation of their conceptual understanding. Individual practice as stated on the Student Activity Sheet (SAS) containing questions and/or instructions to interconnect the three levels of chemical phenomena and/or crossword puzzle.	1. Representative of the group takes a random order of presentation. 2. Group representative presents his/her group work results. 3. Responding or posing questions to the presenting group or during a panel discussion, moderated by the teacher. 4. Conducting individual practice using SAS.
Phase IV Evaluation	1. Reviewing the student's work result. 2. Assigning work on interconnection of three levels of chemical phenomena and providing feedback. 3. Conducting formative and summative evaluation.	Being involved in a review conducted by the teacher and making inquiries regarding future lessons.

Teaching approach

The *SiMaYang* model has syntax with 4 (four) study phases as stated in Table 1 (Sunyono, 2013). Implementation of learning in the classroom (experimental and control) are held separately. In the experimental class, the implementation of learning is done by using the SiMaYang model (learning based on multiple representation), while the control class used conventional models, namely a regular learning model commonly encouraged by basic chemistry teachers. This conventional model focuses on lectures, in-class practices, and assignments.

Research Design

The research was performed using a 2x3 factorial design (Fraenkel & Wallen, 2003) to compare the improvement of mental modelling and chemistry concept mastery between students in the experimental and controlled classes, based on the same initial capability. The mental model measured during the research is a conceptual mental model arising out of a response to questions in a test on atomic structure (especially the Rutherford, Bohr and wave mechanics atomic models).

Research Instruments

1. An atomic structure model test (ASMT), comprising 4 items complete with evaluation topic, was used as the main test instrument, adapted from the model developed by Wang (2007), and also included a written test in the form of an essay, completed with sub-micro drawings. The mental model test was used as both pre- and post-test for all classes. Each pre-test objective question consisted of 5-options derived from a National Exam and University Entry test.
2. An interview was conducted with 3 (three) chosen students representing each initial knowledge group. The interview was conducted using a self-developed interview guide by the researchers and validated by experts. The interview was performed to further evaluate the students' answers and the difficulties arising out of trying to solve the problems posed.

Data Analysis

Analysis was performed through descriptive and quantitative means. Quantitative analysis involves inferential analysis using a statistical test. Data of mental models were determined based on the N-Gain scores $\langle g \rangle$ achieved by students, namely the difference between the average score of post-test and pre-test. Score ⟨g⟩ was calculated using the formula proposed by Hake (2002):

$$\langle g \rangle = \frac{\%\ actual\ gain}{\%\ potential\ gain} x100 = \frac{\%\ skor\ postes - \%\ skor\ pretes}{100 - \%\ skor\ pretes}$$

Criteria of ⟨g⟩ score is (1) the course with <g> score of "high," if ⟨g⟩ > 0.7; (2) the course with ⟨g⟩ score of "moderate," if ⟨g⟩ lies between 0.3 < ⟨g⟩ ≤ 0.7; and (3) the course with ⟨g⟩ score of "low," if ⟨g⟩ ≤ 0.3 (Hake, 2002).

Statistical analysis used variants analysis (ANOVA) and advanced test with t-test on the margin between two independent samples with significant level ($\alpha = .05$). The statistics were calculated with the aid of SPSS v. 17.0 program.

Descriptive analysis was performed through transcription and categorization in order to identify the students' mental model and difficulties commonly occurring when facing an external representation at the sub-microscopic level, especially in solving problems regarding the atomic model concept. Classifying the appearance of a mental model in the students' test answers was performed through the assignment of scores. The scoring technique was undertaken in two ways: evaluating the students' test answers and determining the problem solution achievement level, which was then classified into the following mental model categories: "very bad" (score = 1), "bad" (score = 2), "moderate" (score = 3), "good" (score = 4) and "very good" (score = 5). Based on the scoring and categorization, the students' mental model was classified at 5 levels (Park, et al., 2009): unclear, intermediate 1, intermediate 2, intermediate 3 and targeted mental model.

RESEARCH FINDINGS

a. Pre-test, post-test, and N-Gain Model Mental Mean Score

The result shows that the mean pre-test scores for the experimental class are relatively similar to the mean per-test scores for the controlled class among students with high, moderate and low capability. The mean post-test score for the experimental class was higher than the score from the control class (Table 3).

Differences in mental model achievement between the experimental class (*SiMaYang* study) and the control class (conventional study) are shown in Table 4, giving the distribution of students capable of achieving a mental model within a category ⟨g⟩ score.

Table 3 Pre-test, post-test, and N-gain scores of students' mental model of atomic structure topic

ICS	n	Stat	SiMaYang									Conventional								
			Exp_1			Exp_2			Exp_3			Ctrl_1			Ctrl_2			Ctrl_3		
			Pre	Post	N-g	Pre	Post	N-g	Pre	Post	N-g	Pre	Post	N-g	Pre	Post	N-g	Pre	Post	N-g
High	12	χ	12.3	74.4	0.64	32.2	68.6	0.54	32.5	68.9	0.54	27.8	48.9	0.29	30.6	46.7	0.23	30.3	50.0	0.28
		SD	6.36	12.3	0.16	5.92	15.9	0.20	8.30	13.0	0.17	7.15	12.9	0.16	4.89	10.9	0.16	9.15	11.8	0.15
Moderate	12	χ	29.7	70.8	0.59	27.5	68.9	0.57	30.3	69.2	0.57	29.2	48.9	0.28	26.9	43.1	0.22	28.6	43.3	0.20
		SD	5.59	10.7	0.14	7.12	9.67	0.12	6.11	14.6	0.19	6.38	13.8	0.16	5.02	12.3	0.17	8.81	11.0	0.16
Low	12	χ	29.7	68.9	0.56	30.6	63.1	0.47	28.1	66.7	0.54	28.6	48.9	0.28	24.4	37.2	0.17	26.7	50.0	0.32
		SD	7.97	13.7	0.17	6.64	12.6	0.16	6.43	12.8	0.17	5.77	14.4	0.20	2.96	10.0	0.13	5.50	13.4	0.18
Total	36	χ	23.9	71.4	0.60	30.1	66.9	0.53	30.3	68.2	0.55	28.5	48.9	0.28	27.3	42.3	0.21	28.5	47.8	0.27
		SD	6.52	12.2	0.16	7.07	22.8	0.19	7.05	13.2	0.17	6.30	13.3	0.17	4.96	11.5	0.15	7.91	12.2	0.16

Notes: ICS = Initial Capability of Student ; n = number of students ; Stat = Statistical calculation ; Pre = Pre-test ; Post = Post-test
N-g = score of ⟨g⟩

Table 4 Percentage of Students in the experimental and control Groups with Category of the average of ⟨g⟩ Score related to a Mental Model of Atomic Structure

Category of ⟨g⟩ Score	Replication 1		Replication 2		Replication 3	
	Exp_1	Ctrl_1	Exp_2	Ctrl_2	Exp_3	Ctrl_3
⟨g⟩-High	22.22	0.00	16.67	0.00	22.22	0.00
⟨g⟩-Moderate	72.22	63.89	75.00	33.33	69.44	38.89
⟨g⟩-Low	5.56	36.11	8.33	66.67	8.33	61.11

In order to identify the level of trust in the existence of different mental models among the students, an analysis was performed on the effect of students' initial capability and learning model on the mental model. The analysis on such an effect was performed using ANOVA-two paths statistical analysis with a significant level of .05. The hypotheses tested were as follows:

H_{01} : learning model doesn't affect the mental model.
H_{11} : learning model affects the mental model.

H_{02} : student's initial capability doesn't affect the mental model.
H_{12} : student's initial capability affects the mental model.

H_{03} : no significant interaction between the learning model and the student's initial capability to achieve mental model.
H_{13} : significant interaction between the learning model and the student's initial capability to achieve mental model.

Table 5 Results of ANOVA-Two Paths to Effect of Different Learning Models and Initial Capability on the Student's Atomic Structure Mental Model

		Source	Statistic	
			F	P
Replication	1	Effect of Different Learning Mod (SIM vs Conv): LM	60.78	0.000
		Effect of Student's Initial Capability (IC)	0.439	0.646
		Interaction (LM*IC)	0.243	0.785
	2	Effect of Different Learning Mod (SIM vs Conv): LM	71.76	0.000
		Effect of Student's Initial Capability (IC)	1.639	0.203
		Interaction (LM*IC)	0.152	0.860
	3	Effect of Different Learning Mod (SIM vs Conv): LM	50.82	0.000
		Effect of Student's Initial Capability (IC)	0.432	0.651
		Interaction (LM*IC)	1.170	0.317

Note: SIM = Experimental Class) ; Conv = Control Class) ; F_{table} = 3,132

Based on the result of ANOVA-two paths analysis, the learning model effect was as follows: $p < 0.05$ and ($F_{hit} > F_{table}$), which means that H_{01} is rejected. For student's initial capability and interaction, $p > 0.05$ and $F_{hit} < F_{table}$ which means that H_{02} and H_{03} are accepted. The conclusion from the analysis results are:

- Differences in learning model in the experimental and control classes significantly affect the students' mental model for atomic structure concepts.
- Differences in the students' initial capability do not affect their mental model for atomic structure concepts.
- There are no differences in interaction between the students' initial capability and their learning method in achieving the students' mental model for atomic structure concepts.

The result of such analysis shows that the factors of initial capability and learning method are independent of one another in affecting the mental model for atomic structure concepts. This result also shows that the interaction effect requires no further testing.

Based on the result of ANOVA-two paths, a t-test analysis was carried out on <g> mean scores for the experimental and control groups using the SPSS v. 17.0 program. The hypotheses tested are:

H_0 : No differences in the students' mental model <g> mean score between those who studied with *SiMaYang* model and those who studied with conventional model from the same initial capability.

H_1 : Difference in the students' mental model <g> mean score between those who studied with *SiMaYang* model and those who studied with conventional model from the same initial capability.

The results of the t-test analysis of the average score of <g> student mental models are shown in Table 6. It is seen that the average achievement scores <g> of mental models of students in all groups for students' initial capability that the value is $p < 0.05$ and $t_{-hit} > t_{-table}$ (1.796), so that H_0 is rejected (which means that H_1 is accepted).

The results of the t-test analysis (Table 6) suggests that there are differences in the average of the <g> score of mental models between classes of student taught using the SiMaYang model and classes of student taught using the conventional model at the same student initial capability level. Therefore, it can be said that learning by using the SiMaYang model can generate student mental models better than learning by using conventional model for each group of students' considering their initial capability.

Table 6 Results of t-Test Analysis on the Average Score of <g> students' Mental Models to the concept of Atomic Structure

	Students' Initial Capability	Average of <g> scores		Statistic Test	
		SiMaYang	Conventional	t	p
Replication-1	High	0.64	0.29	5.172	0.000
	Moderate	0.59	0.28	4.720	0.001
	Low	0.56	0.28	3.331	0.007
Replication-2	High	0.54	0.23	5.873	0.000
	Moderate	0.57	0.22	6.618	0.000
	Low	0.47	0.17	5.338	0.000
Replication-3	High	0.54	0.28	3.549	0.005
	Moderate	0.57	0.20	6.055	0.000
	Low	0.54	0.32	3.994	0.003

b. Descriptive Analysis of the Students' Mental Model on Atomic Structure

Table 7 shows the percentage of students who were able to achieve an atomic structure mental model in a certain category, before and after their studies in the experimental and control classes.

The results from analysis of students' answer to questions ASMT_1 to ASMT_4, after the *SiMaYang* learning model is implemented, show that more than 44% students were able to achieve a mental models rank of "good" or "intermediate 3" and "very good" or "targeted", whereas in the conventional learning class the majority of students (>50%) were only able to achieve a mental models of "bad" or "intermediate-1" and "mediocre" or "intermediate 2."

DISCUSSION AND CONCLUSION

The result of statistical analysis shows that there are significant differences in mental model N-gain mean scores between students who learned using the *SiMaYang* method and those who learned using a conventional method of similar initial abilities. Such result indicates that the *SiMaYang* learning method is more effective in constructing the students' mental model compared with the conventional method. Based on their initial capability, the result of the statistical analysis shows that the students' initial capability does not affect their mental model achievement, as shown with relatively similar mental model N-Gain mean score for students with high, moderate and low initial capability for replication 1, replication 2 and replication 3.

The result of this research shows that the capability to create interconnection between the chemical phenomenon of students with high,

Table 7 Percentage of Students with Mental Model (MM) on Atomic Structure in every test Item (ASMT).

ASMT	Category of MM	Percentage of Students											
		Replication 1				Replication 2				Replication 3			
		SiMaYang		Conv		*SiMaYang*		Conv		*SiMaYang*		Conv	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
	Very Good	0.00	27.78	0.00	5.56	0.00	25.00	0.00	0.00	0.00	16.67	0.00	0.00
	Good	8.33	47.22	16.67	27.78	2.78	19.44	8.33	13.89	8.33	50.00	5.56	25.00
1	Moderate	16.67	11.11	19.44	11.11	30.56	30.56	5.56	13.89	16.67	19.44	11.11	16.67
	Bad	41.67	13.89	22.22	27.78	36.11	22.22	36.11	50.00	36.11	11.11	36.11	38.89
	Very Bad	33.33	0.00	41.67	27.78	30.56	2.78	50.00	22.22	38.89	2.78	47.22	19.44
	Very Good	0.00	2.78	0.00	0.00	0.00	16.67	0.00	8.33	8.33	11.11	2.78*	2.78
	Good	8.33	69.44	19.44	47.22	16.67	47.22	2.78	13.89	2.78	58.33	0.00	44.44
2	Moderate	30.56	22.22	2.78	22.22	19.44	27.78	13.89	30.56	30.56	22.22	22.22	36.11
	Bad	8.33	0.00	8.33	2.78	8.33	0.00	5.56	13.89	5.56	5.56	11.11	5.56
	Very Bad	52.78	5.56	69.44	27.78	55.56	8.33	77.78	33.33	52.78	2.78	63.89	11.11
	Very Good	0.00	0.00	0.00	0.00	0.00	2.78	0.00	0.00	0.00	5.56	0.00	0.00
	Good	0.00	19.44	0.00	19.44	0.00	19.44	0.00	2.78	0.00	16.67	0.00	8.33
3	Moderate	0.00	72.22	0.00	41.67	0.00	38.89	0.00	5.56	0.00	36.11	0.00	8.33
	Bad	2.78	5.56	0.00	19.44	2.78	36.11	0.00	27.78	5.56	33.33	2.78	38.89
	Very Bad	97.22	2.78	100.00	19.44	97.22	2.78	100.00	63.89	94.44	8.33	97.22	44.44
	Very Good	0.00	19.44	0.00	2.78	0.00	11.11	0.00	2.78	0.00	13.89	0.00	2.78
	Good	0.00	30.56	0.00	5.56	0.00	25.00	0.00	11.11	0.00	16.67	0.00	22.22
4	Moderate	0.00	2.78	0.00	5.56	0.00	16.67	0.00	5.56	0.00	33.33	0.00	0.00
	Bad	13.89	44.44	8.33	63.89	5.56	36.11	8.33	41.67	5.56	25.00	11.11	41.67
	Very Bad	86.11	2.78	91.67	22.22	94.44	11.11	91.67	38.89	94.44	11.11	88.89	33.33

moderate and low initial capability is similar, which means that ultimately they have the same understanding and reasoning of chemical representation at macro, sub-micro and symbolic levels. These findings are in alignment with the research conducted by Devetak and Glažar (2010) who reported the lack of statistical differences between students of different initial capabilities when solving a problem by reading and/or drawing sub-microscopic representation phenomena. The ability to read and draw the sub-micro representation phenomena is related with one's reasoning abilities, as expressed as a mental model. Furthermore, Devetak and Glažar (2010) report significant correlation between the students' chemistry knowledge and reasoning and the mental model in reading sub-microscopic drawing. Mumford et al. (2012) report that a person's mental model is more about the concept of critical causality to produce a high quality, original and creative solution to a problem. Cook (2011) further reports that course content, student characteristics, and resource availability affect how teachers use visual representations in science courses.

The students' comprehension level of all three chemical representations, as a result of reasoning and interpretation of the representation of phenomena, is expressed in various forms such as charts, visual drawings, mathematical calculations and verbal explanations. The forms expressed in this research are identified as mental model in accordance with the statements of several experts that the forms expressing models as responses to an external representation are verbal explanations, diagrams, visual drawings, symbols or mathematical calculations (Horison & Treagust, 2000; Coll & Treagust, 2003). Several other researchers, such as Park (2006), interpreted the students' answers to mental model questions as the ability to reason, explain and interpret, later identified as a mental model. Wang (2007) states that the students' ability to accurately interpret and explain the external representation phenomenon at hand is identified as a mental model in the "high" or "targeted" category.

Descriptive analysis of the students' mental model for atomic structure shows that the majority of students from the *SiMaYang* learning method class were able to interpret the sub-micro and the macro-sub-micro-symbolic transformation phenomena through various presentations (verbal, visual and symbolic), as shown by their answers to questions ASMT_1, ASMT_2, ASMT_3, and ASMT_4.

The result of the analysis show that the atomic structure mental model by students who learned using the *SiMaYang* model is better than those who learned using conventional method, as shown by the differences in the number of students who could achieve a certain level of mental model (Tables 4, 5 and 6).

Analysis of the students' answers to question ASMT_1 shows that after learning with the *SiMaYang* model, the students were able to transform the macroscopic phenomenon (Thomson, Goldstein, Chadwick and Rutherford experiments) to sub-microscopic and symbolic phenomenon by imagining the particle structure in an atom, and then creating a sub-micro image of parts of an atom, as well as the position of electrons, proton and neutron in an atom, based on a visual drawing. In the conventional class, the students appeared to be able to create sub-micro drawings of atomic structures in the forms of symbols, but had difficulties interpreting the drawings verbally. This indicated that the students preferred working with symbols and visuals rather than merely text, as is common in conventional learning. Interviews with three students also indicated that they preferred simple visualization as opposed to text-only lessons, aligned with the result of previous research indicating students preferred the use of visuals in addition to verbal lessons and that the use of visuals in class might improve their motivation and results (Stokes, 2002; Sanky, 2005; Chittleborough, 2004).

Analysis of students' reply to the ASMT-2 question also shows that by using the *SiMaYang* learning model, students were able to transform macroscopic (Bohr atomic model phenomenon) to sub-microscopic and symbolic levels, by imagining the phenomenon described in the verbal question ASMT_2, and then by creating a Bohr atom model drawing for certain atoms, based on the result of the students' imagination. This result showed that the majority of students were able to interpret the sub-micro phenomenon into visual drawing for the Bohr atom model for fluorine and sodium atoms. This is aligned with the reports made by Wang and Barrow (2013), which stated that the students who learned sub-micro and symbolic representations had a higher conceptual knowledge and were able to describe the Bohr atom model in more detail compared to those who did not learn the sub-micro feature. Meanwhile, those who learned in conventional classes still found difficulties in transforming verbal representation into visual Bohr atom models (Question ASMT_2), because they had less imagination and practice throughout the class.

Similar to ASMT_1, analysis of question ASMT_2 shows that students from the conventional class are able to interpret and transform a phenomenon, but there are mistakes in their comprehension in drawing a fluorine and sodium atom model. The answers students give from conventional class are mixed for the quantum model, despite the question specifically seeking the electronic configuration for the Bohr model. Due to misinterpretations, the students' answers to question ASMT_2 result in a "bad" and "very bad" mental model category. Students via the conventional method are never taught to distinguish between the Bohr and Quantum model. This aligns with the result of research by Wang & Barrow (2013) indicating a learning method which did not integrate sub-micro and symbolic representations, results in the students having difficulties drawing and explaining the Bohr atom model in detail (and accuracy). The result of the interview also indicate that the students show difficulties due to the abstract atomic model at the sub-microscopic level, and the ability of their imagination to understand the representation of sub-microscopic phenomena is not covered in the classroom. This aligns with research reported by Suits and Hypolite (2004) indicating students who never learn using an atomic model visual representation approach encounter difficulties in understanding the Bohr atomic model and quantum mechanics, possibly due to the abstract nature of the atomic model representation. Guzel and Adadan (2013) report that a learning method designed with comprehensive representation instruction may result in a more in-depth comprehensive of chemical representation, which can be retained for up to 17 months. The same analysis result is also found with the students' answer to Question ASMT_3. Question ASMT_3 is related with the visual statement, where students are asked to conduct transformation from verbal to visual and symbolic representations or vice versa regarding the orbit of electrons according to Bohr, and then create a visual drawing through an energy level chart. As a result, the majority of students from the *SiMaYang* class are able to answer Question ASMT_3 quite well. This means that they are able to transform sub-micro phenomena to symbolic or vice versa, or transform from verbal to visual forms and vice versa, regarding the orbit of electrons according to Bohr and its energy level chart.

In the conventional class, the majority of students (>80.00%) experienced difficulties in transforming (Table 7). Students from the conventional class were unable to create decent drawings for the orbit of electrons according to the Bohr model and the corresponding energy level. These difficulties were caused by their lack of experience in interpreting the orbit of electrons according to Bohr and the corresponding energy. The result was consistent with the studies by Park & Light (2009), who stated that the students encounter difficulties with abstract concept due to their daily learning experiences. Furthermore, according to Park, et al. (2009), the theory of the atom was the main concept in science, and atomic theory education using atom models needed to be subject to scrutiny and careful approach in selecting the best strategy to improve the students' mental model from "intermediate 1" or "bad" to "intermediate 3" and "targeted" category. Wang and Barrow (2013) reported that students with moderate and low mental model had great difficulties in creating the visual representation of electrons in an atom and the energy transition. Wang (2007) in his dissertation reported that students with high, mediocre and low mental model score encountered difficulties in visualizing electrons in an atom.

The result of the mental mode analysis, as a response to question ASMT_4, showed that the improvement in students' mental model scoring, as answer to Question ASMT_4, was quite high. This question was related with the correlation between energy level and the electron configuration of an atom, in which students were asked to transform verbal representation to visual (sub-micro) and symbolic form and vice versa regarding electron configuration, based on the energy level chart of an atom and the four quantum numbers, followed by visual drawing of the energy level of each orbital filled with electron.

Differences in mental models between students from the *SiMaYang* class and conventional class might be caused by the different nature of learning. The *SiMaYang* learning method was attractive and the students were encouraged to use visualization (static and dynamic), presented by the teacher, or self-accessed by the students on webpage/weblog. Visualization of the movement of electrons in an atom, electron transition from one orbit to another, as well as spectroscopic phenomenon were more attractive to students, as shown by their positive response to the learning activities. Students felt that it was easier to understand the phenomena at the sub-microscopic level if the learning involved visualization of the abstract atomic model. The information was derived from the students' statements during the interview. On the contrary, in the conventional class, students had difficulties understanding the electron phenomenon through verbal learning, and therefore their mental model was not well established.

The result of this research was also in accordance with reports by Suits & Hypolite (2004) indicating the atomic model learning method designed to assist the students through visualization and animation of abstract sub-micro phenomena, produced a higher understanding of a meaningful atomic model. Hilton & Nichols (2011) reported that the understanding of a more complex and abstract phenomenon could never be achieved without using various representations to integrate sub-microscopic and symbolic phenomena. Park (2006) stated that a low mental model was caused by poor understanding and reasoning of atomic structure, which might be improved by making use of a sub-micro visualization model.

Mental model theories have stated that the students' mental model was an internal representation built from experience, interpretation and explanations of previously accepted concepts, implemented into the students' comprehension of sub-microscopic external representation phenomenon (Canas, 2001., Treagust *et al., 2003;* Park *et al.*, 2009; Wang & Barrow, 2013; and Laird, 2013). Other statements made by Norman (in Barsalou, 1992) include "*people form mental models through experience, training and instruction.*"

Based on the above theories, we conclude that the *SiMaYang* learning method may provide experience and skills to the students in interpreting, providing conceptual explanation and interconnecting three levels of chemical phenomena to establish mental model of "good" and "very good" categories. When connected with Park et al.'s mental model classifications (2009), the mental models established through the *SiMaYang* learning method in this research are laregly "intermediate 3" and "targeted" mental models

Based on the result of researches, we can conclude that

1. the *SiMaYang* learning model is more effective in constructing the students' mental model in understanding the concept of atomic structure compared with the conventional learning model;
2. the *SiMaYang* learning model is suitable for lessons in classes where the students have low capability level in order to keep up with those who have medium and high capability level;
3. the students' mental model characteristics which can be established / nurtured in the *SiMaYang* learning model for all levels of initial capability are those with "good" or "intermediate 3" mental model characteristics and those with "very good" or "targeted" mental models.

The result of this research indicates that the learning method which integrates all three phenomena (macro, sub-micro and symbolic) in chemistry education becomes very important in improving the students' reasoning abilities. Chemical learning which only emphasizes macro and sub-micro phenomena through verbal instruction result in low level of reasoning. However, a learning method which involves macro, sub micro and symbolic phenomenon using the *SiMaYang* model may improve the mental model and overall effectiveness of atomic structure learning. The *SiMaYang* learning method can be used as an alternative in class lessons in order for the students with initially low capability to keep up with those of medium and high capability in constructing their mental model. In this case, the elements of its method such as collaboration, cooperation and imagination can be implemented throughout the chemistry course in order to establish a mental model and improve the students' reasoning abilities.

SUGGESTIONS AND RECOMMENDATIONS

1. The information regarding mental model can be used as a basis to determine the next learning strategy to establish a meaningful concept comprehension. Establishing a meaningful concept comprehension requires the development of mental model and learning packaging in order to produce systematic reasoning skills.
2. A learning model capable of developing the students' mental model to "good" and "very good" involves the integration of three levels of chemical phenomena: macro, sub-micro and symbolic through collaborative, cooperative and imaginative strategy.

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