Improving chemistry teacher candidates’ mental models in the kinetics course using SiMaYang type II learning

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Abstract. This study aims to investigate the profile of chemistry teacher candidates’ mental models in the kinetics course and improve it using SiMayang Type II learning. The subject of this study was a class of chemistry education students at UIN Walisongo Semarang who had taken kinetics course. Sample was carried out using convenience sampling technique. This study used a descriptive design and pre-experimental one group pretest-posttest design. The results of investigation showed that before being given treatment using SiMayang Type II learning, mental models of students were dominated by initial mental models with a percentage of 55.53% while the rest were synthetic one. After being treated, it was found that there were reduction in the number of initial mental models by 18.03% and synthetic mental model by 4.47%. Meanwhile the scientific mental model increased by 22.50%. The results of statistical tests showed that the learning of SiMayang Type II is effective in improving students’ mental models of chemistry teacher candidates. Learning outcomes have increased with the moderate category based on the N-gain test.

1. Introduction
Chemistry is a natural science that explains the properties, structure, and changes in substances, as well as the principles, concepts, theories, and laws that support these changes (Effendy, 2008). The characteristics of material contained in chemistry are complex and abstract (Treagust and Chittleborough, 2001). Abstract chemical concepts can be seen from the concepts that discuss atoms, ions, molecules, orbitals, chemical bonds, protons, electrons, and others. Beside that, Kean and Middlecamp (1984) stated that chemistry has several characteristics, such as (1) chemistry is a simplification of the real condition, (2) chemistry concepts are sequential and develop rapidly, and (3) chemistry is not only just solving problems.

According to Yuanita and Ibrahim (2015), chemistry basically involves three types of representation levels, i.e. macroscopic, submicroscopic, and symbolic. Macroscopic representations describe the nature of phenomena that can be observed directly in the surrounding. Submicroscopic representations are representation of phenomena at deeper/micro level. Symbolic representations are explanations which involving chemical symbols and formulas.

In understanding chemistry, a deep and comprehensive understanding of chemical concepts is needed. This understanding is determined by the ability of students to transfer and connect between macroscopic, submicroscopic and symbolic phenomena. However, Li and Arshad's (2014) research shows that students are not able to integrate observational (macroscopic) activities with symbolic and
submicroscopic phenomena due to their inability to visualize particles. This makes students feel bored, frustrated, and the chemistry learning activity ends with remembering facts’ activities. Dori and Homeiri (2003) explain that learning activities by memorization are barrier to the creation of meaningful learning.

Chemical concepts and phenomena that are considered abstract can be understood using a model (Halim et al., 2013). The model can link theory with real systems, making it easier for students to understand abstract concept. The model is an important tool used to help unseen and untouched something be more-realistics (Pringle in Polat-yaseen, 2012). Every single student has their own model in describing or understanding a phenomenon. This model is often known as a mental model. Mental model is a cognitive representation of a person in learning, understanding, and remembering a phenomenon or information. Laird in his research argues that the mental model is a reasoning mechanism found in the working memory (Jones et al., 2011). The concept of chemistry depends on chemical representation and its contribution to the development of mental models. The three levels of chemical representation connect and reflect the mental models of students. It’s built through experience, interpretation, and explanation when students learn chemistry. Mental models are needed by students to predict, test new ideas and solve problems while studying chemistry (Bodner and Domin, 2000).

According to Franco and Colinvaux (as cited in Wang, 2007), mental models have 4 characteristics. First, mental models are generative, it can connect students to new information, so they can use the information to predict and explain things. Second, mental models involve hidden knowledge, students can explain with their mental models to solve problems or consider new information, but are not aware of the mental models they have and how to use them. Third, mental models are synthetic (artificial), they are dynamic and continuous but can be modified if there is new information entered or related to the previous mental model. Fourth, mental models are limited by world-views, influenced by initial knowledge, experience, and mastery concepts.

Mental models have several functions. Vosniadou and Brewer (1992) mention 3 functions of mental models, namely as scaffold in explaining theoretical construction, as a mediator in explaining information that is new as well as in learning, and as scaffold in research and theory revision.

The three chemical representations (macroscopic, submicroscopic and symbolic levels) are interconnected (interconnected) with each other (Johnstone, 1991; Treagust, Chittleborough, and Mamila, 2003). The basis of the representation is the macroscopic level then followed by the microscopic and symbolic levels to explain the processes that occur at the macroscopic level. Detevak (in Halim et al., 2013) builds Interdependence on the Three Levels of Science Concepts (TLSC) to explain the connections between the three levels of chemical representation by integrating mental models as factors that induce knowledge into long term memory. Interdependence of Three Levels of Science Concepts (TLSC) is shown in Figure 1.

![Figure 1. Interdependence of three levels of science concepts (TLSC)](image)

Generally, from the three levels of representation that are considered difficult are understanding symbolic and sub-microscopic levels. This is caused by cognitive limitations so students’ mental models are still simple. Based on research conducted by Sunyono et al. in Yuanita & Ibrahim (2015) it is known that the mental models of students still tend to be at the level of macroscopic representation.
because it can be understood through direct observation. This is reinforced by the research of Handayanti, Setiabudi, & Nahadi (2015) on the reaction rate concept, which states that students' understanding at submicroscopic level is lower than the other representation levels. In the macroscopic level, students do not experience difficulties because something that is observed is not abstract.

Generally, the chemistry learning only emphasizes on macroscopic and symbolic representations, while the submicroscopic level is studied separately from the other two levels (Farida, 2010). Furthermore, Farida (2010) states that students' activities tend to solve mathematical problems without deep understanding. Learning chemistry which only focuses on algorithmic understanding, will produce superficial understanding. Halim et al., (2013) states that the difficulty of students in connecting three levels of representation causes students tend to have an unscientific mental model.

On of chemical concept that studied by chemistry teachers’ candidates is kinetics. In the kinetic material, they learn about the reactions associated with the calculation of the reaction order (symbolic aspects). Students also observe natural phenomena which are examples of reactions at different rates (macroscopic aspects). In addition, they learn the molecular level that describe changes in the concentration of reactants into products in partuculate phenomena (submicroscopic aspects). Thus to understand it well, they should understand the three levels of representation and be able to connect them so that knowledge and mental models are intact.

However, from observations it is known that 33% of chemistry teachers’ candidates at State Islamic University stated the kinetics concept was difficult. It’s because educators have not involved all three levels of representation in learning process. Though this material must be taken and mastered by them to become provision as chemistry teachers’ candidates.

Efforts to improve the representation ability of chemistry teachers’ candidates can be done by applying appropriate learning models to develop the representation ability and mental models of students (Suryani, Sunyono, and Efkar, 2015.) Learning models that can develop mental models that are packaged by involving three levels of chemical phenomena, so it gives impact on increasing mastery of students' chemical concepts (Sunyono, Yuanita, and Ibrahim, 2011). This is supported by research by Sunyono, Yuanita, and Ibrahim (2015) which confirms that learning by using multiple representations is more effective in constructing students' mental models of atomic structure concepts compared to conventional learning.

One of the multilevel representation based learning models is the SiMaYang Type II. It has a syntax consisting of the orientation phase, the exploration-imagination phase, the internalization phase, and the evaluation phase (Sunyono, 2012). These phases have characteristics of collaborative, cooperative and imaginative. Through the application of this learning model students are expected to be able to understand chemical concepts that are complex and abstract by linking multilevel representations. Students will be taught skills in building mental models through optimizing the ability of imagination (Sunyono, 2014). Thus, the SiMaYang Type II learning model can be used to improve the mental model on kinetics.

2. Methodology
This research used descriptive and pre-experimental designs. Descriptive design is used to reveal the profile of mental models of the chemistry teachers’ candidates on the kinetics course. The result of investigation is used as basis for reference in implementing learning strategy. The pre-experimental research design was one group pretest-posttest design. It is a continuation of the first step by making learning improvements using the SiMaYang Type II learning model. An overview of the pre-experimental research designs can be seen in Table 1.

| Table 1. Pre-experimental research designs |
|-------------------------------------------|
| Research Class | Pretest | Treatment | Posttest |
|----------------|---------|-----------|---------|
| Experiment     | T₁      | X         | T₂      |

3
The sample in this study was a class of chemistry education students at State Islamic University who had obtained kinetics. It were selected using convenience sampling technique. This research involves two kinds of variables, i.e independent and dependent. The independent variable in this study is the learning model, in this case SiMaYang Type II while the dependent variable is the mental model of chemistry teachers’ candidates.

This study uses treatment and data collection instruments. The treatment instruments includes SiMaYang Type II learning scenario, learning module, and Worksheet. Written test is used to determine the student's mental model. Before they were used, instrument quality test is first performed. The quality test are test of validity and reliability. This research using descriptive and statistical analysis. Descriptive analysis is carried out to parse the mental model.

Student answer patterns were analized by looking the tendency of understanding levels of the description (Kurnaz and Eksi, 2015; Supriyadi, 2016). Grouping is done by giving a score of 0-4. Students who give a complete description and in accordance with scientific concepts, get 4 and are included in the Sound Understanding (SU) group. Students who provide descriptions / explanations in accordance with scientific concepts but are not whole / partial will get a grade of 3 and are grouped into the Partial Understanding (PU) group. Students who provide answers that are understandable but contain alternative concepts are given 2 and put into the Partial Understanding with Alternative Conception (PU-AC) group. Students who give answers that do not fit scientific concepts, are illogical and incorrect are given score of 1 and are included in the Alternative Conception (AC) group. Students who did not describe, did not finish describing, and the answers given were not relevant to the question, were given score of 0 and grouped into the Not Understanding (NU). In summary, the assessment rubric for student description results based on the level of understanding is described in Table 2.

| Level of understanding                        | score | criteria                                              |
|-----------------------------------------------|-------|-------------------------------------------------------|
| Sound Understanding (SU)                      | 4     | All of descriptions are scientific                     |
| Partial Understanding (PU)                    | 3     | Partial descriptions are scientific                    |
| Partial Understanding with Alternative Conception (PU-AC) | 2     | The description are understandable but having misconceptions |
| Alternative Conception (AC)                   | 1     | The description didn’t fit with scientific concept, illogical and didn’t correct |
| No Understanding (NU)                         | 0     | did not describe, did not finish describing, and the answers given were not relevant to the question |

Types of mental models are divided into three category, i.e scientific, synthetic, and initial mental models (Vosniadou and Brewer, 1992; Kurnaz and Eksi, 2015, Supriyadi, 2016).

| Mental model         | Content                                      | Level of understanding each score |
|----------------------|----------------------------------------------|-----------------------------------|
| Scientific           | Scientific concept with answer that grouped in PU and SU | 4                                 |
| Synthetic            | Perception that partially scientific          | 3                                 |
| Initial              | Unscientifi perception with answer that grouped in NU, AC, and PU-AC | All are included |
|                      |                                              | 0                                 |
|                      |                                              | 1                                 |
|                      |                                              | 2                                 |

The classification of mental model types is adjusted to the rubric in Table 3 (Kurnaz and Eksi, 2015). Students are classified to scientific mental model if the answers indicate a description of Sound Understanding (SU) or Partial Understanding (PU). Students are grouped into initial mental model if the answers given only revolve around the description of Partial Understanding with Alternatives Conception (PU-AC) or Alternative Conception (PU-AC) or Not Understanding (NU). Furthermore, if the students' answers vary from Sound Understanding (SU), Partial Understanding (PU), Partial...
Understanding with Alternative Conception (PU-AC), Alternative Conception (PU-AC) to Not Understanding (NU), student grouped into synthetic mental model.

The prerequisite test used in this study is the normality test using SPSS 16 for Windows. This test is used to determine whether the data is normally distributed or not. Hypothesis testing is used to test the effectiveness of the Type II SiMaYang learning model in improving student mental models on kinetics courses. This hypothesis test uses paired sample t-test using SPSS 16 for Windows. The SiMaYang Type II learning model is effective in improving students' mental models if there is a significant difference between the pretest and posttest scores. The N-gain test is used to find out how much influence the X variable has on the Y variable.

3. Results and Discussion

![Graph showing percentages of understanding categories]

**Figure 2.** Chemistry teacher candidates' understanding

Mental model diagnostic test include 4 topics on chemical kinetics, i.e determining the concentrations of products and reactants in a single reactant with various reaction orders, determination of reactant concentrations for sequence 1 reactions with more than one stoichiometric reactant, consecutive reactions, and determining the reaction mechanism from the equation of the law of reaction rates. Student answers from mental model diagnostic tests were analyzed and grouped into various student mental models (Fauziah, 2014). Diagrams of student understanding on kinetics can be seen in Figure 2.

Based on Figure 2, it is known that the majority of students' understanding is categorized as Not Understanding (NU) with the percentage of 34%. This shows that most students are unable to describe or are not finished describing and the answers given are not relevant to the question. Besides that the second highest level of understanding is Alternative conception (AC) with a percentage of 28%. This indicates that some students have alternative concepts on kinetics. From this level of understanding, then the type of mental model is determined. The diagram of chemistry teacher candidates' mental models can be seen in Figure 3.
Figure 3. Chemistry teacher candidates' mental models

Based on Figure 3 it is known that none of the students developed scientific mental model. Most students have initial mental model, which is 56%. This indicates that many students develop non-scientific understanding. The rest, students develop synthetic mental models. The existence of this synthetic mental model indicates that in the four topics tested, students develop incomplete understanding where some of the understanding is in accordance with scientific understanding but misconceptions are still being found.

Figure 4. The decay of C-14 carbon atom

In the first concept, determining the order of reaction using the integrated rate law, students are given a discourse about the use of carbon 14 (C-14) as a radioactive carbon isotope. The discourse explains that the C-14 atom is produced in the upper atmosphere by cosmic radiation. To determine the age of the skeleton found by archeologists radioactive tracing is usually done using the C-14 isotope. The carbon decays into nitrogen and electrons. Students are then asked to understand the submicroscopic representation of the decay of C-14 atoms at t = 1, 2, and 3 minutes with the picture presented as Figure 4. The questions given require students to understand the reasons for the use of the radioactive substance, the reaction order, graphs of the relationship between mass and time, half-life, depiction of the number of atoms every few minutes, and the time required by the radioactive substance to undergo decomposition (in seconds). The results of the pretest show that all students develop synthetic mental models, in which all students have an understanding that is partly incompatible with scientific understanding. For example, in Figure 5 it can be seen that respondent A8 is unable to provide a relationship between the mass of decaying substances with respect to time.
Figure 5. Chemistry teacher candidates’ answer of relationship between the mass of decaying substances with respect to time

The answer shows that respondent A8 has an understanding that the more time decreases the reactant mass will increase. This understanding is contrary to scientific understanding where it is supposed to increase in time so that the mass of substances that decay / react will be less. Figure 6 shows a graph of the relationship between mass and time in accordance with scientific understanding.

Figure 6. Scientific concept of relationship between the mass of decaying substances with respect to time

From the answers to determining the order of reaction, respondent A8 answered correctly and completely that the decomposition reaction of the C-14 atom is first order. Respondent A8 was also able to mention correctly that the reason of using C-14 atom to determine the age of the organism but could not be for inanimate objects is because they do not contain C-14 as plants. Its indicates that respondent A8 has scientific understanding and group as Sound Understanding (SU). However, respondent A8 was not able to show a good symbolic understanding in determining the reaction rate constants. In accordance with scientific understanding, it is known that the reaction rate constants are the result of the division between the natural logarithm difference of the product and reactants with the coefficient and time. The calculation results show a rate constant of 0.6931 s\(^{-1}\) but the calculation of respondent A8 shows a rate constant of 1.388 \times 10^{-3} without including the unit. In determining the half-life, respondent A8 was also unable to provide the right calculation results even though he was able to write the right formula. In accordance with scientific understanding, half-life is a quotient between 0.6931 with coefficients and rate constants. Even though the formula used is correct, because the calculation of the rate constant is wrong, the results of the calculation of the time interval become incorrect.

In the test problem to describe C-14 atoms within 4 minutes, respondent A8 could not show an exact calculation of the number of remaining C-14 atoms and did not describe them. This is because respondent A8 miscalculates the rate constant even though the formula for determining the concentration after a certain time interval is correct. In scientific understanding, it is known that the amount of concentration after a certain time interval is the result of the multiplication between the initial concentration and the Euler number raised by negative multiplication between the coefficient, rate constant and time given. With the combination of scientific and non-scientific understanding, this is the reason why A8 respondents are included in students who have a synthetic mental model.
In topic 2, students presented a discourse regarding nitrogen gas. It was also explained that NO$_2$ gas can be formed from the reaction between nitrogen monoxide gas and nitrogen trioxide. The reaction is first order for each reaction with a total order of reaction of 2. Figure 7 describe submicroscopic level for producing NO$_2$ after 8 second.

![Figure 7. Submicroscopic level for producing NO$_2$ after 8 second](image)

From the results of the pretest, it was found that most of the students developed the initial mental model. Only 5% have a synthetic mental model. In Figure 8 it is known that respondent A5 depicts submicroscopes of reactants and products based on a comparison of the number of coefficients of each molecule. The number of NO and NO$_3$ molecules are depicted as much as 2 pieces while NO$_2$ molecules are described as 4 pieces. Respondents do not pay attention to the reaction order that occurs. If the sum of the total reaction order is 2, so the formula is using order 2. Respondents use the formula 1 to determine the concentration of each reactant.

In the third question Chemistry Teacher Candidates' were given a discourse regarding the chlorination of methane. In the discourse, it was explained that methane can be chlorinated by a consecutive reaction. In the problem the reaction and its molecular representation are given as shown in Figure 9.

![Figure 9. Consecutive chlorination of methane and it’s submicroscopic representation](image)

It is known that the first-order reactions and initial methane concentrations of 0.20 moles with $k_1 = 0.0346$ s$^{-1}$ and $k_2 = 0.0190$ s$^{-1}$. Students are asked to determine the concentrations of CH$_4$, CH$_3$Cl, and CH$_2$Cl$_2$ as well as the molecular representation of all the molecule at t = 20 seconds. Scientific understanding with scientific mental models is expected to determine the concentration of products and reactants, namely methane concentration of 0.10 mol / L, chloromethane concentration of 0.08 mol / L and dichloro methane concentration of 0.02 mol / L. By using a mole ratio, if at 0.20 mole CH$_4$ depicts 20 CH$_4$ molecules then in 0.10 mole CH$_4$ can be described with 10 CH$_4$ molecules; 0.08 mol CH$_3$Cl can be described with 8 CH$_3$Cl molecules; and 0.02 mol CH$_2$Cl$_2$ can be described by 2 CH$_2$Cl$_2$ molecules. Thus the submicroscopic representation can be seen in Figure 11.
Based on the results of the pretest, it is known that 2 out of 3 students have the initial mental model. One type of initial mental model can be found in Respondent A19. From the answers given it is known that the respondent has written the formula correctly to find out the concentration of methane. But respondents generalize the formula used to calculate intermediates and products. Respondents use the same formula to determine the entire concentration of products, reactants and intermediates. As a result, the respondent was wrong in answering the composition of each substance at the specified time.

The fourth question examines students’ understanding of determining the reaction mechanism based on the equation of the reaction rate law. In the question presented the discourse of Iodine monochloride (ICl) which is one of the interhalogen compounds. The compound in liquid form reacts with hydrogen gas to produce HCl and I\(_2\) in gaseous form. Figure 11 show the formation reaction of I\(_2\) and HCl.

By knowing the law of reaction rate, students are asked to determine the mechanism of reaction that takes place and describe the molecule. In addition, students are also asked to prove that the proposed mechanism is correct. One correct answer about the proposed reaction mechanism is as follows.

1. \(2ICl \rightleftharpoons I_2 + Cl_2\) (Fast)

   \[ k_1 \]

2. \(H_2 + Cl_2 \rightarrow 2HCl\) (Slow)

   \[ k_2 \]

Based on the proposed mechanism above, the evidence that the proposed mechanism has a rate law as requested is as follows.

\[ r = k_2[H_2][Cl_2] \]

Cl\(_2\) is intermediet compound

\[ \frac{d[Cl_2]}{dt} = k_1[ICl]^2 \]  \hspace{1cm} (1)
\[
\frac{d[\text{Cl}_2]}{dt} = -k_{-1}[[\text{I}_2][\text{Cl}_2]] \\
(1) + (2) = 0 \\
k_3[[\text{ICl}]]^2 = k_{-1}[[\text{I}_2][\text{Cl}_2]] \\
[\text{Cl}_2] = K_1 \frac{[[\text{ICl}]]^2}{[[\text{I}_2]]^2}
\]

Figure 12. Submicroscopic level of A17 answer

However, based on the results of the pretest, it is known that 19 out of 20 students have the initial mental model. Almost all students cannot determine the reaction mechanism correctly. From Figure 12 it is known that respondent A17 only writes the reaction equation by equating the coefficient and describing its molecular representation. The essence of the question has not been answered, namely writing down the reaction mechanism. When asked to prove the answer to the mechanism, respondent A17 only rewrites the reaction and states that the reaction has a rate law like the one in the problem.

SiMaYang Type II learning is done after the type of understanding and mental models of students in the kinetic course are identified. Improvements were made to all four lecture topics. In general, learning begins with orientation (phase I). In this phase the instructor conveys the purpose of learning. Besides that students are also given apperception by presenting phenomena related to the material provided. In the second phase, the exploration and imagination phase, the instructor invites students to observe chemical events by presenting visualizations and inviting students to actively ask questions. In addition, the instructor also invites, guides, and directs the discussion of students to build mental models in order to make interconnections among other levels of chemical phenomena.

In the third phase, internalization, the teacher guides and directs students in communicating the results of their thoughts through group presentations. After that the teacher gives exercises or assignments to articulate his imagination. Students complete the worksheet containing questions to make connections between the three levels of chemical representation. In the last phase, evaluation, the teacher invites students to conduct a review of the activities that have been carried out. In addition, the teacher evaluates the learning outcomes of students by giving the same questions as the pretest.

In general, after learning SiMaYang Type II, it is known that the dominant type of student knowledge is Sound Understanding (SU) with a percentage of 44.23% and the lowest percentage is in the type of understanding Not Understanding (NU) with a percentage of 9.62%. This shows that most students already have scientific understanding. Compared with the pretest data, the highest increase in the number of understanding of Sound Understanding (SU) is equal to 27.31%. Meanwhile, the types of understanding of Pure Understanding (PU) and Pure Understanding with Alternative Conception (PU-AC) increased respectively by 2.69% and 1.54%. In the type of understanding Alternative Conception (AC) and Not Understanding (NU) different things occur with other types of understanding, having decrease in the number of successively by 6.92% and 24.62%. The percentage of students understanding of concepts is shown in Figure 13.
The mental models that dominated after the improvement were synthetic mental models (40%) followed by initial mental models at 37.5% and scientific mental models at 22.5%. Compared to the initial mental model, there was a reduction in the number of initial mental models by 18.03% and synthetic mental models by 4.47%. Meanwhile the scientific mental model increased by 22.50%. This shows an increase in scientific understanding and a decrease in non-scientific understanding of students. Pictures of the types of mental models of students after being given treatment can be seen in Figure 15.

T test results show that $H_0$ is rejected and $H_1$ is accepted, so it can be said that there is a significant difference between the mental models of chemistry teacher candidates before and after being given an improvement by using the SiMaYang Type II learning model. The results of this study are in accordance with the research of Suryani, Sunyono, Efkar (2015) where the results of the study show that the SiMaYang Type II model is practical and effective for improving mental models and mastering students' concepts in the material development of atomic theory. The improvement of scientific mental models on the material of chemical kinetics shows that students have been able to represent and interconnect chemical levels. This is confirmed by Sunyono (2014) which states that students' abilities in interpreting and transforming macroscopic, submicroscopic, and symbolic phenomena through various representations by developing thinking skills show that students' mental models have been formed.

4. Conclusion

Prior to the improvement learning, the student's mental model on the kinetics course was dominated by initial mental models with a percentage of 55.53% while the rest were synthetic mental models. No one chemistry teacher candidates’ developed a scientific mental model. This indicates that none of the students developed scientific understanding. After making improvements, it is known that the SiMayang Type II learning model is effective in improving the mental models of chemistry teacher candidates. N-gain testing shows that there is an increase in learning outcomes in the medium category.
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